Solar Energy Engineering and Technology
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Module 6
Grid Connected PV System
Lecture 15
Functioning and Components of PV System

Dear students, today we will be discussing about Grid connected PV system.

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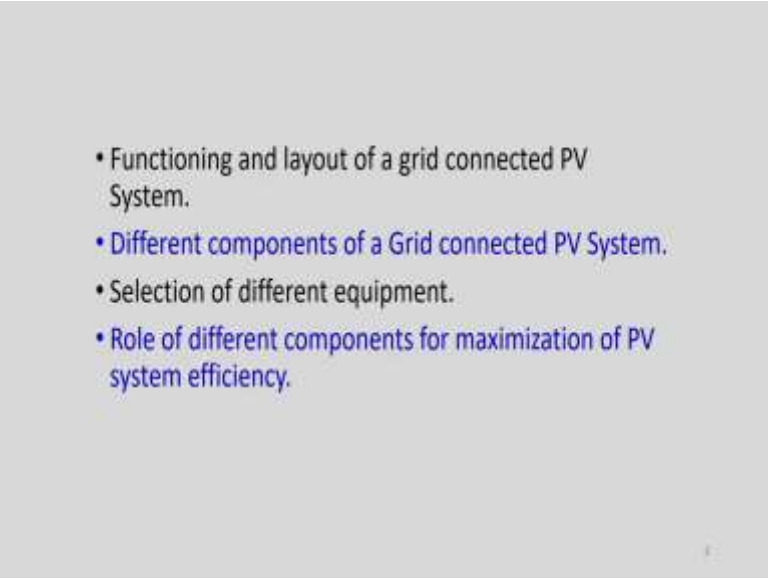

So, basically we will discuss functioning and layout of a grid connected PV system, different components of a grid connected PV system, then selection of different equipment, role of different components for maximization of PV system efficiency.

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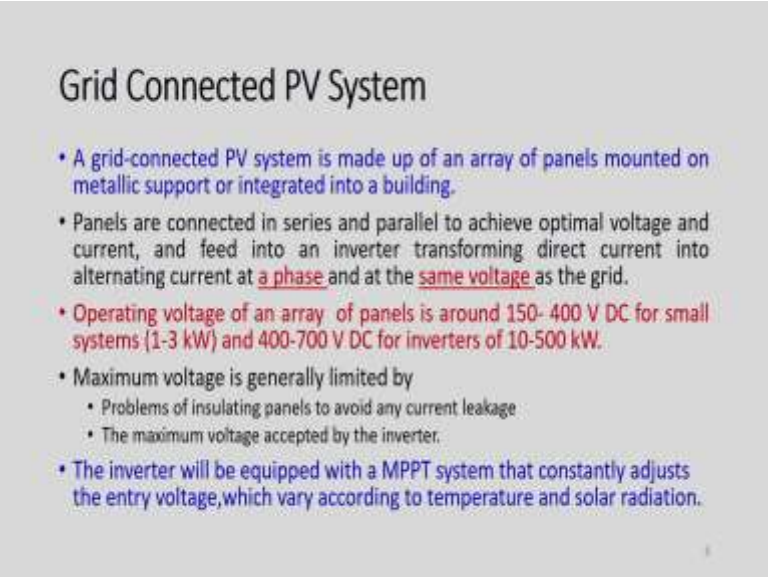

So, what is grid connected PV system? A grid connected PV system is made up of an array of panels mounted on metallic support or integrated into a building. The panels are connected in series and parallel to achieve optimal voltage and current and feed into the inverter which transforms direct current into alternating current at a phase and at the same voltage as the grid. The operating voltage of an array of panels is around 150 to 400 volt DC for small systems of capacity 1 to 3 kilowatt and 400 to 700 volt DC for inverters of capacity varies from 10 to 500 kilowatt and the maximum voltage is generally limited by the problems of insulating panels to avoid any current leakage and the maximum voltage accepted by the inverter.

These two are very, very important. The inverter will be equipped with a MPPT system that constantly adjust the entry voltage because this will vary with solar insulation and temperature.

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So, now see the basic flow diagram of a grid connected PV system. So, we have sun, so electromagnetic radiation will come and strike on the PV surface and then we can generate DC current, so then that has to be converted to alternating current by using an inverter, so we need an inverter to convert DC current to alternating current, then that can be connected to some load, this is called AC load and if we have generated more energy then through meter we can give it to the utility grid.

So, day time, suppose in a household we are generating energy through this PV system and we are not utilizing it, so what we can do, we can provide the energy to the utility grid, at the night time since we do not have any battery backup, so we can take the energy from the utility grid for meeting the demand.

So, that way we can take, so this is known as net meter, this will take care of the amount of energy what is given to the grid and the amount of energy which is taken from the grid that is called net metering system or net meter. So, this is an very basic flow diagram of a grid connected PV system.

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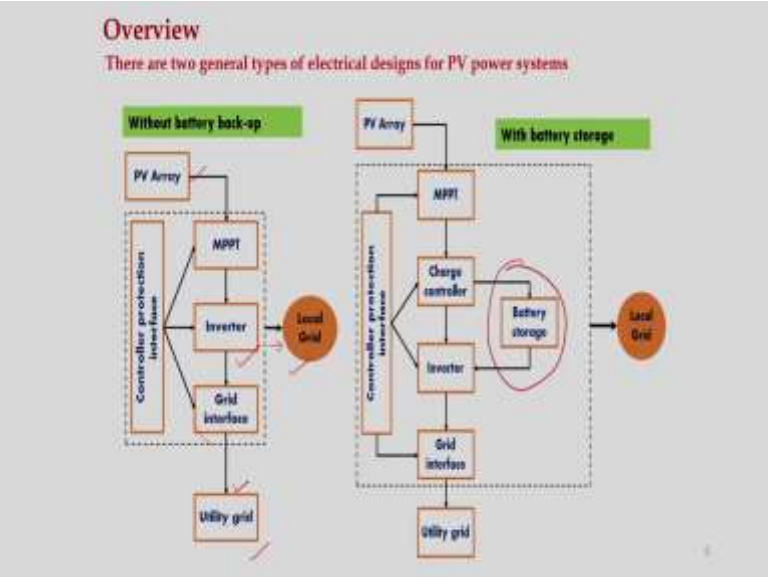

So, there are two general types of electrical designs for PV power stations and the first design is without battery backup and second design is with battery backup. So, components already it is known to us now PV arrays we need then we need MPPT because we need to operate at maximum power point by using the electrical or mechanical system and then we need to have inverter to convert direct current to alternating current and then grid interface.

So, if we are done with this then we can give it this power to local grid or we can give it to utility grid. So, similarly same thing happens only change is here one storage system, okay energy can be stored whenever required and that can be delivered as per the requirement.

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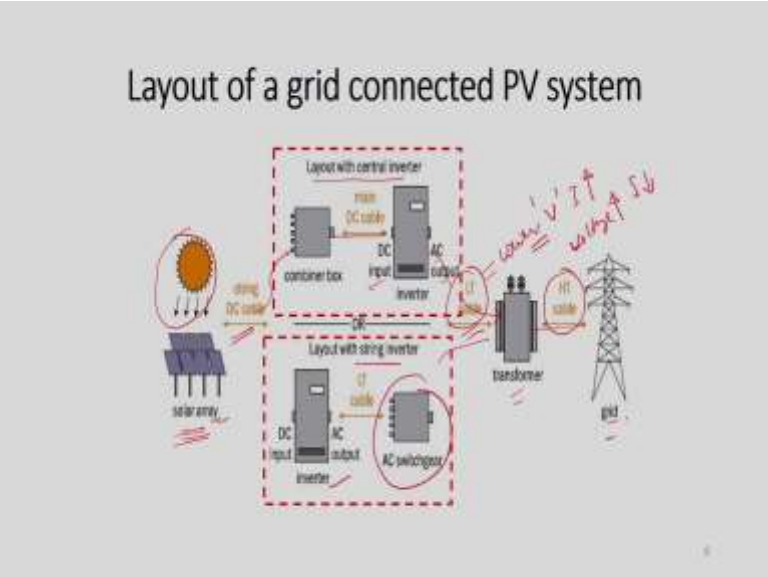

Now, this figure shows the layout of a grid connected PV system, as we have discussed this energy from the sun is received by this PV array and after generating this current that has to be transferred to this inverter, so different kinds of inverters are there, we will discuss in the coming slides.

So, if we use central inverter then this DC current will connect to this combiner box then it goes to inverter again we need DC cables and as you know the function of inverter is to convert this DC input to the AC output then from here it goes to transformer and then it will go to grid.

So, when it goes from transformer to grid then we will use high tension cable and from inverter to transformer we use low tension cable, means low tension means at lower voltage, at lower V is voltage and current is high, for in case of high tension cable so voltage, voltage is high but current is low and sometimes other inverters are also used may be string inverters, so in case of string inverter what happens, so we need a AC switch gear before it goes to transformer.

So, we will learn all different kinds of inverters in the coming slides but this tells about how this system works, we need solar energy and then PV modules or arrays and we need different cables like DC cables, AC cables then inverters, transformers and then grid.

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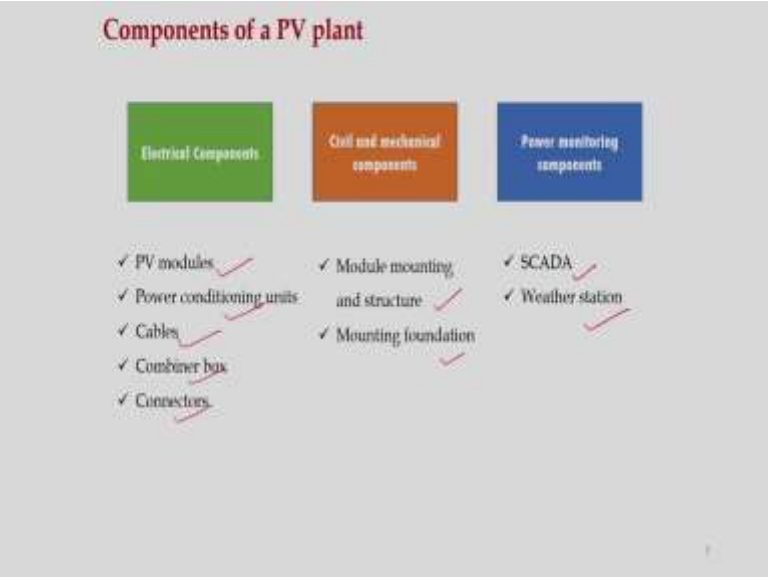

Now, let us see what are the different components involved in this grid connected PV system. So, primarily we have three components electrical components, so under electrical components we will have PV modules, then power conditioning units, cables, combiner box then connectors.

Next thing is civil and mechanical components. So, under civil and mechanical components we will have module mounting and structures, then mounting foundations and third category is power monitoring components which includes SCADA and weather stations.

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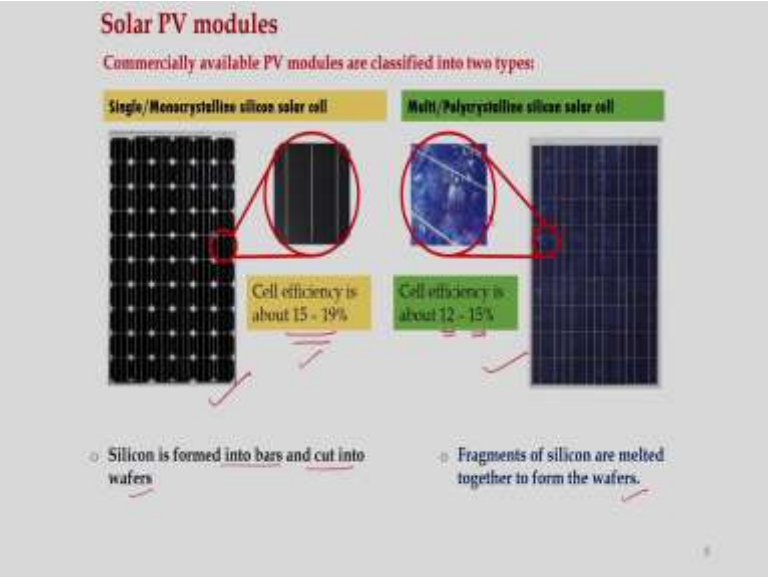

Now, we will discuss one by one. So, solar module, already we know that 90 percent of the solar modules are made of silicon based solar cells, it may be single crystalline or maybe multi crystalline. So, we need to select the best module for the particular applications, so this configuration is for single or mono crystalline silicon solar cells and already we know how it look likes, we also studied the crystal structure and why it looks something like this and also we have studied the conversion efficiency, it varies from 15 to 19 percent for mono crystalline silicon solar cells.

And this silicon is formed into bars and cut into wafers in case of single crystalline or mono crystalline silicon solar cells, in case of multi or polycrystalline silicone solar cells configurations is something like this and we can get this kind of picture because of this grains, there are many grains and this conversion efficiency is about 12 to 15 percent. So, mostly this multi crystalline solar cells are used in many of the solar power plants because of the cost. Here, in mono crystalline solar cells we will have higher cost and we have to invest more for purchase of this module.

Also we know this fragments of silicones are melted together to form wafers that is known to us, already we have studied how these cells are manufactured and why their configurations are something like this.

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So, there are some criterias for choosing grid connected panels, what are those criterias? Reliability and reputation of the manufacturer is very, very important because now once it is installed that has to work for 25 years, minimum 25 years, good price of course, when we are investing something we must know the price, if we are getting at a lower rate but without compromising the other parameters then always it is welcome.

Then closely power matching modules, so power has to be matched, so when we solve problems then you will understand what does it mean power matching modules, then good mechanical quality, well designed frame and easy to install panels, these are very, very important aspects and good quality connectors.

Then, cooled anti-return diodes with a junction box designed to dissipate their heats, in case of hotspot generation, this is also important. Sometimes, hot spots are generated as we have discussed in the class when we were discussing about the modules, so how hot spots are generated and what are the alternatives technique to this remove these hotspots, these are attached to this system.

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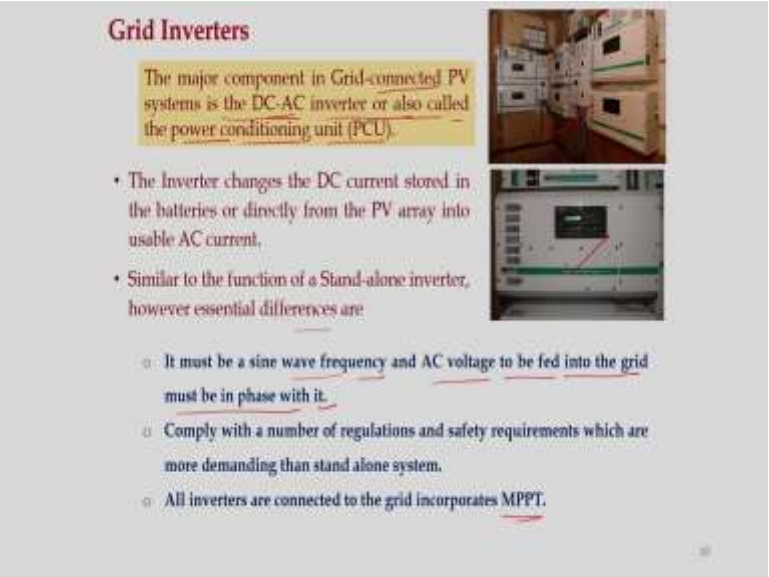

Now, come to the inverter parts which is one of the key components for functioning of a grid connected PV system. So, this major component in grid connected PV system is the DC-AC inverter or also known as power conditioning unit or PCU, it looks something like this, these are the photographs of this PCU.

Already we know what is the function of inverter, it converts direct current to the alternating current, so if we compare with the inverter what is available for standalone there are some differences, so what are differences?

So, in case of the inverter used in grid connected system it must be a sine wave frequency and AC voltage to be fed into the grid must be in phase with it and it must comply with the number of regulations and safety requirements which are more demanding than stand-alone system. All inverters are connected to the grid incorporates MPPT. So, here this kind of inverters, MPPTs are attached with it.

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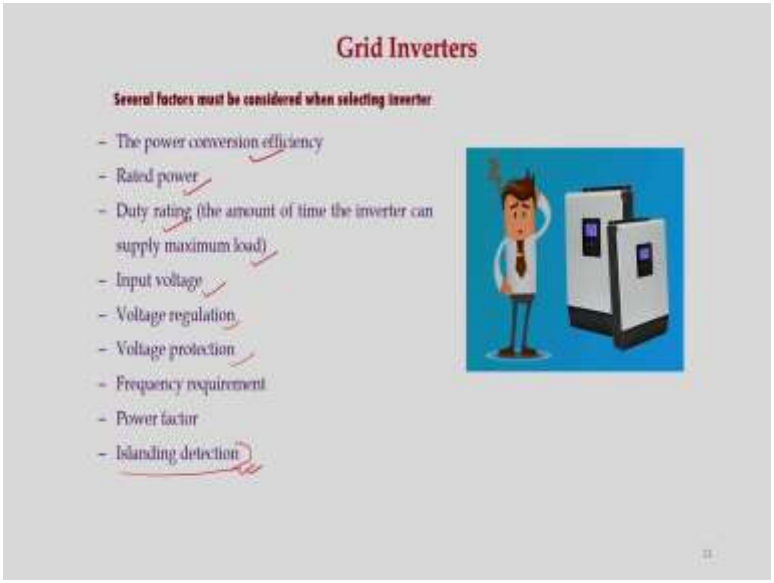

So, there are some factor which must be considered when selecting an inverter. So, what are those factors? Like power conversion efficiency, rated power then duty rating which means the amount of time the inverter can supply maximum load, then input voltage, then voltage regulation, voltage protection, frequency requirement, power factor and islanding detection, this is very, very important. So, we will discuss what is islanding and islanding detection.

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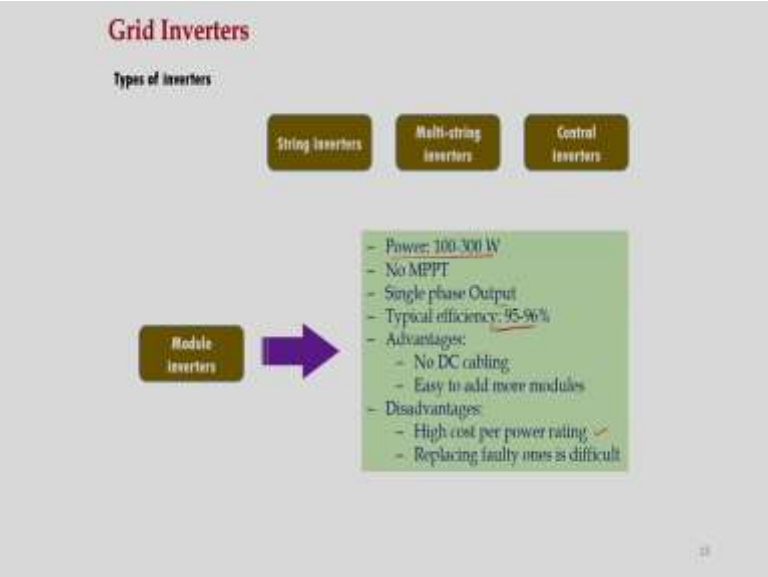

So, there are different kinds of grid inverters, so primarily there are four categories module inverters, then string inverters, then multi-string inverters and then central inverters. Let us study one by one, so what do you mean by module inverters? So, basically these are classified based on the power ratings, so here in case of module inverters, this power is varies from 100 to 300 watt and no MPPT is attached in this kind of inverters.

And of course, it is a single phase output and this conversion efficiency was 95 to 96 percent and advantages are no DC cabling are required, easy to add more modules, but major disadvantages are high cost per power rating, this is important and replacing faulty one is difficult for this kind of inverters.

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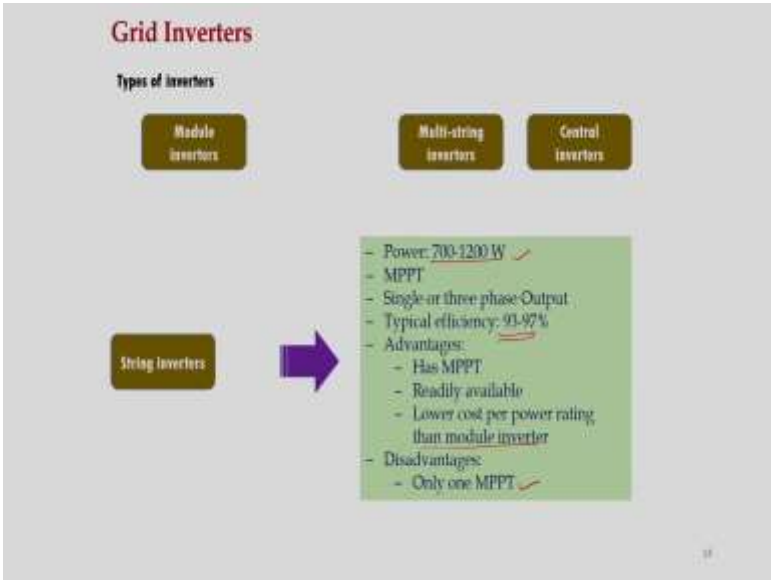

In case of string inverters we can go power from 700 to 1200 watt and MPPT attached in this inverter and it may be single or three phase output and efficiency of conversion, it varies from 93 to 97 percent, advantages are it has a MPPT, readily available and lower cost per power rating then module inverter and only one disadvantage is only one MPPT is attached. Even though it is costly but this is a really good one for many of the applications.

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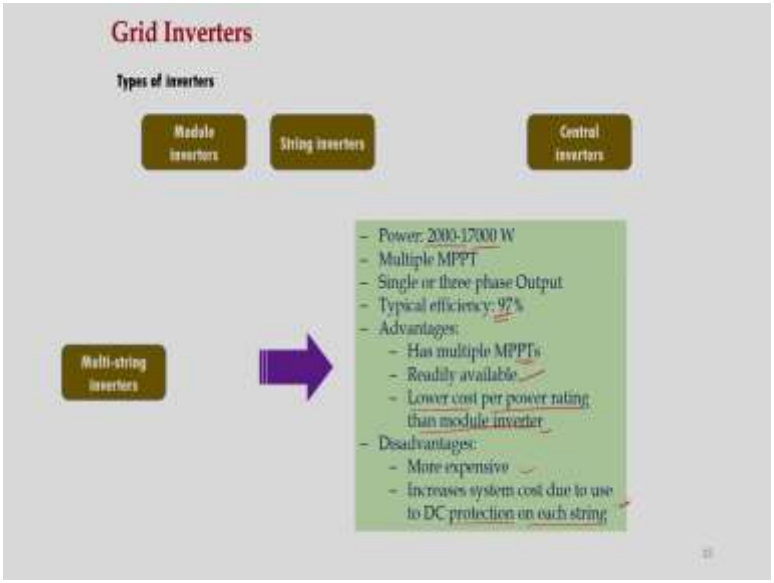

Next inverter is multi string inverter, so power rating goes from 2000 to 17000 watt and multiple MPPTs are attached and it may be used for both single phase and three phase output and efficiency is about 97 percent, so advantages includes it has got multiple so it is more precise and readily available and most importantly lower cost per power rating then module inverter and disadvantages are something like more expensive and increases system cost due to use to DC protection on its string, so this is one of the disadvantages.

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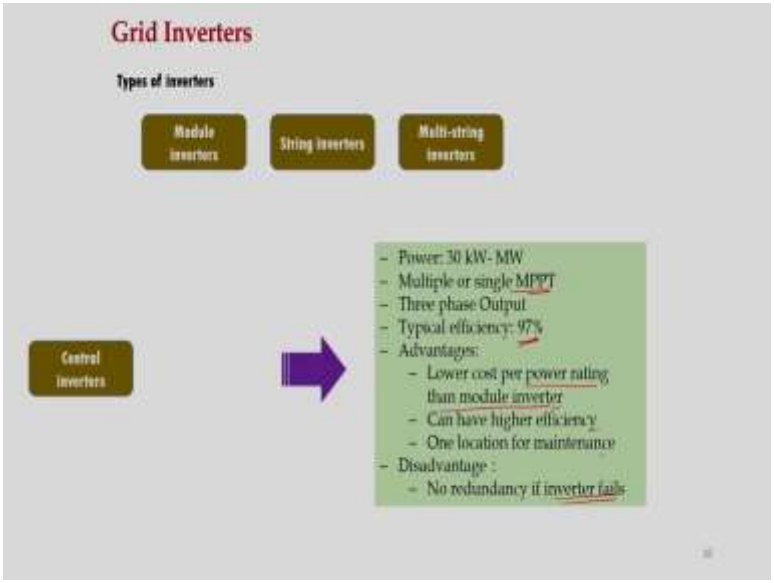

And for central inverters normally for very high power ratings we will go for central inverters, so it will be having multiple MPPTs and always three phase output will be there and efficiency is quite good about 97 percent and it has advantages like lower cost per power rating than module inverter and can have higher efficiency and one location for maintenance and only one disadvantage is no redundancy if inverter fails, so these are different kind of inverters based on the situation, we can select the best inverter for particular application.

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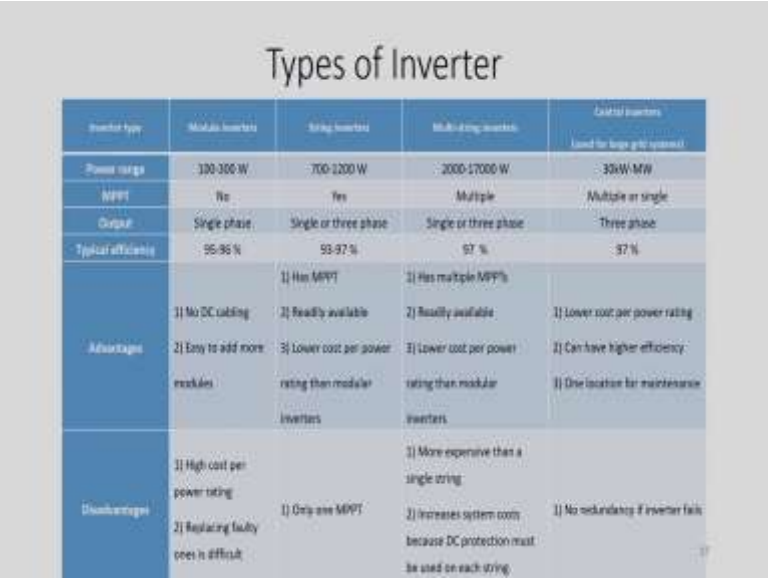

So, this table shows the comparison of all the four inverters, so we can see the power ratings and we can compare and what condition we need what kind of inverter. Now, let us understand what is islanding, why this is so important, why this component is need to be attached with inverter?

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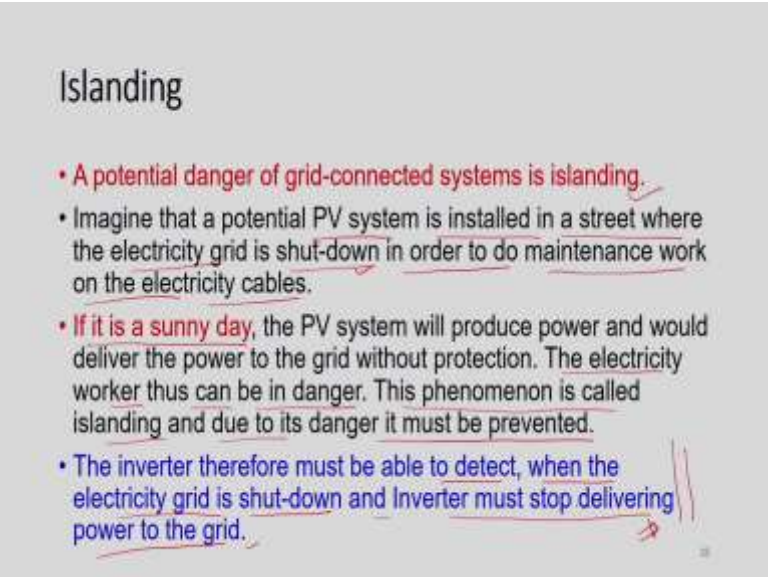

For example, a potential danger of grid connected system is islanding, imagine that a potential PV system is installed in a street where electricity grid is shut down, in order to do maintenance work on the electricity cables. So, that has to be shut down because know maintenance work has to be carried out in the cables. If it is a sunny day, solar radiation is received by those PV modules, the PV systems will produce power of course and would deliver the power to the grid without protection. The electricity worker thus can be in danger, this phenomenon is called islanding and due to its danger it must be prevented.

The inverter therefore must be able to detect when the electricity grid is shut down and the inverter must stop delivering power to the grid, this is very, very important aspects of an inverter, normally this component is attached to the modern inverters. So, we must know what is islanding and what is the potential danger without islanding.

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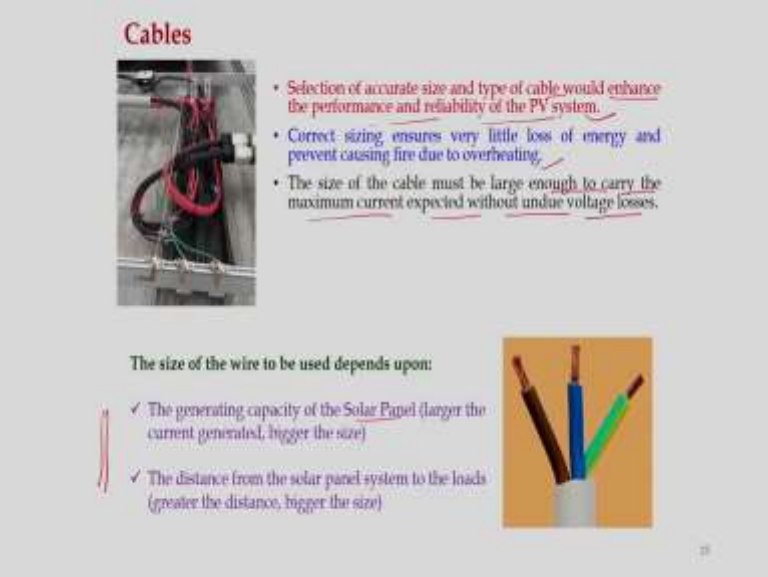

So, now let us learn something about the cables, the kind of cables used in grid connected PV system. So, this selection of cable plays a key role in the proper functioning of a grid connected PV system. So, this selection of accurate size and type of cable would enhance the performance and reliability of the PV system, the correct sizing ensures very little loss of energy and prevent causing fire due to overheating.

So, the third bullet point is the size of the cable must be large enough to carry the maximum current expected without undue voltage losses. So, these are very, very important and also we must know something on the parameters which depends on like the generating capacity of solar panels, then distance from the solar panel system to the load okay, so this size also depends on these two factors. So, what will the generation capacity of the solar panel and then the distance from the solar panel system to the load, so these are very, very important aspect because it involves a lot of cost, if we are talking about a megawatt level power plant.

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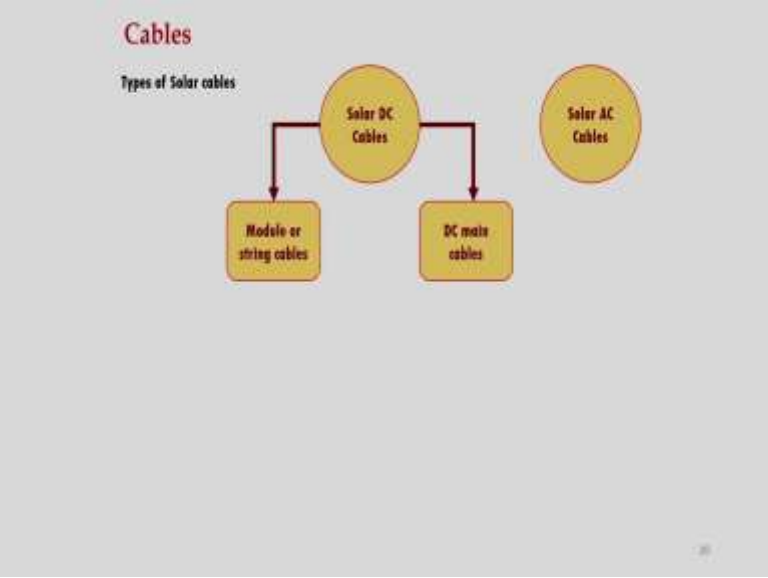

And primarily these cables are classified into two categories DC cables and AC cables, so DC cables again we have modular string cables and DC main cable.

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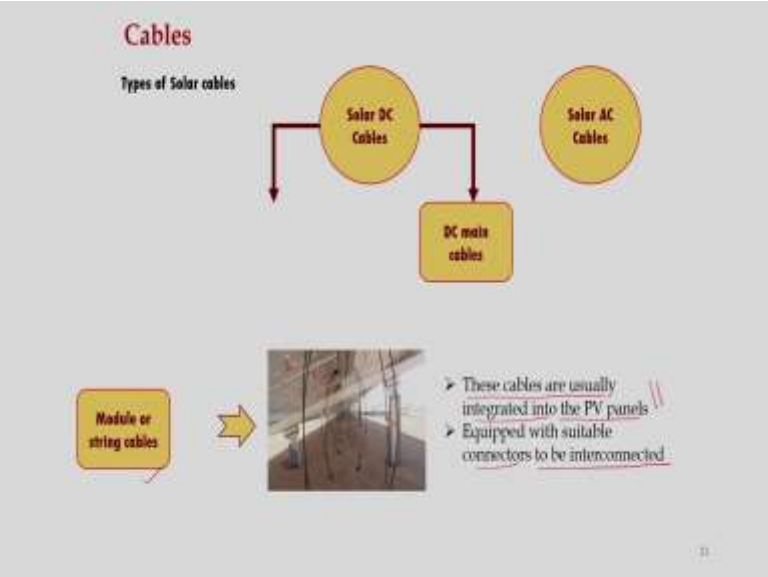

So let us see what is a module or string cables so as you can see this is module there are many modules are here and these are the connections, so these are nothing but string cables, so these cables are usually integrated into the PV panels, so this is with the PV panels and it is equipped with suitable connectors to be interconnected. So, from here to here maybe this is one panel, this is two panel, so these two are to be connected so by using this cable we can connect these two modules, may be for series connection, may be for parallel connections.

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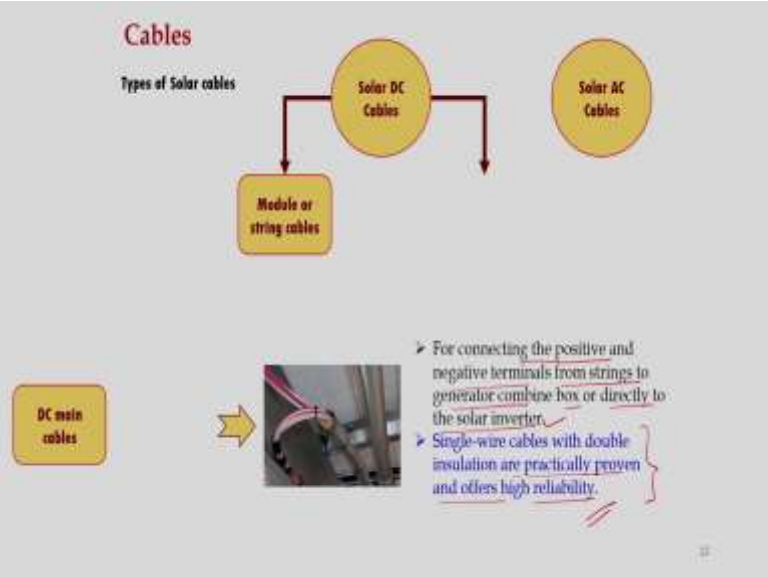

So, what is DC main cables? These cables are used for connecting positive and negative terminals from strings to the generator combine box or directly to the solar inverter, this single wire cables with double insulation are practically proven and offers high reliability. So, this is also very important aspect which we need to know.

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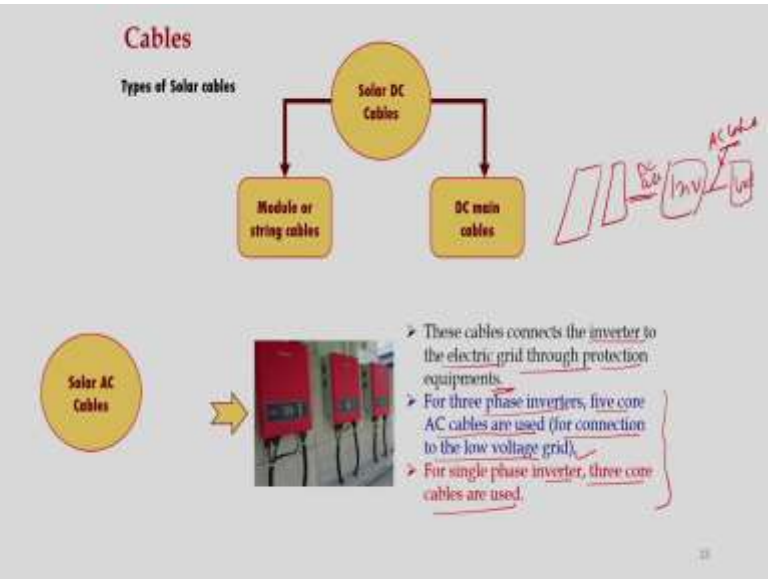

And let us learn what is solar AC cables. Already we know once we have inverter so maybe what we can consider here, so we have these are maybe modules, modules and then we have inverter, then we have cables and then it goes to the load or maybe grid. So this cable is DC cable, this DC cable and this is AC cable, so what we are talking about this AC cable.

So this cables connects the inverter, so this is inverter to the electric grid through protection equipment of course, there are many equipment will be there in between and for three phase inverters five core AC cables are used for connection to the low voltage grid and for single phase inverter, three core cables are used, so that also we know when to use what kind of cables.

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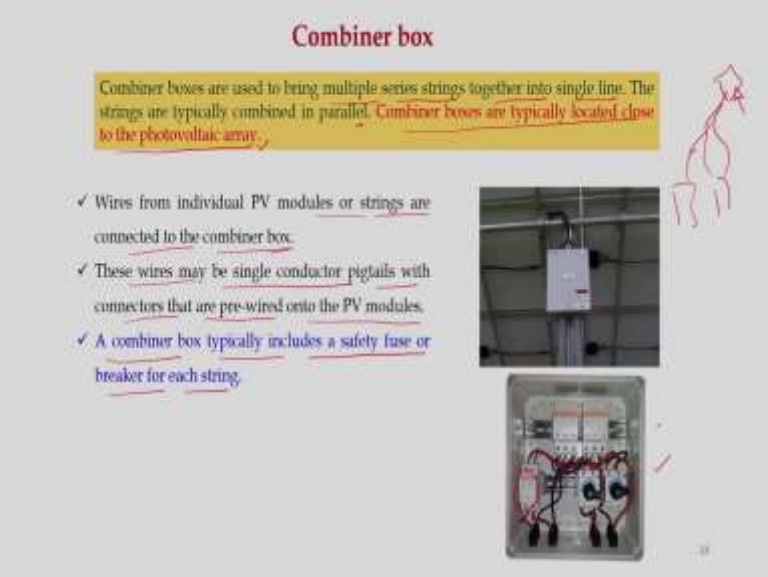

Now, let us see what is combiner box, this combiner box are used to bring multiple series string together into a single line, know already we know these modules and that has to be connected and finally it will come as a single wire and where it will be connected? It will be in combiner box. The strings are typically combined in parallel, this combiner box are typically located close to the photovoltaic array, so this we must know.

And these wires from individual PV modules or strings are connected to the combiner box and these wires may be single conductor pigtails with connectors that are pre-wired

into the PV modules. So, already this wires are with that PV module when you purchase the newly PV modules. A combiner box typically include a safety fuse or breakers for each string, what you can see these are the safety fuse, so these are attached in the combiner box, so it looks something like this.

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So, there are some connectors we must know about the connectors what kind of connectors are used, so solar connectors are used to connect solar panels to form strings, so normally these MC4 connectors are used, what does it mean? MC4 means multi contact connectors and 4 means the diameter of the contact pin, so that is how it designates, this connectors come in both male and female type which are designed to snap together, it looks something like this. So, female component is male component so these are classified something like this.

And this connectors must comply with the following requirements, whatever those requirements like stability against the dynamic load because with respect to irradiance and temperature the load will vary, so that has to be stable against the dynamic load. Then strength it should have carry some kind of strength and absolute protecting from dust and water infiltration, it should not enter water and dust in the connector and voltage overload stability is also an important factor, then fire proof, so fire, it should not catch

fire immediately so an insulant stability to negative effect of ultraviolet radiation. So, these are the requirements know of a connector, so this requirement should fulfill.

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So, now let us understand the module mountings, what are different configurations of mountings? So, as you understand the grid connected PV system is made up of an array of panels mounted on metallic support or integrated into a building. So, we can see some of the configurations, so this is in configuration for roof mounted, so roof is here and parallel to the roof these modules are connected so of course, there is a gap and clamps are there to hold the structure, so these are the modules, so this way you can see different configurations.

And here what you can see is a ground mounted system, so this may be ground, maybe roof top, it is a flat ground and here we need some kind of structure to hold this entire system and this is at grass, so what a grass this is installations, we need this structure to hold this the entire PV system.

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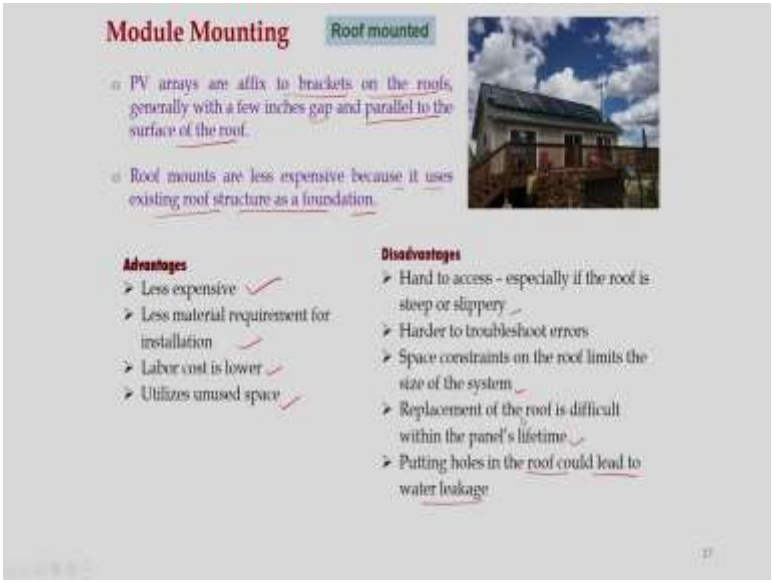

So, we will study one by one. So, in case of roof mounted, as you can see here so this is the modules and is the roof and this parallel to this roof, this modules are installed and there is a gap in between, so this PV arrays are fixed to brackets on the roof, generally with a few inch gap and parallel to the surface of the roof, what you can see here and this roof mounts are less expensive because it uses existing roof structure as a foundation.

So, you do not have to build that structure to hold this entire PV system, so that is one advantage but at the same time you must be confirmed about the strength of that roof to carry that much of load. So, what are advantages of this kind of configurations? It is less expensive, less material requirement for installation, then labour cost is lower, then utilizes unused spaces and what are the disadvantages?

It is hard to access especially if the roof is steep or slippery, so it is very difficult to climb here to fix those panels and harder to troubleshoot errors, again if something goes wrong then some technician has to visit the site and then rectify the system so it is difficult and space constraints on the roof limits the size of the system.

So, if we design a very high capacity PV systems on a small roof then it is not feasible that limits the system and replacement of the roof is difficult within the panel's lifetime, so once it is removed then what happens there might be many opertional difficulties, so it

might be some kind of holes then, water when rain falls it may goes in so there are many, many problems, so putting holes in the roof could lead to the water leakage, so these are different problems associated with this kind of roof mounted grid connected system.

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So, for ground mounted system, as you can see we need to have a strong structure to hold this entire PV panels and other components, then how we can define it? This PV array are hold in place by rack or frames that are attached to ground based mounting supports, so again we have to do something here civil work, so cement and other thing you need to apply then we have to have a pole then strong foundation needs to be made so that involves lot of cost.

This ground mounts take more space but easier to access for installation and repair, so this is one of the advantages and provide greater control over the orientation of PV array to maximize production. Now, advantages primarily, is easy to access, then easy to clean, then easier to troubleshoot because when dust accumulation will be there so every time you have to clean it that is why it is very, very important to make an arrangement to clean so that that people can move around and clean it in order to maximize the conversion efficiency, for roof mounted it is difficult sometimes to clean it.

And other disadvantages like installation is more labor intensive, installation is more expensive and requires more parts and pieces, not aesthetically pleasing to everyone, so sometimes people are claims know it looks not good if we install this kind of systems in the maybe near the playground or near to their garden, so this is one of the disadvantages of ground mounted PV system.

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And also we need to have a SCADA system for this kind of grid connected PV system. So, what does this SCADA stands for? This is something like Supervisory Control and Data Acquisition and this is used to monitor data from a plethora of devices including meters, inverters, weather stations, trackers, DC strings and substation equipment.

So, primarily it provides the information about the health of the plant, so there will be separate rooms from there they can monitor all those information, once you know the kind of radiation is falling, the amount of radiation is falling, what is the temperature, how much energy is generating all the information can be monitored by using this SCADA system.

So, this SCADA provides measurement option for lifetime power production, so this will be in kilowatt hour, record of daily power production for a month or so and money saved using solar power, then amount of carbon dioxide reduction, then record of any system

warning or fault, so if something some of the component is not working properly that can be diagnosed and current system power generation, then total everyday energy production, then photovoltaic input voltage, how much input voltage is generated on the particular day and at particular time and photovoltaic input current at that time.

So, it looks something like this it is a very sophisticated of course, it needs power so that has to be provided from the PV system itself but this kind of system are very, very important to know the health of the plant.

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And also for this kind of PV systems we need weather monitoring stations, this weather monitoring station is one of the important instruments required for a grid connected PV system, so what information we normally get from this weather monitoring stations? So, we get wind directions, wind speed, temperature, humidity, rainfall, solar radiation and barometric pressure.

So, this kind of systems are there as you can see this is anemometer so when the wind comes it strikes on this, sorry this is a anemometer, this strike on this bucket and it start rotating, so that we can understand the amount of wind speed on a particular time and day and of course, other parameters like temperature, humidity, rainfall everything can be monitored by using this weather monitoring station.

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And also there are components like cable glands these are required so small, small components for fitting tightly all those connectors and then we need cable lugs, so this these are something like this and this is normally used to connect the cables to electrical appliances, other cables surfaces and mechanisms and we will have cable ties and ferrules so this kind of components are required to connect those cables.

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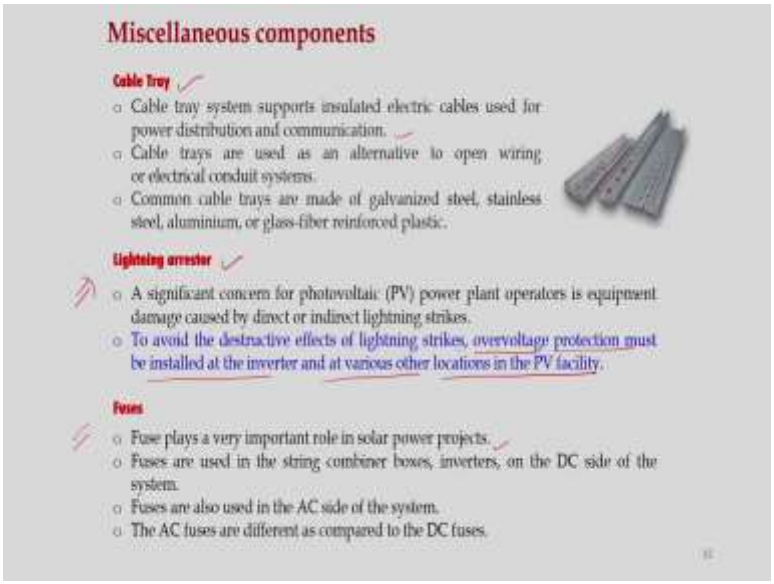

And of course, we need cable trays for installing those PV modules in this grid connected system, this cable tray system supports insulated electric cable used for power distribution and communication. So, as you can see it is something like this kind of brackets are used and then these are holes where in order to tighten the system so nut bolts are provided and then that will tighten the entire PV system.

And one very important aspect is lightning arrester which is very, very important to protect the unit, so to avoid the destructive effect of lightning strikes the over voltage protection must be installed at the inverter and at various other locations in the PV facility, so this is very, very important because without any arrestors very, very risky otherwise all the things will damage, so lightning arrestors are primary.

And of course, fuses are required so this fuses plays a very important role in solar power projects, so the different fuses like AC fuses are different as compared to DC fuses, so as per requirement so these fuses are installed in the prominent places and this will protect the equipment for a longer life.

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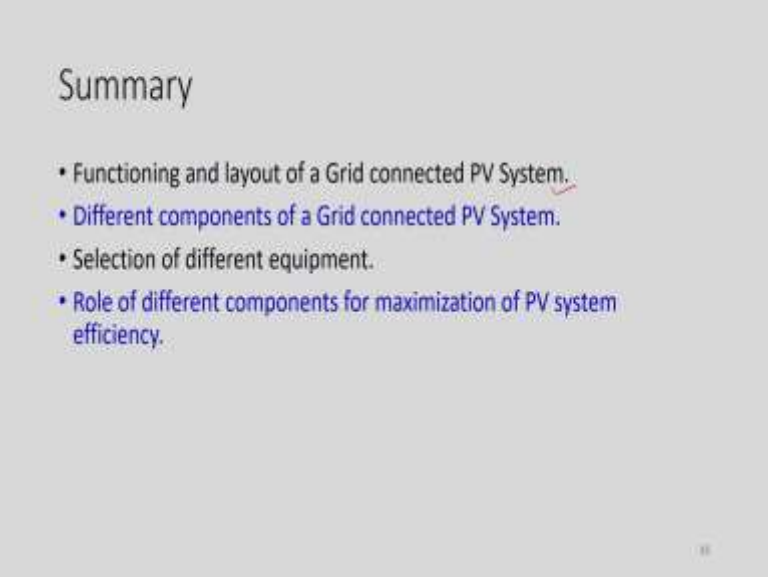

So, we can summarize what we have discussed today, primarily we have discussed the functioning and layout of grid connected PV system and then we have understand the different components of a grid connected PV system, then how this can be selected and

role of different components for maximization of PV system efficiency. I hope that you understand the things very clearly and maybe in the next class we will study more on design aspects of grid connected PV system. So, thank you very much for watching this video.