

SOLAR PHOTOVOLTAIC SYSTEM AND ITS

DESIGN PRACTICES

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Professional Training –I of
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Electrical and Electronics Engineering
By

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SCHOOL OF ELECTRICAL AND ELECTRONICS BONAFIDE CERTIFICATE

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“SOLAR PHOTOVOLTAIC SYSTEM AND IT’S

DESIGN PRACTICES” from 21st JULY 2021 to 5th AUGUST 2021.

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II.

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III.

Abstract

Solar energy has incredible potential to power our daily lives. Researchers suggest that the amount of sunlight that strikes the Earth's surface in an hour and a half is enough to handle the entire world's energy consumption for a full year.

Solar power system is one of the best renewable energy technology which is not only cost effective but environment friendly as well. For my research, I have suggested methodologies that may be applicable to other off grid applications. I will be explaining design methodology using an example of an off-grid bus shelter. Off-grid or standalone systems can be defined as independent systems that are not connected to any electrical grid. These come in different sizes and are mostly used in location where there is little access to grid infrastructure.

The off-grid bus shelter project will completely depend on the solar energy i.e. solar photovoltaics will harvest electricity to supply the devices such as lighting LED, Wi-Fi router and advertising billboard. A battery backup would be used as a continuous power supply in case of the worst weather.

This paper will focus on how methodology of off grid systems/stand-alone systems can help to reduce the dependency of grid and allow us to live in self-sufficient manners without reliance on one or more

public utilities. Further, a PV system will be designed for a bus shelter at EIU to demonstrate the concept.

IV.

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Introduction

Energy is a necessity like food and water. Everything around us requires energy. Over the years there has been an increase in the earth's population which is directly proportional to the energy used as well. All the possible gadgets and equipment need some or the other kind of energy to function. With depleting fossil fuel reserves it becomes necessary to identify viable renewable energy resources that can decrease the dependency on fossil fuels.

Solar energy is the most abundant form of energy available to us. It is approximated that 10000 TW worth of solar energy is incident on earth's surface in a day (Bosshard, 2006). According to a report, the world energy consumption in 2015 was 17.4 TW altogether (Seeger, 2016). There has been a minimal increase in the energy consumption every year, approximately 1-1.5% annual growth. The world's total energy consumption is expected to grow by 56% by the year 2040 (U.S Energy Information Administration, 2013). Comparing current consumption, projected growth in two decades, and the amount of solar radiation received in an hour we can just imagine the potential solar energy holds. The total energy consumed is not small fraction of what we receive in an hour. Despite this energy potential available to us the current utilization of solar energy is less than 5% globally. There are countries that are taking initiatives to switch from using fossil fuels to solar applications. These countries form a pool called the G-20 countries which have taken the global leadership to adopt renewable resources of energy.

Germany is one of the G- 20 countries that has switched its energy needs to approximately 38% to solar, and aims to go completely stop its dependency on nuclear and replace it with solar by the year 2050 (Richardson, 2017). Similarly, most of the countries have abundant solar potential and can take a lesson from Germany.

Apart from harvesting the resource and decreasing the dependency on fossil fuel because they are limited, one must understand the consequences of using fossil fuels. Burning of fossil fuels for energy has an adverse effect on the environment. It releases CO₂ into the atmosphere which is responsible for the greenhouse effect. Further, it also causes the ozone layer to be depleted. These mentioned phenomena can cause several events to occur such as; acid rain, air pollution, land pollution because of excavating operations, etc.

A 4 KW solar panel used in homes for 25 years can offset 199,697 lbs of CO₂ , is equivalent to planting, and is equal to 208,166 (RGS- Rethink your roof, n.d.). It is fascinating that how much just one home can make an impact in the environment by using Solar panels. One could imagine, what would be the benefit of using this technology on larger scale.

Photovoltaic Cells

In the 18th century, Swiss physicists assembled a warm trap, which was a small-scale greenhouse. He developed a hot box, by a glass box in another larger glass box, a total of up to five boxes. When they are proposed to coordinate the sun illumination, the temperature in the deepest box can be raised to 108 degrees Celsius; warm enough to soak water and cook food.

These crates can be considered the world's first solar collection. In the late 1950, some organizations and research facilities began to create a silicon based

solar cell that considers the goal of controlling Earth-orbiting satellites. These include RCA, Hoffman Electronics, and in addition, the U.S. Army Alert Corps (Desideri, Zapparelli, & Garroni, 2013).

A solar cell, or photovoltaic cell, is an electrical device that converts the energy of photons that are incident on it to electrical energy, which is a natural and synthetic marvel. A separate cell unit can be connected to a frame module, also known as a solar panel. Different solar cells in a unified set, all arranged in the plane represents a solar photovoltaic board or module.

PV modules usually have a glass in front of the panel, allowing light to pass through, while ensuring that the semiconductor plate is protected inside the case. Solar cells are usually associated, and arranged in series or parallel module, depending upon the requirement of the customer.

The parallel interface unit gets higher current; however, the problem, for example, that shadow effects can turn off weaker (less bright) parallel strings (different permutations of cells) can cause great unpleasant effects and may cause damage because of their enlightened complicity and the reversal of dark cell tendencies. A series of stacked units are usually autonomous and not parallel, but starting from 2014, each module provides a singular power box on a regular basis and connects in parallel.

PV Module or **Solar PV Module** is an assembly of photovoltaic (PV) cells, also known as solar cells. To achieve a required voltage and current, a group of **PV modules** (also called **PV panels**) are wired into large array that called **PV array**. A PV module is the essential component of any PV system that converts sunlight directly into direct current (DC) electricity. PV modules can be wired together in series

and/or parallel to deliver voltage and current in a particular system requires.

Working Principle of Solar Panels

In the previous discussion it has been established that there is abundance of solar energy available to be harvested. A brief discussion of what PV cells is also being covered. It is necessary that we understand how these cells generate electricity so that we can design systems that can be in tandem with these basic concepts. The following discussion will explain how the cells generate electricity.

Principle

Sun is a powerhouse of energy and this energy moves around in the form of electromagnetic radiations. These radiations are of several types such as light, radio waves, etc.

depending upon the wavelength of the radiations emitted. A very less percentage of sun's radiations reach the earth's atmosphere in the form of visible light. Solar cells use this visible light to make electrons. Different wavelength of light is used by different solar cells.

Solar cells are made up of semiconductor materials, such as silicon, which is used to produce electricity. The electricity is conducted as a stream of tiny particles called electrons and the stream is called electric current.

Two main types of electric currents are; DC (direct current) in which the flow of current is in the same direction while in AC (Alternating current) it may reverse the direction of current. A typical solar cell has two layers of silicon, which is n-type at the top and p-type at the bottom. When sunlight strikes the solar cell, the electrons are absorbed by silicon, they flow between n and p-layers to produce electric current and the current leaves the cell through the metal contact. The electricity generated is of AC type.

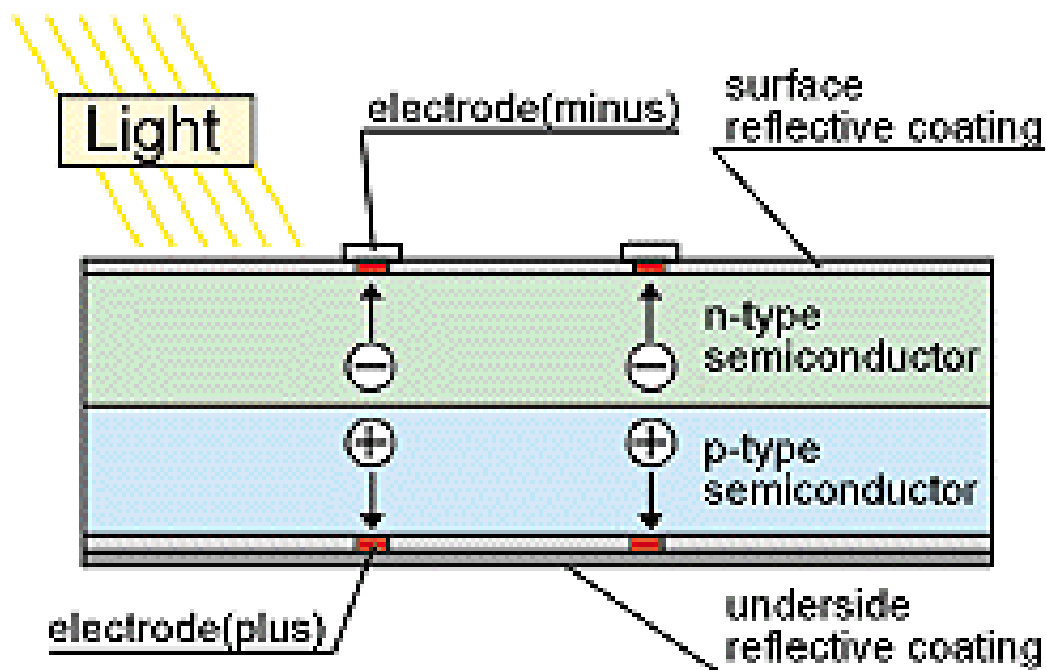


Figure 1 working of solar cell

Advantages and Disadvantages?

Did you know that the energy sun provides to the earth for one hour could meet the global energy needs for one year? Undoubtedly, the sun is a **powerful energy source**, and even though we are not able but to collect a fraction of this energy, yet harnessing this power by installing [solar panels](#) can make a significant difference to the planet.

While it has been widely criticised for being expensive or inefficient, **solar energy** has now proved to be extremely beneficial - not only for the environment but also for the private economy.

Thanks to available [solar panel grants](#), as well as, the increasingly competitive prices in the market, **solar energy** has become the **main source of energy** for more and more families. The technology has been drastically improved the last years and has been complemented by [solar battery storage systems](#), turning solar into a significantly more efficient source of clean energy.

Pros and Cons of Solar Energy

Advantages of Solar Energy	Disadvantages of Solar Energy
Renewable Energy Source	Cost
Reduces Electricity Bills	Weather Dependent
Diverse Applications	Solar Energy Storage is Expensive
Low Maintenance Costs	Uses a Lot of Space
Technology Development	Not Associated with 100% reliability

Solar energy systems and power plants do not pollute the environment or emit greenhouse gases. When solar energy replaces or decreases the usage of other energy sources with greater environmental impacts, it can have a beneficial, indirect effect on the climate.

Photovoltaic cells are made of harmful products and chemicals which are used for converting light into electricity. The atmosphere could be

harmful if potentially hazardous fluids leak. Environmental regulations in the United States govern the use and disposal of these products. Large solar power plants, like any other form of a power plant, can have an effect on the world around them.

The clearing of land for building and the location of the power plant will have a long-term impact on native plant and animal habitats. Water may be needed at some solar power plants to clean solar collectors and concentrators, as well as to cool turbine generators.

In certain arid areas, using large amounts of groundwater or surface water to clean collectors can have an effect on habitats that depend on these water supplies. Furthermore, the concentrated sunlight generated by a solar power tower can destroy birds and insects that fly into it.

Types of PV Systems

With growing demand for PV systems, the utilities provided an option for the consumers to connect their systems to the grid. This step introduced a new term called “Net Metering.” Net metering allows the consumers to send back the electricity they generate from their PV systems to the grid. This is possible because of the grid-tied connection enabled by the utility.

Similarly, we also have systems that are independent and do not require themselves to be connected to the grid such systems are called off-grid systems or standalone systems. Both the systems have been explained in detail below:

1. Standalone or Off-Grid Systems

The off-grid system term states the system not relating to the grid facility. Primarily, the system which is not connected to the main electrical grid is term as off-grid PV system (Weis, 2013). Off-grid system also called standalone system or mini grid which can generate the power and run the appliances by itself. Off-grid systems are suitable for the electrification of small community. Off-grid electrification system is viable for the remote areas in the countries where they do have little or no access to the electricity because of the distinct living and spread population in the vast area. The off-grid system refers to the support that would be adequate for a living without depending on the grid or other system. Electrical energy in the off-grid system produced through the Solar photovoltaic panels needs to be stored or saved because requirement from the load can be different from the solar panel output, battery bank is also used for the purpose generally.



Figure 2. Off-Grid solar PV system

This project is considering the viability of having an off-grid PV system which can be used to power a bus shelter. This concept can also be utilized on a larger scale to support all types of homes which are in remote areas and where the cost of connecting cables and other infrastructure of electricity to the house is expensive.

2. Integrated or Grid-Tied System

Grid connected photovoltaic power system is an electricity generating system which is linked to the utility grid (energy.gov, n.d.). This photovoltaic system contains solar panel, inverter and the equipment to provide connection to the grid. Grid connected systems are feasible for various setup such as residential. Commercial and larger scale grid tied system different than the off grid solar power systems. Usually grid connected system does not need battery backup, because when system generate the energy more than the load it will automatically transfer to the linked utility grid.

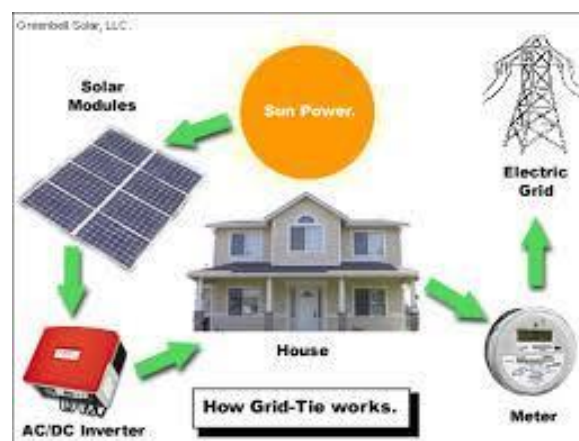


Figure 3. Grid-tied PV system

In the residential setups grid connected rooftop systems usually having the capability of 10 kilowatts which could be enough to meet the house requirements, and the excess would feed the grid which can be used by other consumers connected to the grid. The feedback or excess power transfer system works through a meter to track the transferred power. In some instances, PV system wattage could be less than the normal consumption due to several different factors and in this scenario, consumer will utilize the grid energy.

System Components

Pre-engineered photovoltaic systems can be purchased that come with all the components you will need, right down to the nuts and bolts. Any good dealer can size and specify systems for you, given a description of your site and needs. Nevertheless, familiarity with system components, the different types that are available, and criteria for making a selection is important.

Basic components of grid-connected PV systems with and without batteries are:

- Solar photovoltaic modules
- Array mounting racks
- Grounding equipment
- Combiner box
- Surge protection (often part of the combiner box)
- Inverter
- Meters – system meter and kilowatt-hour meter
- Disconnects:
 - Array DC disconnect
 - Inverter DC disconnect
 - Inverter AC disconnect
 - Exterior AC disconnect

If the system includes batteries, it will also require:

- Battery bank with cabling and housing structure
- Charge controller
- Battery disconnect

Solar Modules

The heart of a photovoltaic system is the solar module. Many photovoltaic *cells* are wired together by the manufacturer to produce a solar *module*. When installed at a site, solar modules are wired together in series to form *strings*. Strings of modules are connected in parallel to form an *array*.

Module Types –

Rigid flat framed modules are currently most common and most of these are composed of silicon. Silicon cells have atomic structures that are single-crystalline (a.k.a. mono-crystalline), poly-crystalline (a.k.a. multi-crystalline) or amorphous (a.k.a.

thin film silicon). Other cell materials used in solar modules are cadmium telluride (CdTe, commonly pronounced “CadTel”) and copper indium diselenide (CIS). Some modules are manufactured using combinations of these materials. An example is a thin film of amorphous silicon deposited onto a substrate of single-crystalline silicon. 8 In 2005 approximately 90 percent of modules sold in the United States were composed of crystalline silicon, either single-crystalline or poly-crystalline. The market share of crystalline silicon is down from previous years, however, and continues to drop as sales of amorphous silicon, CdTe and CIS modules are growing.

Building Integrated Photovoltaic Products –

PV technology has been integrated into roofing tiles, flexible roofing shingles, roofing membranes, adhesive laminates for metal standing-seam roofs,

windows, and other building integrated photovoltaic (BIPV) products. BIPV modules are generally more expensive than rigid flat modules, but are anticipated to eventually reduce overall costs of a PV system because of their dual purpose.

Rated Power –

Grid-connected residential PV systems use modules with rated power output ranging from 100-300 watts. Modules as small as 10 watts are used for other applications. Rated power is the maximum power the panel can produce with 1,000 watts of sunlight per square meter at a module temperature of 25o C or 77o F in still air. Actual conditions will rarely match rated conditions and so actual power output will almost always be less.

PV System Voltage –

Modern systems without batteries are typically wired to provide from 235V to 600V. In battery-based systems, the trend is also toward use of higher array voltages, although many charge controllers still require lower voltages of 12V, 24V or 48V to match the voltage of the battery string.

Using Manufacturer's Product Information to Compare Modules –

Since module costs and efficiencies continue to change as technology and manufacturing methods improve, it is difficult to provide general recommendations that will be true into the future regarding, for example, which type of module is cheapest or the best overall choice. It is best to make comparisons based on current information provided by manufacturers, combined with the specific requirements of your application.

Two figures that are useful in comparing modules are the modules' price per watt and the rated power output per area (or efficiency). When looking through a manufacturer's catalog of solar modules, you will often find the rated power,

the overall dimensions of the module, and its price. Find the cost per watt by dividing the module's price by its rated output in watts. Find the watts per area, by dividing its rated output by its area.

Module Cost per Watt –

As a general rule, thin film modules have lower costs than crystalline silicon modules for modules of similar powers.

Module Efficiency (Watts per Area) –

Modules with higher efficiency will have a higher ratio of watts to area. The higher the efficiency, the smaller the area (i.e. fewer modules) will be required to achieve the same power output of an array. Installation and racking costs will be less with more efficient modules, but this must be weight against the higher cost of the modules. Amorphous silicon, thin film CdTe and CIS modules have rated efficiencies that are lower than crystalline silicon modules, but improvements in efficiency continue.

Amorphous Silicon in Cloudy Climates –

Of importance to the Pacific Northwest, amorphous silicon modules have higher efficiency than crystalline silicon under overcast conditions. In cloudy weather, all types of amorphous silicon modules tend to perform better than crystalline silicon, with multi-junction (i.e. double- and triple-junction) amorphous silicon modules performing as much as 15 percent better. In Britain, which has a similar climate to ours, multi-junction amorphous silicon modules have been shown to produce more power over the course of the year than crystalline silicon modules.

Note that because the power ratings of modules are determined under high light, their rated efficiency (or rated watts per area), will not reflect performance in overcast weather.

Poly-crystalline or Single-crystalline Silicon? –

The power output of single-crystalline and poly-crystalline modules of the same area is quite similar.⁵ Both types of crystalline silicon are very durable and have stable power output over time. Therefore, do not be too concerned about the distinction between single-crystalline and poly-crystalline silicon in selecting a module. On the other hand, higher module efficiencies can be achieved by some combination products that have recently appeared on the market, such as amorphous silicon deposited on a single-crystalline substrate. These high efficiency modules may be a good choice particularly if the area available for the installation is limited.

Silicon Modules versus Other Module Types? –

The power output of CdTe modules has been less stable than silicon modules,⁶ although improvements are being made. For the time being, as for modules of any type, check manufacturer's warranties. A warranty guaranteeing high power output over 20 to 25 years is an indication of the longevity of the cell material.

Warranty –

It is important to verify warranty periods of all components of the system, including solar modules. Most modules are very durable, long lasting and can withstand

To Consider When Researching Inverters –

Many references on sizing and selecting inverters have been developed for off-grid systems, but may not clearly state that they are 15 specific to off-grid systems. Sizing and selecting grid-connected inverters entails different considerations and is easier, since the system does not have to provide 100 percent of the energy requirements. In particular, peak energy demand and surge capacity do not need to be considered for grid-connected systems.

Disconnects

Automatic and manual safety disconnects protect the wiring and components from power surges and other equipment malfunctions. They also ensure the system can be safely shut down and system components can be removed for maintenance and repair. For gridconnected systems, safety disconnects ensure that the generating equipment is isolated from the grid, which is important for the safety of utility personnel. In general, a disconnect is needed for each source of power or energy storage device in the system.

For each of the functions listed below, it is not always necessary to provide a separate disconnect. For example, if an inverter is located outdoors, a single DC disconnect can serve the function of both the array DC disconnect and the inverter DC disconnect. Before omitting a separate disconnect, however, consider if this will ever result in an unsafe condition when performing maintenance on any component. Also consider the convenience of the disconnect's location. An inconveniently located disconnect may lead to the tendency to leave the power on during maintenance, resulting in a safety hazard.

Array DC Disconnect – The array DC disconnect, also called the PV disconnect, is used to safely interrupt the flow of electricity from the PV array for maintenance or troubleshooting. The array DC disconnect may also have integrated circuit breakers or fuses to protect against power surges.

Inverter DC Disconnect –

Along with the inverter AC disconnect, the inverter DC disconnect is used to safely disconnect the inverter from the rest of the system. In many cases, the inverter DC disconnect will also serve as the array DC disconnect.

Inverter AC Disconnect –

The inverter AC disconnect disconnects the PV system from both the building's electrical wiring and the grid. Frequently, the AC disconnect is installed inside the building's main electrical panel. However, if the inverter is not located near the electrical panel, an additional AC disconnect should be installed near the inverter.

Exterior AC Disconnect– Utilities commonly require an exterior AC disconnect that is lockable, has visible blades and is mounted next to the utility meter so that it is accessible to utility personnel. An AC disconnect located inside the electrical panel or integral to the inverter would not satisfy these requirements. One alternative that is as acceptable to some utilities as an accessible AC disconnect is the removal of the meter itself, but this is not the norm. Prior to purchasing equipment, consult the electric utility to determine their requirements for interconnection.

Battery DC Disconnect –

In a battery-based system, the battery DC disconnect is used to safely disconnect the battery bank from the rest of the system.

Battery Bank -

Batteries store direct current electrical energy for later use. This energy storage comes at

a cost, however, since batteries reduce the efficiency and output of the PV system,

typically by about 10 percent for lead-acid batteries. Batteries also increase the complexity and cost of the system.

Types of batteries commonly used in PV systems are:

- ❖ Lead-acid batteries

- Flooded (a.k.a. Liquid vented)
- Sealed (a.k.a. Valve-Regulated Lead Acid)
 - Absorbent glass mat
 - Gel cell

- ❖ Alkaline batteries

- Nickel-cadmium
- Nickel-iron

Lead-Acid Batteries – Lead-acid batteries are most common in PV systems in general

and sealed lead acid batteries are most commonly used in grid-connected systems.

Sealed batteries are spill-proof and do not require periodic maintenance. Flooded leadacid batteries are usually the least expensive but require adding distilled water at least monthly to replenish water lost during the normal charging process.

There are two types of sealed lead acid batteries: sealed absorbent glass mat (AGM) and gel cell. AGM lead-acid batteries have become the industry standard, as they are maintenance free and particularly suited for grid-tied systems where batteries are typically kept at a full state of charge. Gel-cell batteries, designed for freeze-resistance, are generally a poor choice because any overcharging will permanently damage the battery.

Alkaline Batteries – Because of their relatively high cost, alkaline batteries are only recommended where extremely cold temperatures (-50o F or less) are anticipated or for certain commercial or industrial applications requiring their advantages over lead-acid batteries. These advantages include tolerance of freezing or high temperatures, low maintenance requirements, and the ability to be fully discharged or over-charged without harm.

Sizing Battery Banks – For grid-connected systems, batteries are usually sized for relatively short time periods with 8 hours being typical. Size may vary, however, depending on the particular needs of a facility and the length of power outages expected.

For comparison, battery banks for off-grid systems are usually sized for one to three cloudy days.

Interaction with Solar Modules– The solar array must have a higher voltage than the battery bank in order to fully charge the batteries. For systems with battery back-up, pay particular attention to the rated voltage of the module, also called the *maximum power point* (V_{mpp}), in the electrical specifications. It is important that the voltage is high enough relative to the voltage of a fully charged battery. For example, rated voltages between 16.5V and 17.5V are typical for a 12V system using liquid lead-acid batteries. Higher voltages may be required for long wiring distances between the modules and the charge controller and battery bank.

Charge Controller

A charge controller, sometimes referred to as a *photovoltaic controller* or *battery*

charger, is only necessary in systems with battery back-up. The primary function of a charge controller is to prevent overcharging of the batteries. Most

also include a lowvoltage disconnect that prevents over-discharging batteries. In addition, charge controllers prevent charge from draining back to solar modules at night. Some modern charge controllers incorporate maximum power point tracking, which optimizes the PV array's output, increasing the energy it produces.

Types of Charge Controllers –

There are essentially two types of controllers: shunt and series. A shunt controller bypasses current around fully charged batteries and through a power transistor or resistance heater where excess power is converted into heat. Shunt controllers are simple and inexpensive, but are only designed for very small systems. Series controllers stop the flow of current by opening the circuit between the battery and the PV array. Series controllers may be single-stage or pulse type. Single-stage controllers are small and inexpensive and have a greater load-handling capacity than shunt-type controllers. Pulse controllers and a type of shunt controller referred to as a multi-stage controller (e.g., three-stage controller) have routines that optimize battery charging rates to extend battery life. Most charge controllers are now three-stage controllers. These chargers have dramatically improved battery life.

Selection – Charge controllers are selected based on:

- ❖ PV array voltage – The controller's DC voltage input must match the nominal voltage of the solar array.
- ❖ PV array current – The controller must be sized to handle the maximum current produced by the PV array.

Interaction with Inverter– Since the majority of charge controllers have been installed in off-grid systems, their default settings may not be appropriate for a grid-connected system. The charge controller must be set up such that it does

not interfere with the proper operation of the inverter. In particular, the controller must be set up such that charging the batteries from the PV array takes precedence over charging from the grid. For more information, contact the manufacturer.

Interaction with Batteries– The charge controller must be selected to deliver the

charging current appropriate for the type of batteries used in the system. For example, on a 12V system, flooded lead-acid batteries have a voltage of 14.6V to 15.0V when fully charged, while sealed lead-acid batteries are fully charged at 14.1 V. Refer to the battery manufacturer for the charging requirements of particular batteries.

Methodology of Designing an Off-Grid PV System

Site assessment

In the introduction of solar photovoltaic (PV) clusters for private, commercial, or agricultural operations; a crucial idea is to determine the merits of the site (Franklin, 2017). Identifying the place and position of the panels is a crucial step in designing a PV system as the later components will be streamlined to this step. A few concepts and tips one must keep in mind while performing the site assessment are:

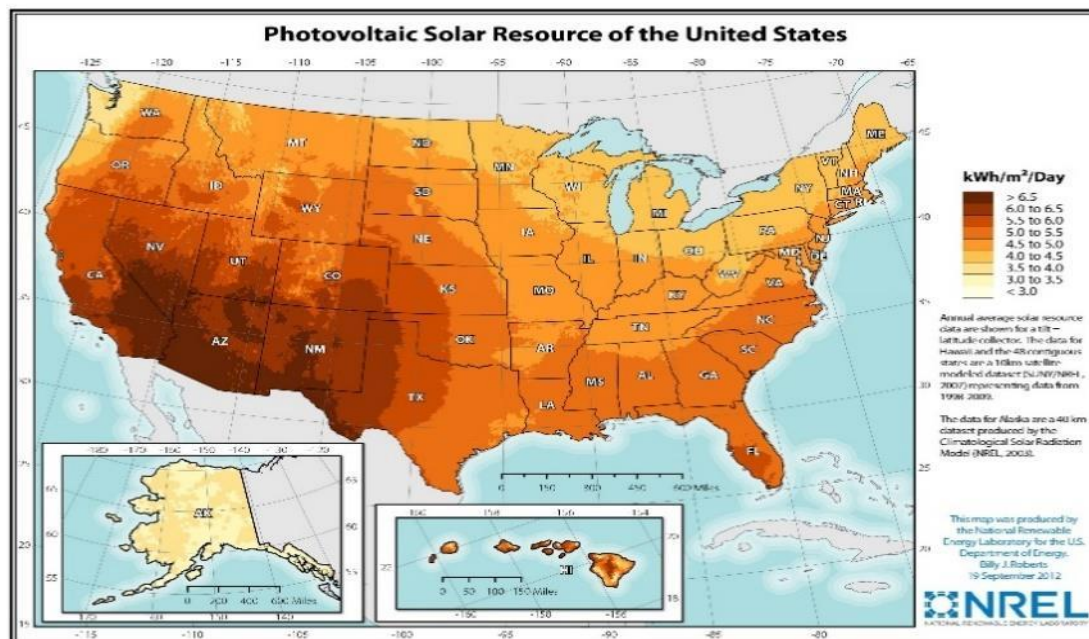
1.Shade Analysis:

Shading can be a problem for the solar panels as they decrease the maximum power that can be generated. Several factors contribute to this issue, the most common cause of shade on a solar panel are; 1) Shade from neighboring trees and buildings in vicinity, 2) typical cloudy weather, and 3) shade from adjacent solar panels (Solar Choice, 2016). While designing a solar PV system one must investigate these factors thoroughly so that maximum

output can be obtained. One of the tools most commonly used is solar pathfinder which gives the direction of the sun through out the year and how much any specific area will receive sunlight throughout the year (Solar Pathfinder, n.d.). Apart from having this tool, it is important that the site assessment is done properly to locate the best site keeping in mind all the aspects.

2. Sun hours:

Sun hours are important to know how much radiance will be required to generate the needed output wattage. This parameter gives us the knowledge of number of hours an area will receive maximum sunlight (Franklin, 2017). With advances in technology we have this data available online and anyone can use it. We have studied the data from NREL and NASA but for our project we will be using data given by NREL as it is giving information of the Sun hours to a closer proximity to Charleston. The following chart gives the required information of the Sun hours depending on different zones classified by NREL.



3. Tilt angle:

Tilt angle is the setting of the panels one needs to have to get the maximum radiance. Ideally the tilt angle is the latitude of the geographic location. It is suggested to have an adjustable panel frames as the sun hours keep changing with respect to the tilt in winters and summers. Hence for any area a specific tilt angle is calculated to get the maximum radiance through out the year for a fixed panel. Also, it is advised to have the panels facing the south to get the maximum afternoon sun. A couple of devices are used in the process of finding the tilt angle and the radiance that will fall upon panel at that tilt angle are inclinometer and pyranometer, respectively.

An inclinometer is kept on the panel and the degrees are read to find the latitude of the area as it is perpendicular to the Sun's radiations when it is at its highest point in the sky. Pyranometer measures the solar irradiance that will fall at a given tilt angle. It measures solar irradiance in Watts per meter Sq. (W/m^2) (Franklin, 2017).

Energy Calculations

The consensus is to add wattage of the equipment that are going to be powered using the PV system. Alternatively, for this task we can use baseload calculators that are available on the internet. We have used one such tool to calculate the baseload of our project, the following link will direct to the website which has the calculator (Wholesale solar , n.d.) Every device has fixed power consumption that can be found on its name plate details. This data from all the devices that are going to be used should be retrieved. The website mentioned above provides a table where this information needs to be entered. Other data that needs to be

entered is number of each appliance that are going to be used and number of hours the appliance is supposed to remain ON. Up on filling the required data the website generates a table that give the total Watt-hours that are going to be used i.e. the total energy consumed or the wattage of the PV system. Another point one must pay attention to is the system voltage. It is required that the system level chosen before we further probe into designing. Subsequent equipment designing would be based on the system voltage level.

Panel Sizing

Once the total load to be energized using the PV system is calculated we must find out what area of solar panels would be required to generate that much amount of power. It is an inherent property of any panel to have internal losses. This factor should be kept in mind. As in the energy calculation we have already found the total watt-hours, for finding the wattage of panels that would be required we need to divide the total watt-hours with peak sun hours (Pelamis wave power, n.d.).

Another useful tool that can be used is PV WATTS that helps use to calculate panel sizing just by putting the parameters such as energy consumption, tilt angle, and Sun hour. We have used this same website to calculate the solar panels. (NREL, n.d.)

The website also enables the user to get the size of the panels that would be required to generate the required wattage.

Battery Sizing

PV battery system assesses various strategies from a financial perspective. The valuable existence of the battery is limited to 5,000 cycles or in the planned living time of 20 years. The maintenance of photovoltaic and rechargeable annual activities and expenditure systems is set at 1.5% per the speculative cost. Assume that the cost system for the battery and PV is comparable to their size.

Following is a formula that will enable to calculate what size of battery they should have. (Leonics, n.d.) $\text{Battery Capacity (Ah)} = \frac{\text{Total Watt-hours per day used by appliances} \times \text{Days of autonomy}}{(0.85 \times 0.6 \times \text{nominal battery voltage})}$

Inverter

Inverter deals with following main tasks of energy: (ALTE store, n.d.)

- Convert DC from PV module to AC
- Ensure that the cycle of alternating current cycles is 60 cycles
- Reduce voltage variations
- Ensure that the condition of the AC waveform is suitable for the application

Most system-connected inverters can be introduced externally, and most of the off-grid

inverters are not weather-resistant. There are basically two types of grid intelligent Inverters:

Those designed for batteries and those designed for systems without battery-connected inverter systems and give excellent void-quality strength. For matrix associations, the inverter should have a "useful-interactive" typeface, which is printed specifically for the publication name. Grid-connected systems measure the power of extracting PV clusters rather than a bunch of prerequisite buildings. It asserts that what each power supply needs are what the matrix-related PV system can give naturally is drawn from the net. Invertors used for solar PV systems are usually based upon the total wattage of the solar panels, as the inverter will be continuously converting the power generated. The second consideration

one must investigate, is the voltage level of the system. For example, if the system is designed to generate 2000 Watts at a voltage level of 12 V then the inverter selected should be rated 12V, 2000 Watts (Alternative Energy, n.d.).

Charge Controller

The charge controller, sometimes referred to as a photovoltaic controller or charger, is only necessary for the system which involves a battery (Wholesale Solar, n.d.). The main capacity of the charge controller is to counteract the battery spoofing. The basic function of charge controller is to monitor charging and discharging of the battery. It prevents the battery from being completely charged or discharged. This is important because over charging can lead to destruction of the battery and under charging decreases the battery life. Another important

reason to use a charge controller is to prevent a reverse current flowing from battery to the system.

There are two types of controllers that are widely available in the market; 1) Pulse width Modulation (PWM), 2) Maximum Power Point Tracking (MPPT) (Northern Arizon Wind and Sun, n.d.)

1. Pulse width modulation: A pulse width modulation charge controller is set match the input power of the battery irrespective of the power generated by the panels. There is an inherent loss in power observed in this type of charger.

2. Maximum Power Point Tracking (MPPT): This type of charger helps to get the optimum charging power for any given point of time and offers better efficiency than PWM.

Though the MPPT charge controllers enable you to have better efficiencies and provides more power than compared to PWM for similar condition, the main cause of not opting for MPPT is price of it (Solar Guy, 2016). MPPT charge controllers are more expensive than PWM controllers. Keeping this parameter

in mind, this project will be using a PWM charge controller for realizing the concept. To select the size of charge controller one must know the voltage level of the system and the maximum operating current. It is a usual practice to over size the controller for safety reasons.

Grid-tied and off-grid PV systems have their own advantages and disadvantages. Depending solely on the need one can decide what they would want to go for. It is a trend that one can observe is that the grid-tied system is mostly found in urban and sub-urban setting where electrification of the area has already been achieved. The off-grid system is more suited to areas where the electrification is yet to be accomplished and/or the consumer chooses not to supply back the energy generated at his/her end. This paper provides the methodology of designing an off-grid PV system. Using a bus shelter at EIU an PV system was designed that would house certain necessary equipment such as WIFI module, charging points, lights, and sensors that would provide service to the students who would be using it. The design methodology is not limited to only bus shelters but could also be used for different purposes where ever a need of having an off-grid system arises.

Economical aspect of the system has not been covered in this paper due to the availability of numerous vendors in the market. Upon identifying the system capacity, one can search the best option of different equipment depending on their financial preferences.

Solar in India -

The Sun has been worshiped as a life-giver to our planet since ancient times. The industrial ages gave us the understanding of sunlight as an energy source. India is endowed with vast solar energy potential. About 5,000 trillion kWh per year energy is incident over India's land area with most parts receiving 4-7 kWh per sq. m per day. Solar photovoltaics power can effectively be harnessed providing huge scalability in India. Solar also provides the ability to generate

power on a distributed basis and enables rapid capacity addition with short lead times. Off-grid decentralized and low-temperature applications will be advantageous from a rural electrification perspective and meeting other energy needs for power and heating and cooling in both rural and urban areas. From an energy security perspective, solar is the most secure of all sources, since it is abundantly available. Theoretically, a small fraction of the total incident solar energy (if captured effectively) can meet the entire country's power requirements.

There has been a visible impact of solar energy in the Indian energy scenario during the last few years. Solar energy based decentralized and distributed applications have benefited millions of people in Indian villages by meeting their cooking, lighting and other energy needs in an environment friendly manner. The social and economic benefits include reduction in drudgery among rural women and girls engaged in the collection of fuel wood from long distances and cooking in smoky kitchens, minimization of the risks of contracting lung and eye ailments, employment generation at village level, and ultimately, the improvement in the standard of living and creation of opportunity for economic activities at village level. Further, solar energy sector in India has emerged as a significant player in the grid connected power generation capacity over the years. It supports the government agenda of sustainable growth, while, emerging as an integral part of the solution to meet the nation's energy needs and an essential player for energy security.

National Institute of Solar Energy has assessed the Country's solar potential of about 748 GW assuming 3% of the waste land area to be covered by Solar PV modules. Solar energy has taken a central place in India's National Action Plan on Climate Change with National Solar Mission as one of the key Missions. National Solar Mission (NSM) was launched on 11th January, 2010. NSM is a major initiative of the Government of India with active participation from States to promote ecological sustainable growth while addressing India's energy

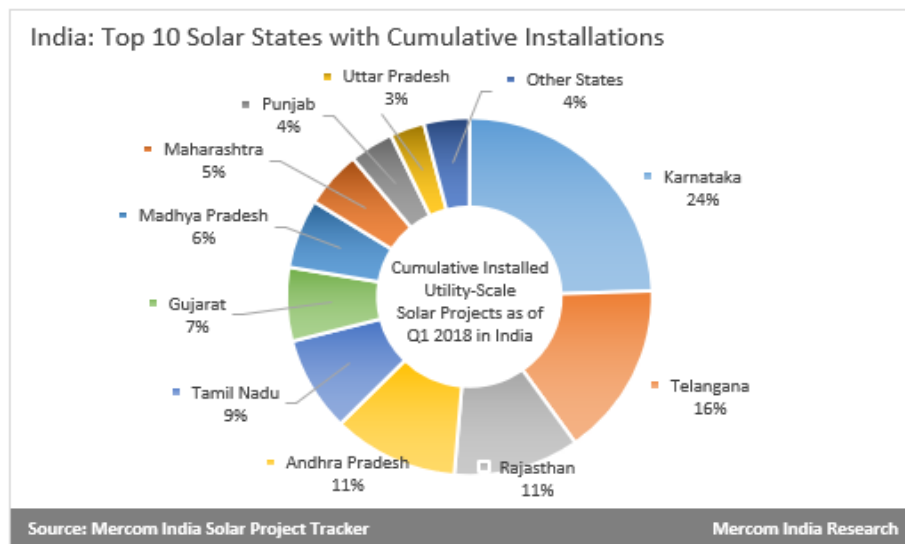
security challenges. It will also constitute a major contribution by India to the global effort to meet the challenges of climate change. The Mission's objective is to establish India as a global leader in solar energy by creating the policy conditions for solar technology diffusion across the country as quickly as possible. The Mission targets installing 100 GW grid-connected solar power plants by the year 2022. This is line with India's Intended Nationally Determined Contributions (INDCs) target to achieve about 40 percent cumulative electric power installed capacity from non-fossil fuel based energy resources and to reduce the emission intensity of its GDP by 33 to 35 percent from 2005 level by 2030.

In order to achieve the above target, Government of India have launched various schemes to encourage generation of solar power in the country like Solar Park Scheme, VGF Schemes, CPSU Scheme, Defence Scheme, Canal bank & Canal top Scheme, Bundling Scheme, Grid Connected Solar Rooftop Scheme etc.

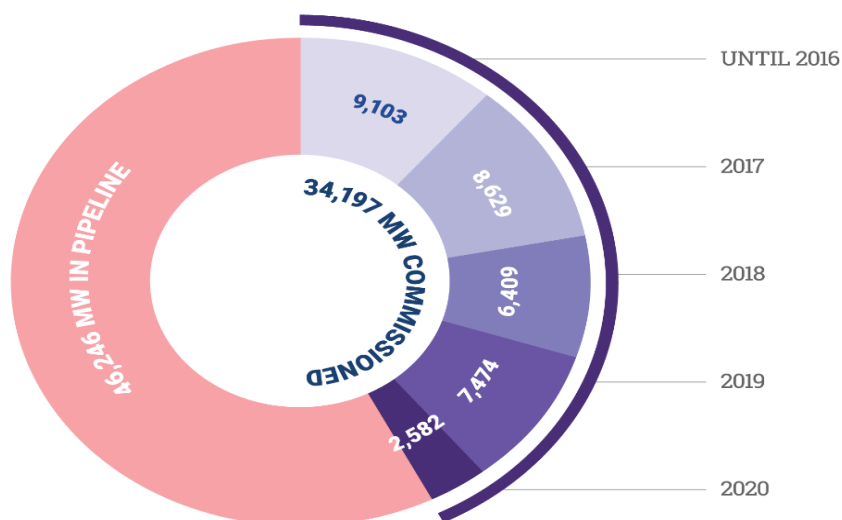
Various policy measures undertaken included declaration of trajectory for Renewable Purchase Obligation (RPO) including Solar, Waiver of Inter State Transmission System (ISTS) charges and losses for inter-state sale of solar and wind power for projects to be commissioned up to March 2022, Must run status, Guidelines for procurement of solar power through tariff based competitive bidding process, Standards for deployment of Solar Photovoltaic systems and devices, Provision of roof top solar and Guidelines for development of smart cities, Amendments in building bye-laws for mandatory provision of roof top solar for new construction or higher Floor Area Ratio, Infrastructure status for solar projects, Raising tax free solar bonds, Providing long tenor loans from multi-lateral agencies, etc.

Recently, India achieved 5th global position in solar power deployment by surpassing Italy. Solar power capacity has increased by more than 11 times in

the last five years from 2.6 GW in March, 2014 to 30 GW in July, 2019. Presently, solar tariff in India is very competitive and has achieved grid parity.



Total utility scale solar capacity as on 31 December, 2020



List of Solar Power Plants / Solar Parks in India-

India's National Solar Mission has the target of producing 20GW by the end of 2020. The mission was launched in 2010. Our country's biggest solar power plants are located in Rajasthan, Karnataka, Andhra Pradesh, Madhya Pradesh

and Tamil Nadu. Know all special facts about these solar power plants in the article below.

India ranks third in Asia and fourth in the world in terms of solar power production. National Solar Mission was launched in India in 2010 . The target set was to develop 20GW by the end of 2020. This has however been crossed long back as there has been heavy activity in this sector since then. Now the Government of India aims to extend the utilization of solar energy upto 100 GW by 2022.

Right now, the country is only using 38% of its total capacity of renewable energy. Also, the world's largest solar park would be constructed in Rajasthan. Some of the country's biggest solar power plants are located in Rajasthan, Karnataka, Andhra Pradesh, Madhya Pradesh and Tamil Nadu.

1. Bhadla Solar Park, Rajasthan

Location: Jodhpur district of Rajasthan

Power Generation: 2055 MW

Area of Park: 14000 acres

2. Pavagada Solar Park

Location: Palavalli, Karnataka

Power Generation: 2000MW

Area of Park: 13000 acres

3. Kurnool Ultra Mega Solar Park, Andhra Pradesh

Location: Kurnool, Andhra Pradesh

Power Generation: 1000 MW

Area of Park: 5932 acres

4. NP Kunta Ultra Mega Solar Park

Location: Anathapuram, Andhra Pradesh

Power Generation: 1500 MW

Area of Park: 7924 acres

5. Rewa Ultra Mega Solar Plant

Location: Rewa, Madhya Pradesh

Power Generation: 750 MW

Area of Park: 1590 acres

Other Solar Plants in India

Listed below are the Solar Power Plants in India along with the location, capacity and developer details

State	Solar Park	Capacity (MW)	Solar Power Parks Developer (SPPD)
Andhra Pradesh	Ananthapuramu-I Solar Park	1500	AP Solar Power Corporation Pvt. Ltd. (APSPCL), JVC of SECI, APGENCO and NREDCAP
	Kurnool Solar Park	1000	
	Kadapa Solar Park	1000	
	Ananthapuramu-II Solar Park	500	
	Hybrid Solar Wind Park	160	
Arunachal Pradesh	Lohit Solar Park	20	Arunachal Pradesh Energy Development Agency (APEDA)
Gujarat	Radhnesada Solar Park	700	Gujarat Power Corporation Limited (GPCL)
	Harsad Solar Park	350	
	Dholera Solar Park Ph-I	1000	
	Dholera Solar Park Ph-II	4000	Solar Energy Corporation of India (SECI)
Himachal Pradesh	Kaza Solar Park	1000	JVC of SJVN & Govt of HP

Jharkhand	Floating Solar Park	150	Solar Energy Corporation of India (SECI)
Karnataka	Pavagada Solar Park	2000	Karnataka Solar Power Development Corporation Pvt. Ltd. (KSPDCL), JVC of KREDL & SECI
Kerala	Kasargod Solar Park	105	Renewable Power Corporation of Kerala Limited (RPCKL), JVC of SECI
Madhya Pradesh	Rewa Solar Park	750	Rewa Ultra Mega Solar Limited (RUMSL), JVC of MPNRED & SECI
	Mandsaur Solar Park	250	
	Neemuch	500	Rewa Ultra Mega Solar Limited (RUMSL), JVC of MPNRED & SECI
	Agar	550	Rewa Ultra Mega Solar Limited (RUMSL), JVC of MPNRED & SECI
	Shajapur	450	Rewa Ultra Mega Solar Limited (RUMSL), JVC of MPNRED & SECI
	Omkareswar Floating Solar Park	600	Rewa Ultra Mega Solar Limited (RUMSL), JVC of MPNRED & SECI
	Chhattarpur Solar Park	950	Rewa Ultra Mega Solar Limited (RUMSL), JVC of MPNRED & SECI
	Barethi Solar Park	550	NTPC
Maharashtra	Sai Guru Solar Park (Pragat)	500	M/s Sai Guru Mega Solar Park Pvt. Ltd. (formerly M/s Pragat Akshay Urja Ltd.)
	Patoda Solar Park (Paramount)	150	M/s Paramount Solar Power Pvt. Ltd. (formerly M/s K. P. Power Pvt. Ltd.)
	Dondaicha Solar	250	Maharashtra State Electricity

	Park		Generating Company Ltd. (MAHAGENCO)
Manipur	Bukpi Solar Park	20	Manipur Tribal Development Corpn. Ltd. (MTDCL)
Meghalaya	Solar park in Meghalaya	20	Meghalaya Power Generation Corporation Ltd (MePGCL)
Mizoram	Vankal Solar Park	20	Power & Electricity Department
Odisha	Solar Park by NHPC	40	NHPC Limited
	Solar Park by NHPC	100	NHPC Limited
Rajasthan	Bhadla-II Solar Park	680	Rajasthan Solar Park Development Company Ltd. (RSDCL)
	Bhadla-III Solar Park	1000	M/s Surya Urja Company of Rajasthan Ltd (SUCRL) JVC of State Govt
	Bhadla-IV Solar Park	500	M/s Adani Renewable Energy Park Rajasthan Limited (AREPRL) JVC of State Govt
	Phalodi-Pokaran Solar Park	750	M/s Essel Surya Urja Company of Rajasthan Limited (ESUCRL) JVC of State Govt
	Fatehgarh Phase-1B Solar Park	421	M/s Adani Renewable Energy Park Rajasthan Limited (AREPRL) JVC of State Govt
	Nokh Solar Park	925	Rajasthan Solar Park Development Company Ltd. (RSDCL)
Uttar Pradesh	Solar Park in UP	440	Lucknow Solar Power Development Corporation Ltd. (LSPDCL) JVC of UPNEDA & SECI

	Jalaun Solar Park	1200	BSUL
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The solar power plants listed above are responsible for more than 25000 MW power generation across India. Prime Minister Narendra Modi would also be inaugurating the world's largest renewable solar and wind energy park in Gujarat's Kutch and another desalination plant, on December 15, 2020.

PM Modi participated in the 15th G20 Summit convened by Saudi Arabia in a virtual format. In his address, the Prime Minister stressed that India would meet its goal of 175 GW of renewable energy capacity target well before the target 2022 and that India is now more focused on reaching its next target of 450 GW capacity by 2030.

Conclusion :-

Photovoltaic systems can have a dramatic impact at the residential level in Puerto rico . during the day, enough electrical energy can be generated to displace fossil-fuel based generation equivalent to the residential load using dispersed residential PV system.

Irradiance variations not a big issue for disbursed PV systems. however due to stringent land issue use limitations ,it is not recommended to use land in PR for large PV arrays.

PV grid interconnection issues are a widely studied field. Several references regarding the operational characteristics of PV DG equipment have already been provided throughout this chapter . a sample of literature dealing with some PV DG grid-interconnection issues at a system level .The operational limits are dependent on the utility's particular operating region .In Puerto Rico, where we have an abundant solar energy resource the question should be not how to best integrate that resource into the adjusting infrastructures, but how the latter should change or transition in order to make way for the maximum penetration possible (technologically, economically and socially) of solar and other renewable sources.