Introduction to Smart Grid
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Lecture – 07
Distributed Generation Resources – I

Good afternoon to all of you. Today in this lecture, we will discuss about the Distribution Generation Resources. First in this lecture, we will discuss: what are the distributed generation resources then I will cover about the solar energy system by definition of many standards.

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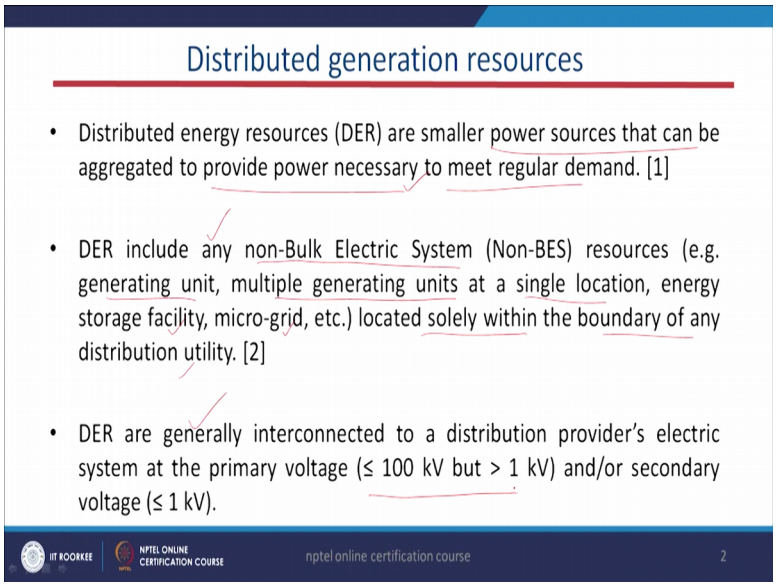

The distributed energy resources are the smaller power sources that can be aggregated provide power necessary to meet the regular demand. And this DER includes any non-bulk electric system resources like generating unit, multiple generating units at a single location and energy storage facility and micro grid.

Basically located solely this is within the boundary of any distribution utility. If you define in other way, this DER basically stands for the Distributed Energy Resource or sometimes also we call it only DR Distributed Resources. DRS means Distributed Resources and DERs means Distributed Energy Resources.

So, those energy resources are basically the maybe we have renewable sources and also we have storage devices. So, together we call it as distributed energy resources. And this DER generally interconnected to a distribution system. In the range of voltage 1 kilo volt, 200 kilovolt; it may also it can be also connected to less than 1 kV also. If will see in our distribution system, we have the voltage level of 440 volt, a 400 volt. So, in that case this renewable sources or battery storage can be also connected to the distribution system.

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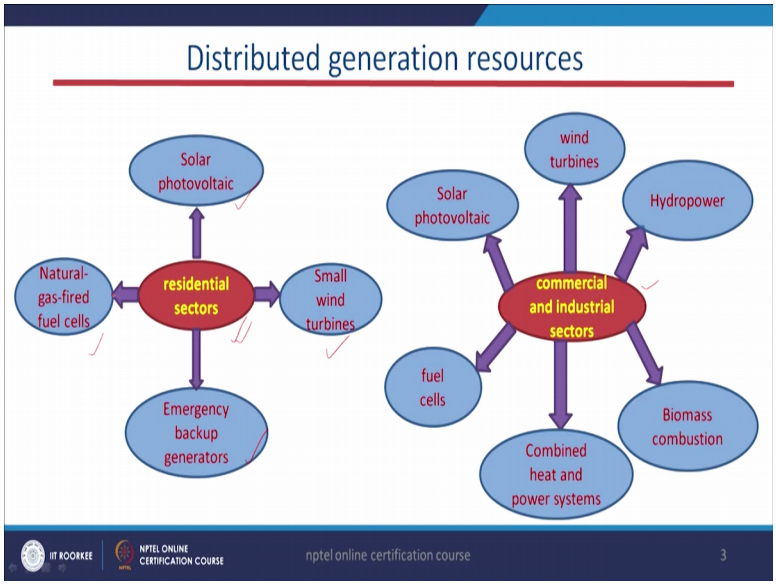

Now, if we will come to this particular part of this presentation, if I talk that we have three types of customers. The first one is residential sectors and the second one I just combined here; commercial and industrial sectors. What are the distributed energy resources available as far as residential customers are concerned? And what are the distributed energy resources are present as far as the commercial and industrial sectors are concerned?

If we see in case of these residential sectors, we have such solar disk water photovoltaic. Now, we are having these roof top solar systems. So, the top of the roof of different homes inside the residential campus, we can put the solar panels and we can harness the power from there.

And next we have small wind turbines near to the customer end and also we have emergency backup generators by the mostly diesel based generators and natural gas fired

fuel cells. So, these are the DERs which are connected near to the residential sectors. Now also we are planning hybrid solar and wind systems. In this case we have will have this solar facility, solar generation system also we shall have the wind generation system. Together we will have and we will connect to the customer end.

Now, if you come to the commercial and industrial sectors, here also we have both I mean solar and wind. Again one more renewable source is added that is the hydro power. Now we are planning for the small hydro power plants. So, these small hydro power plants can be connected to our commercial and industrial customers. And along with this, we have biomass and combine heat power plants; also we should have these fuel cells; So, these are the DERs or distributed energy resources which are connected to the residential commercial and industrial sectors.

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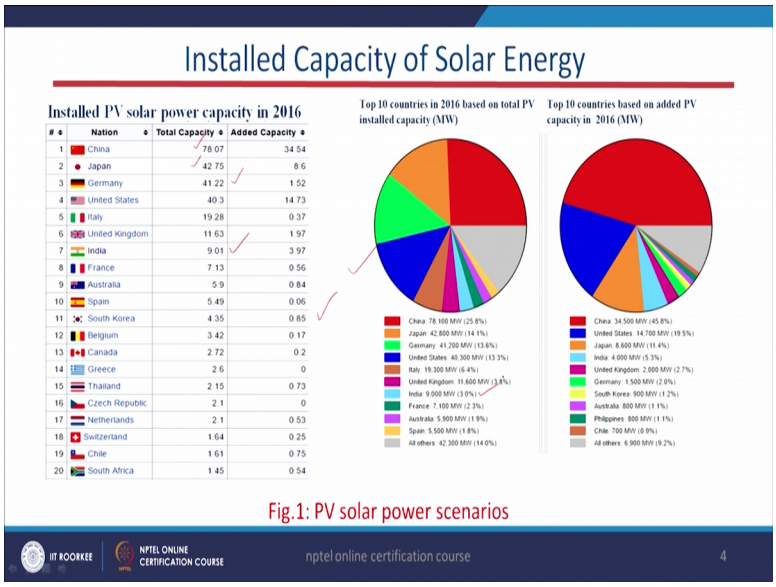

#	Nation	Total Capacity	Added Capacity
1	China	78.07	34.54
2	Japan	42.75	8.6
3	Germany	41.22	1.52
4	United States	40.3	14.73
5	Italy	19.28	0.37
6	United Kingdom	11.63	1.97
7	India	9.01	3.97
8	France	7.13	0.56
9	Australia	5.9	0.84
10	Spain	5.49	0.06
11	South Korea	4.35	0.85
12	Belgium	3.42	0.17
13	Canada	2.72	0.2
14	Greece	2.6	0
15	Thailand	2.15	0.73
16	Czech Republic	2.1	0
17	Netherlands	2.1	0.53
18	Switzerland	1.64	0.25
19	Chile	1.61	0.75
20	South Africa	1.45	0.54

Fig.1: PV solar power scenarios

In this particular PPT, I will just explain that: what are the install capacities of solar energy throughout the globe. If you see this first table here, the China is at the top. This is the unit of this total capacity or added capacity are in megawatt. This is 78.07 megawatt and after that we have Japan that is 42.75 megawatt and next Germany that is 41.22 megawatt and so on.

Now, if you see where is India? It is here 0.01 megawatt as far as the total capacity is concerned. And this is these are the this pie chart and here is the India status. Here it is 3 percent of the total global capacity. It indicates that we need more effort to install the

solar energy as far as the our country is concerned and one more important point, here I just want to inform that we have that facility throughout our India, we have that reasons where we can harness more and more power from the solar system.

So, this is a very good chance. It is a very good facility; if we have, so we should utilize it. That is what the that should be our aim and that is also the aim of our country right now. So, the country the our government also I mean helping and propagating and motivating to all researches industries that we could harness more and more power from the solar system to utilize at the customer end. Now, this we will discuss one by one about the solar cell. First I will discuss about, what is solar cell and what is solar modules, solar array; then subsequently we will learn about the solar cell modeling, what is the mathematical modeling of the solar cell and its characteristic.

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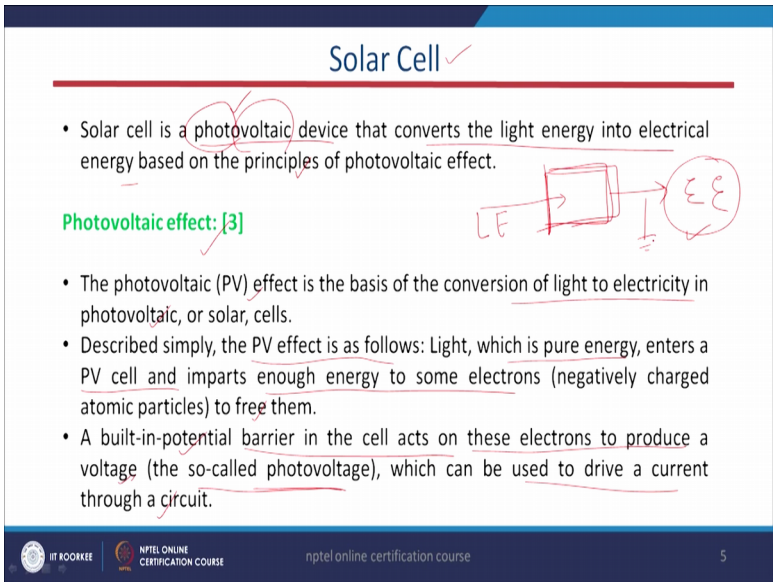

If I will come to the definition of the solar cell, the solar cell is a photovoltaic device that converts light energy to electrical energy. So, if you see sometimes this solar cell is also called photo voltaic. What is the name of this photovoltaic? Photo means this photo stands for light and voltaic stands for electrical energy voltage.

So, when this light energy is incident on a solar cell, then it generates the electrical energy. This means the light energy is converted to electrical energy with help of this solar cell. The input to this cell is light energy; the light comes from the sun and it converts to the electrical energy. The output of this cell is electrical energy.

So, that is the main function of this solar cell and this photovoltaic effect is based on the conversion of light of electricity in photovoltaic or solar cells. And simply this PV effect is as follows. Light which is pure energy enters to the PV cell and impacts enough energy to some electrons; negative these electrons are negatively charged atomic particles to make them free. It will have free electrons, free holes; then only there will be the flow of current. That is what the main goal of the this light energy. When these electrons will be free? So, they will have a path. So, they will move from one terminal to other terminal, then the current will flow.

A built-in-potential barrier in the cell acts on these electrons to produce the voltage; so-called photo voltage which can used to drive a current through a circuit. Basically this potential barrier in the cell acts on these electrons and to produce a voltage and that basically that voltage will drive a current through a particular load; the load which is connected across this terminal of this particular solar cell.

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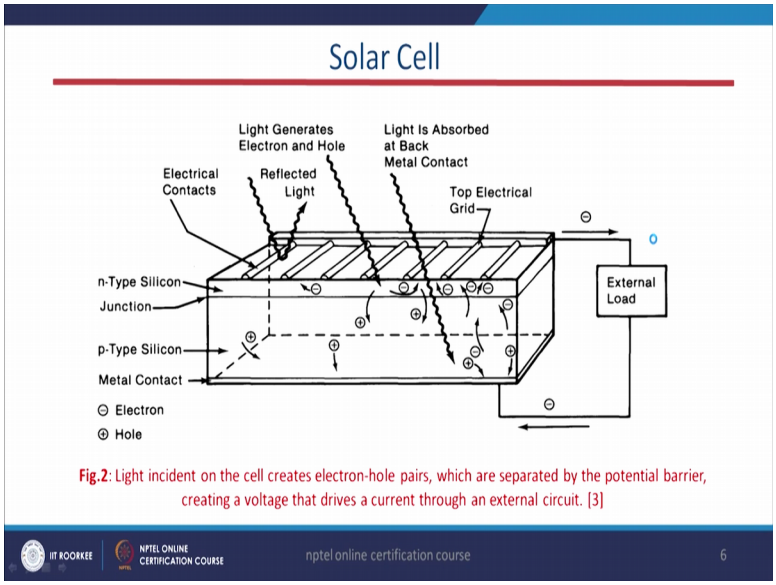

Now, this is a principal how it works. I have shown a very simple block diagram; schematic diagram of the solar cell. Here is a n-Type silicon. This is n-type silicon and this one is p-type silicon and this is the junction, this is the junction and we have on the both sides, we have metal contact. Here we have metal contact and here these are the electrical contacts.

When the light falls; when the sunlight falls on this cell, basically it is a cell. It is behaves like a pn junction diode. It is a photodiode. Now when this light falls on this particular pn junction type, then this free electrons and wholes are released and due to this electron flow, so we will have a current outside the circuit. If we will just connect this two terminals; terminal number 1, this is terminal number 2. If I will connect one external load, so the current is going to flow; that is how this current flows across this particular pn junction type solar cell which is made up of silicon material.

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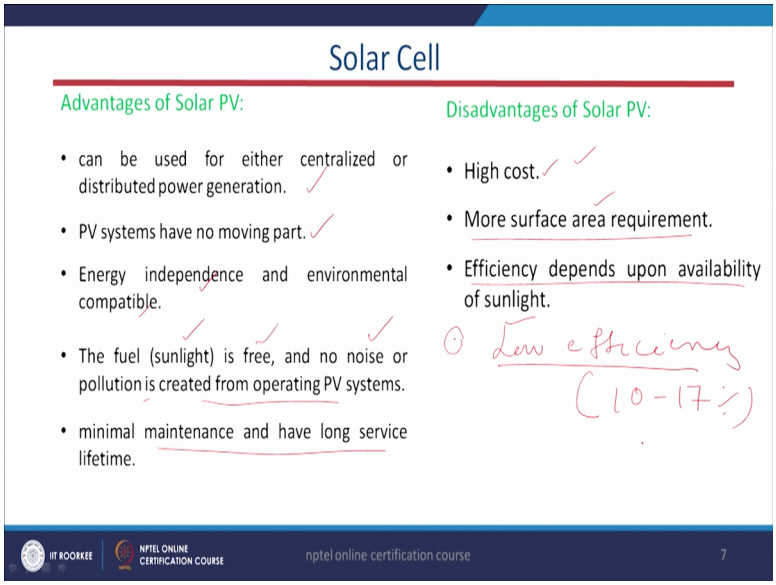

Now, what are the advantages of this particular system, the solar generation system. The first one, it can be used either for centralized purpose. Also it can be also used for decentralized purpose. I can put a solar panel near to my home, from there I can access the power to different loads which are present inside the home. And also we can put the solar cell at a particular location and from there we can supply the power to different loads as well as to the grid. And that is the major advantage first advantage and the second one is the PV system have no moving part. There is no moving part, one solar panel is installed.

Now, these energies are independence of an environmental compatible. This is very important. That is why it is the very important. One of the most important renewable sources which is very user friendly I mean the environmental friendly. No pollution. A user friendly means the environmental friendly means there is no pollution we expect

from the solar cell. And this fuel cell, this fuel is basically the sunlight which is free. What is the input to the solar cell? The input to the solar cell is the fuel. The output is electrical energy.

So, this fuel is basically our sunlight. This sunlight acts as a fuel or input to the solar cell or solar energy system. So, in that cases this solar the sunlight is you know, it is a very huge and there is I mean that is why it is known it is renewable sources. We can we can expect the sun will be I mean throughout the years; many many years. That is why it is also free and no noise and pollution is created from operating this PV systems and minimal maintenance and have long service life time. Whenever we design any system, we expect that the maintenance would be less and it should provide a very long service life time which are present in case of the solar energy system.

Now, coming to this disadvantages of the solar system. The first one is the installation cost of the solar system is high that is first disadvantage and the second one is it has like a more surface area requirement. If you could see that near to the like (Refer Time: 13:28) field or like near to any buildings of commercials or industrial applications, use many number of large number of solar cells are installed at the roof top or may be certain area is occupied by those solar panels. So; that means, for this generation of the energy generation of the power using the solar cell, we need large I mean number of I mean areas area is used. That is why more surface area requirement and efficiency depends upon the availability of the sun light.

One point I just want to mention here, in case of solar cell; we have low efficiency. This is very very important. Low efficiency basically the range is 10 to 17 percentage. The input is I mean the cost is high, insolation cost is high, but we are having low efficiency. So, that is why this system little bit I mean we still the solar is the ultimate source as far as the renewable sources are concerned.

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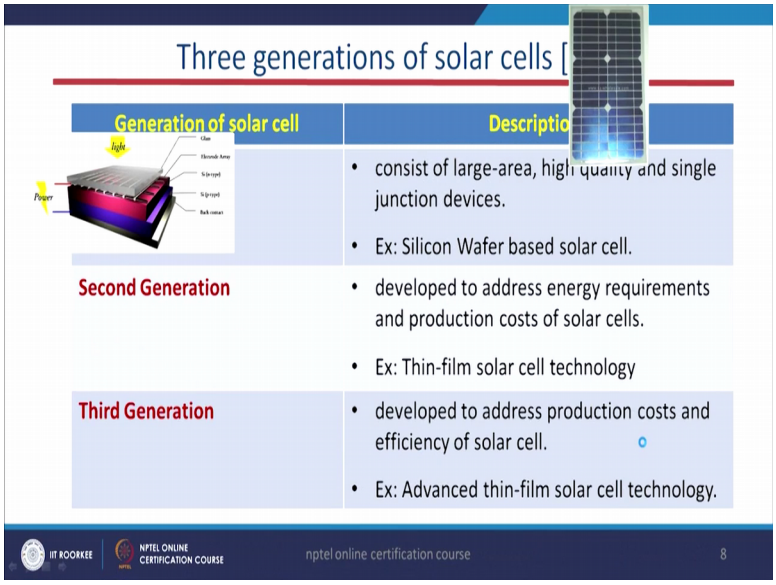

I will just here discuss the three generation of solar cell. The first one is a the first generation consist of large area high frequency and single junction device and example the silicon offer based solar cell. And second generation basically thin films solar cell technology. Here we have multi layers. Here we have single layer, but in this case we have multi layers and coming to the third generation, here we have developed production cost efficient solar cell basically advanced thin film solar cell technology.

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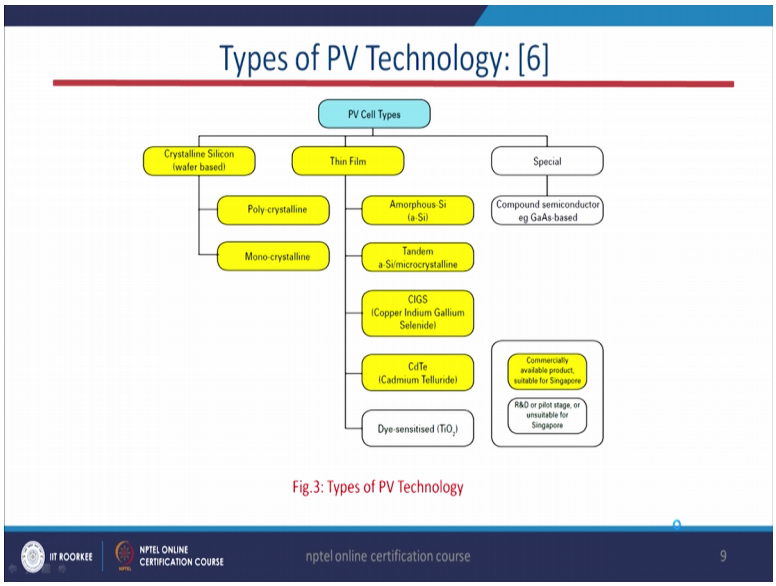

So, this is three technologies are in developed stage. And here just a broad discussion on this particular technology that a as far as the silicon crystalline silicon is concerned, we have polycrystalline and also mono crystalline type solar cells. And as far as the thin film

is concerned, we have amorphous a-Si that is a-Si and the second one is tendem that is a-Si and micro crystalline. This is the second one. And third one is CIGS; that is copper, indium, gallium, solenoid. And this one is CdTe that is cadmium, telluride and next TiO 2. So, these are the different technologies which are used as far as the thin film PV cells are concerned. Now, this is the special type that is the compound semi semiconductor type PV cells and basically that is G a A s based this PV cells.

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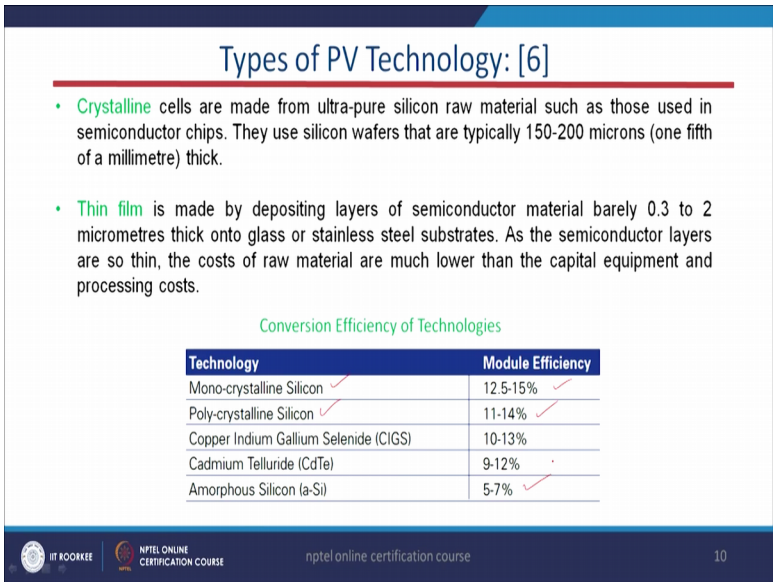

Now, as far as the technology concerned, their efficiency also varies. If you see here mono crystalline silicon, the efficiency is 12.5 to 15 percent and again if you see this polycrystalline silicon is concerned, 11 to 14 percent and so on. So finally, this amorphous silicon 5 to 7 percent of course, that is what researches work. We have to develop such material I mean for the solar cell, so that we will it will be more efficient; more reliable. That is what the research.

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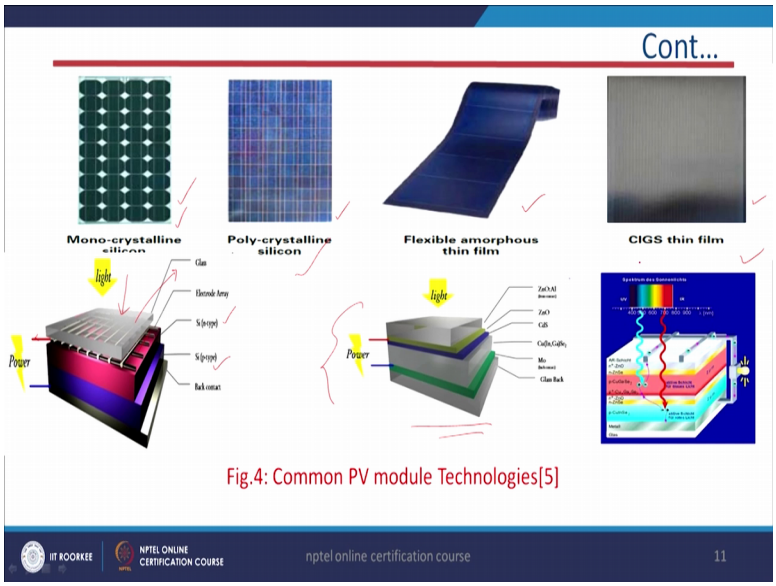

Now, these are the some of the pictures for this mono crystalline silicon and here you can see this glass. This top one is the glass and this is the basically these are the electronic rods RA and silicon n-type and this is silicon p-type and last one is the back contact. When this slide falls, then the power will be generated. Here the current is going to flow.

Now, the second one is poly crystalline silicon type. This is the Mono-crystalline silicon type and this is the Poly-crystalline silicon type solar cell. And this one is the flexible amorphous thin film. Here we have different layers. Here only single layer; p-n junction type, but here we have different layers. And this is the basically pictorial representation, how it looks like the material. This is C i G s type, thin film solar cell.

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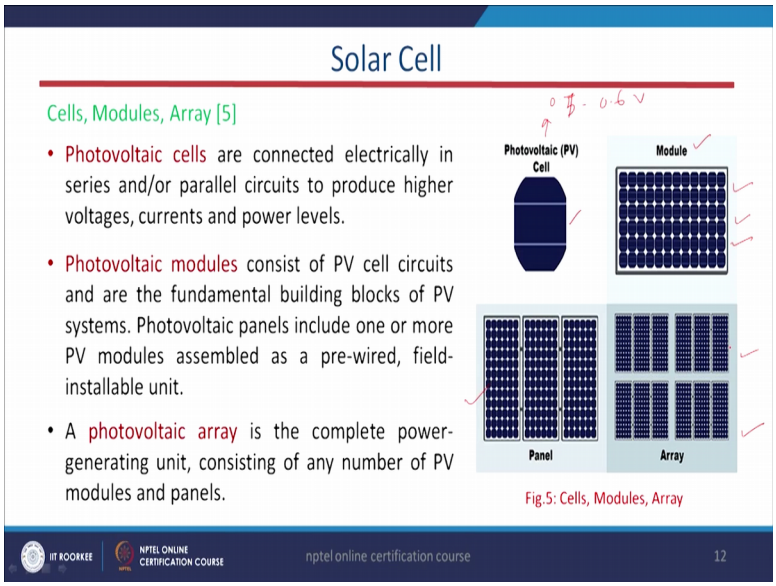

Fig.5: Cells, Modules, Array

So, coming to different, now I will discuss here different types of photovoltaic cell, module, panel and array. How to distinguish this four? This is one PV cell and when the number of PV cells or solar cells are connected in series or parallel, that structure is known as module. And when more than two, I mean more than one modules are connected that particular structure is known as panel. And further when more number of panels are connected series in parallel that particular structure is known as array.

Basically why we are interested for this? Because if you see the literature and the standards one particular cell generates basically up to may be 5 to 0.6 0.5 to 0.6 fold dc, but our requirement is more. We need more power, more voltage, more current. So, for that purpose one cell is not sufficient. So, increase the power we have to connect those cells either in series or either in parallel. So, in case of parallel circuits, the current increase and in case of series circuit, the voltage increases

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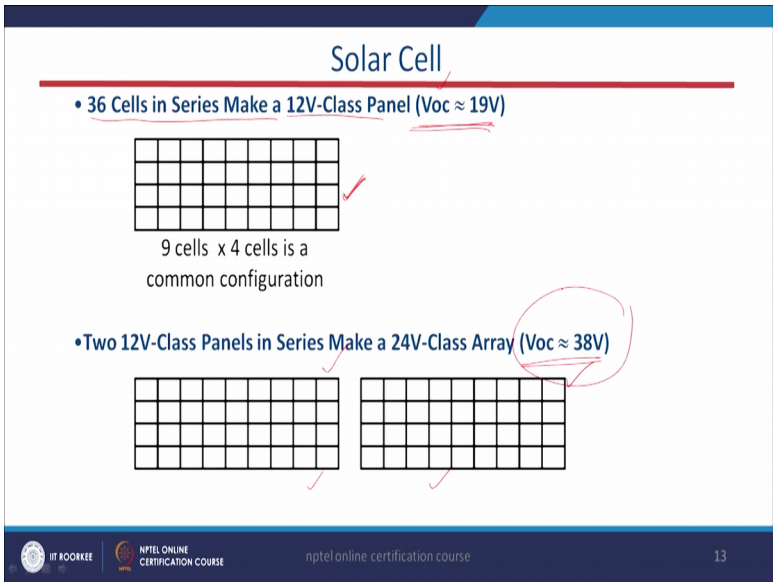

Now, this is how this I have taken one cell structure where basically the RA structure. If you see here, 36 cells in series. In this configuration in the structure, we have used 36 cells and from this cell structure, we will get 12 volt as a output voltage and also we have, I have written here this open circuit voltage 19 volt. We will discuss about more about this, what is the open circuit voltage in the subsequent parts.

Now, this configuration the structure provides us open circuit voltage as 38 volt. Here how many cells are available? You can see here in series, we have here it is 9 cells into 4. Similarly it will just connect different cells in series or parallel. So, corresponding voltage also will get; that means, it will increase the number of cells in series, the voltage will increase and if we will increase the number of cells or number of panels in parallel, so the current manager will increase.

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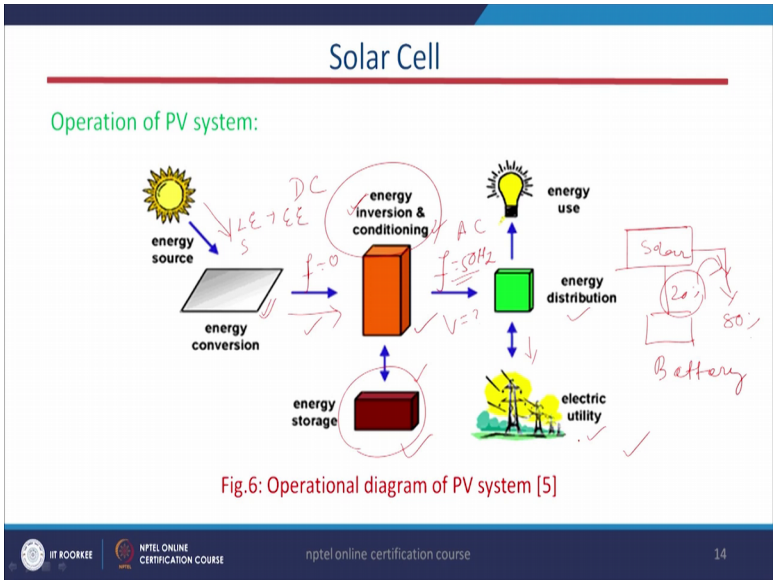

Fig.6: Operational diagram of PV system [5]

Here I will discuss about the basic principle of operation of the solar system or solar energy system. Here is our solar panel and this solar panel gets some light. That is the energy which is coming from the sun. And after this conversion of solar energy, this is the light energy to the electrical energy.

The electrical energy or power flows through the energy conversion and conditioning block. What is the meaning of this energy conversion and conditioning block? The energy conversion means if you see the output of output power, output voltage of a solar cell is basically dc. So, we have to make this DC voltage or current or power to AC voltage. So, this conversion is DC to ac, we need some inversion. We basically we call it invertor. The invertor converts changes to DC to AC.

Now, this conditioning also necessary because we have to maintain because a DC has 0 frequency, but here the frequency we have to match according to our requirement. If suppose basically in our grid, we have 50 hertz frequency as well as the AC system is concerned the loads also demand 50 hertz, so we have to assure that the frequency as well as the voltage of the grid should be maintained properly. That is what we have to take care.

Now, along with this conversion and conditioning system, we have the energy storage system. The energy storage basically the batteries we use for this solar system where we can use, we can store the energy which is basically excess Let us say we have one solar system and in this solar system we have connected some loads. The load requirement let

us say is 80percent at this moment. The 20 percent of the energy we will, we can store easily by using a battery.

So, that is what is a meaning of this energy storage. If any surplus energy is there as far as the solar energy system is concerned, so always we can store it. And when it is required, let us say this solar energy is not ready during the night time. It is not produced during the night time. This 20 percent energy, we can always divert to the load side. That is the benefit of the storage system, in case of the solar energy system.

Now, this is how I just explained that here this ac, basically this side is AC and this side is dc. This AC energy is ready to be distributed to different loads and also we can if you have surplus energy and also we can supply to the electric utility. That is what we do in case of a solar energy system.

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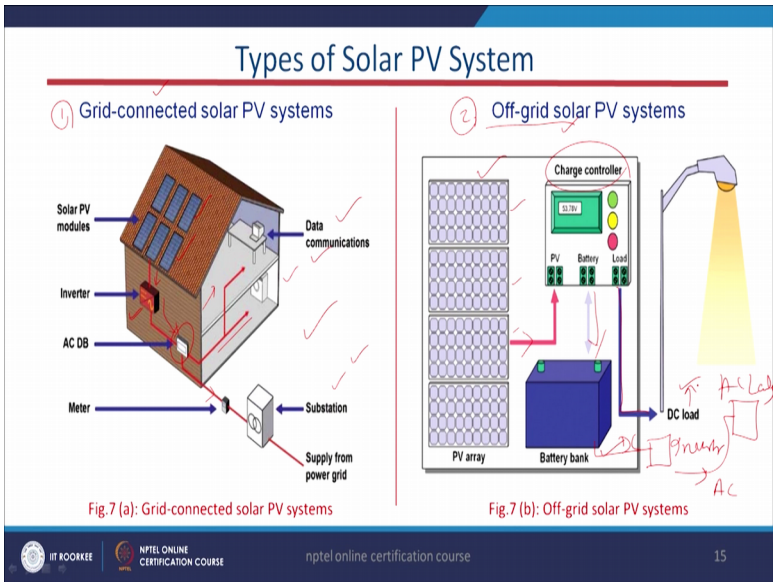

But if will just classify a solar system, it is broadly of two types. The first one is the Grid-connected solar PV system and the second one is Off-grid solar PV system. What is this off-grid? The grid connected is well understood from the name itself. It is grid connected the solar system is connected to the grid and also to the it is supplying power to the load. But in case of this off grid solar system, it is a basically a standalone system where it is required? Mostly if we will see a in rural cities where we cannot, there is we cannot supply to the remote end loads.

So, in that case we can install the solar panels to supply the power to the loads. That the first requirement of this off-grid solar PV systems. Or in some case we call it eye landed or this is a standalone mode of operation of the solar system. In that case in rural cities, again also we have sometimes it happens the cost is very high, if you just supply power from the grid to the remote load terminals. In that case also we can take the help of off-grid solar PV systems.

so coming to first this grid connected solar PV system, here basically what happens? If you see this particular picture, this in this particular home; here is our PV panels. PV panels are basically installed or mounted on the roof top and from there we are getting the DC power and this is DC power is coming to the invertor. And this invertor converts from DC to AC power and this AC power is going to the AC distribution board.

This is our board where we will get the AC power and this AC power will go to our respectively loads inside our home which are installed inside our home. And we can also go for further data communication using this some monitors, monitoring systems or sensors which will sense the AC power and it will just send to other devices or other nearby home or to the other places where we require the information. That is what this data communication means. And then rest of the power, if any surplus power we have then, it will be send to the substation nearby substation. The substation will receive the surplus power.

Now, if you could see here, I did not discuss about the storage system because if the solar system is grid connected, so it is always better to supply the surplus power export; the surplus power to the grid itself. Basically sometimes we also go for storage system, but is recommended we should supply the power to the grid, because for battery also we did some storage. If the grid can manage, that is also one important question.

Now, if you will see this come to this off-grid solar PV system. That is known as the standalone PV system and here you see, we have the solar panels which are connected basically here in series or parallel fashion and the DC output power will go to this charged controller. What is the function of this charged controller? Now I will just discuss in the next PPT, what is the function of this chart controller. Why it is necessary here? And from this charge control controller, the power will come to the battery bank.

The battery bank basically stores the energy and also sometimes this battery bank also connected to the invertor. This invertor this invertor inverts or converts this DC to AC supply and this particular power will go to our AC loads. And sometimes from the charge controller itself, if we have some DC loads, to there also we can supply the DC power.

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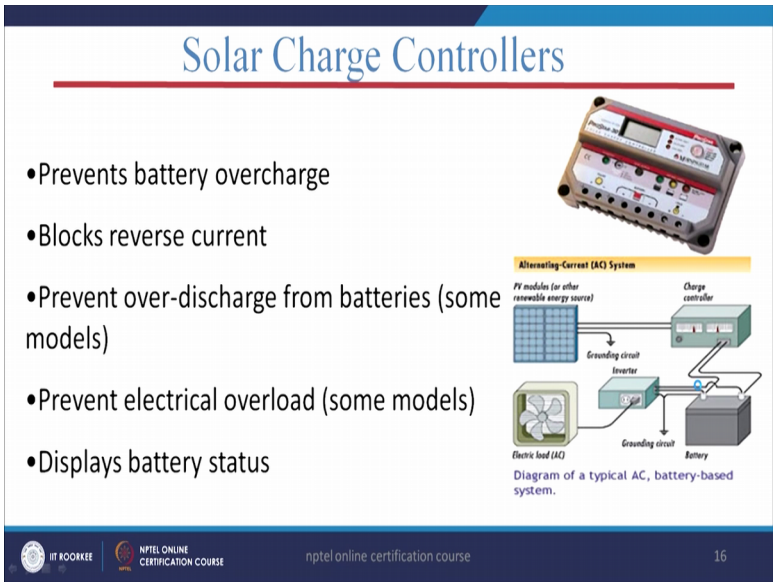

Now, coming to this charge controller, just we have discussed in this is pervious ppt that this output of this PV panel goes to the charge controller and this charge controller output also communicates. It is connected with the battery. There these are the functions of the charge controllers. It prevents battery over charge because the output of this charge controller is also connected to the battery. The battery will charge and discharge.

So, this charge controller will take care that battery should not be over charged. Because if it will be overcharged, then it may be damaged the life cycle will be reduced. And also it blocks the reverse current. Reverse current means reverse current means the this is our battery, the current should not flow in a reverse direction. The current should flow in the forward direction towards the load. It may be a DC load or it may be a AC load the reverse current should not flow.

So, that particular charge controller helps in blocking this reverse current and also prevents over discharged from the batteries in some cases and also prevent electrical over load and displays battery status. So, these are some of the key functions of the charge controller which is used basically here you can see in this case.

In this figure also we have displaced very clearly. We can see here that this is the PV modules. These are the PV modules and this is our charge controller. And here the from the charge controller, the output comes to the battery and from the battery it goes to the invertor and from the invertor the AC output power goes to the load AC loads. That is how this circuit is.

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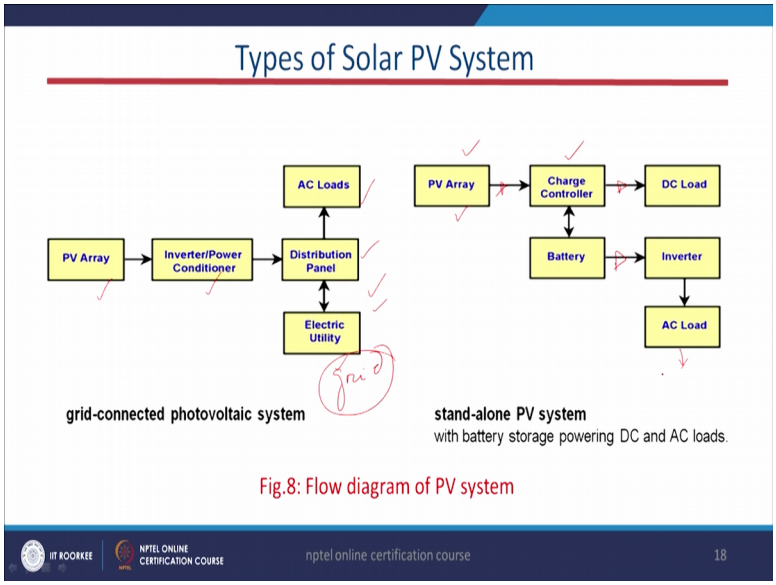

And this is how we have just already discussed. I will just come to the basic block diagram of this particular solar system. Just whatever I have discussed in the previous two three slides, the same thing is represented like in terms of the blocks.

The first one is the PV array and the second one is the invertor the power conditioner and from there it will go to the distribution panel and it will go either to the AC loads and to the utility electric utility. Electric utility means it is the grid section. This is the grid basically. And now the second one is our standalone PV system, here the PV array and from there the DC output power will go to the charge controller and from the charge controller, it will go to DC load or it will go to the battery. And from the battery it will go to the invertor and the invertor will supply the AC to the AC power to the AC loads. So, these are basically the types of solar system.

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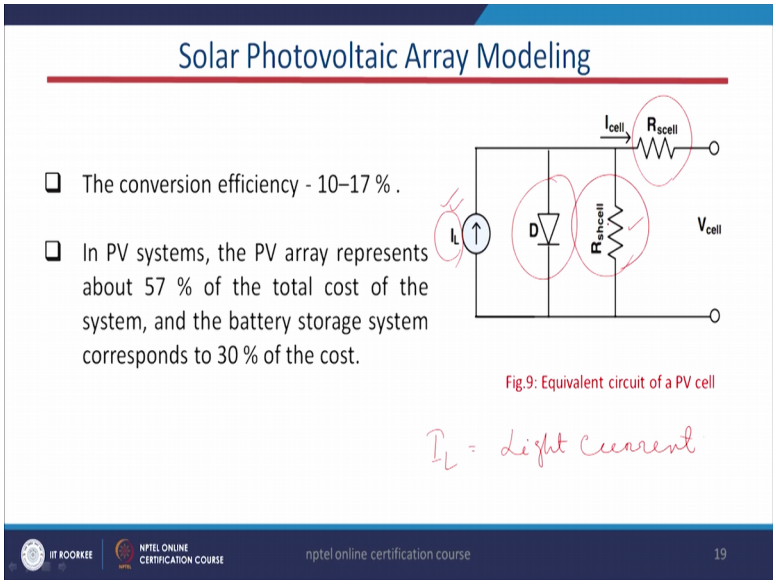

Now coming to the solar photovoltaic array modeling, here a single solar cell basically represented in terms of this electric current. This I l stands for the light current. I can write here, this is the light current. Why it is light current? Because from the very beginning as we have discussed, that in case of solar cell we use basically the photo diodes or basically the light produces the current. So, that is your light current. And we have a diode. So, that this is the diode symbol or mathematics in the equivalence circuit of the cell we have kept and this is the sound resistance and this is the series resistance.

So, we will just wind up today's class here. I will come to the conclusion, what we have discussed in this particular class. First we have started with that what is basically the definition of distributed energy resource and what are the distributed energy sources we can use as far as the different types of customers are concerned, like a we have residential customers, we have commercial industrial customers.

So, in those I mean peripheries premises what are the DERs basically connected. And next we have discussed what is basically a single solar cell and what are different types of technologies are involved in manufacturing the solar cell and then we have also discussed different types of PV systems. Basically we have discussed the grid connected or grid tied solar cell or solar PV system and also we have standalone PV system. And next class, we will discuss about the modeling of the PV system or solar photovoltaic array.

Thank you all.