بسم الله الرحمن الرحيم

Study of Renewable Energy Based On Solar Energy Cell

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ABSTRACT

Solar photovoltaic (PV) energy is becoming an increasingly important part of the world's renewable energy. In order for effective energy extraction from a solar PV system, this research investigates solar PV energy generation and conversion from devices to grid integration. First of all, this dissertation focuses on I–V and P–V characteristics of PV modules and arrays, especially under uneven shading conditions, and considers both the physics and electrical characteristics of a solar PV system in the model development. The dissertation examines how different by pass diode arrangements could affect maximum power extraction characteristics of a solar PV module or array. Secondly, in order to develop competent technology for efficient energy extraction from a solar PV system, this research investigates typical maximum power point tracking (MPPT) control strategies used in solar PV industry, and proposes an adaptive and close-loop MPPT strategy for fast and reliable extraction of solar PV power. The research focuses especially on how conventional and proposed MPPT methods behave under highly variable weather conditions in a digital control environment. A computational experiment system is developed by using Mat Lab Simulation Power Systems and Opal-RT (real-time) simulation technology for fast and accurate investigations of the maximum power extraction under high frequency switching conditions of power converters. A hardware experiment system is built to compare and validate the conventional and the proposed MPPT methods in a more practical condition. Advantages, disadvantages and properties of different MPPT techniques are studied, evaluated, and compared

Contents:-

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Chapter 1

Background Study

Solar Cells

A solar cell or photovoltaic cell is a device which generates electricity directly from visible light by means of the photovoltaic effect. In order to generate useful power, it is necessary to connect a number of cells together to form a solar panel, also known as a photovoltaic module. The nominal output voltage of a solar panel is usually 12 Volts, and they may be used singly or wired together into an array. The number and size required is determined by the available light and the amount of energy required.

FIG 1.0 Solar Cell

Fig. 1.1 shows an image of typical solar panel.

Storing of Power

The amount of power generated by solar cells is determined by the amount of light falling on them, which is in turn determined by the weather and time of day. In the majority of cases some form of energy storage will be necessary. In a Grid-connected system, the solar array is connected to the mains. Any surplus power is sold to the electricity company, and power is bought back from them when it is needed. In a Stand-alone system, however, this is not possible. In this type of system the usual choice for energy storage is the lead-acid battery. The number and type of batteries is dependent on the amount of energy storage needed.

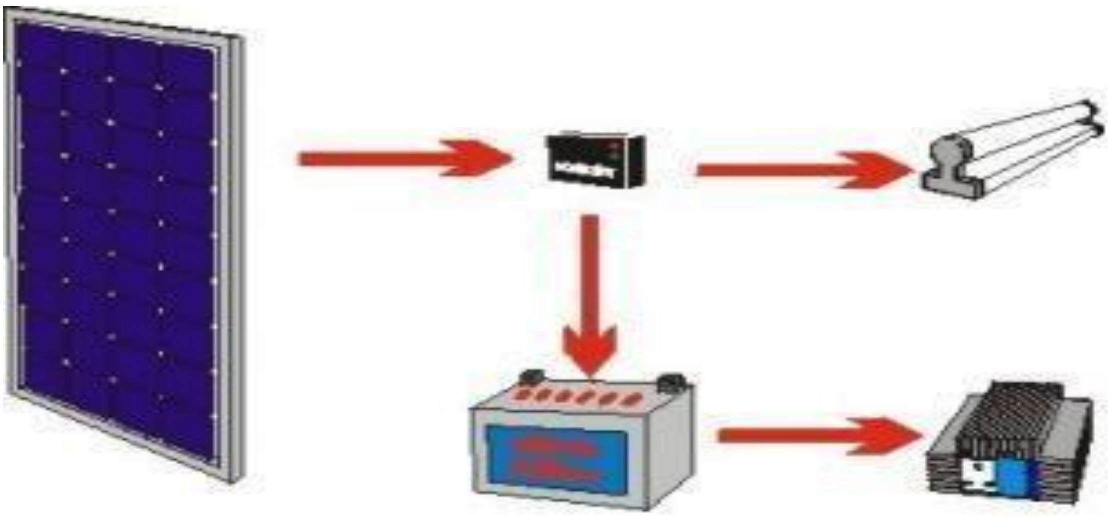


FIG 1.1 Storing of Power

Fiq.1.2 shows an image of solar storing of power

Solar Power Batteries

In stand-alone systems, the power generated by the solar panels is usually used to charge a lead-acid battery. Other types of battery such as nickel-cadmium batteries may be used, but the advantages of the lead-acid battery ensure that it is still the most popular choice. A battery is composed of individual cells; each cell in a lead-acid battery produces a voltage of about 2 Volts DC, so a 12 Volt battery needs 6 cells. The capacity of a battery is measured in Ampere-hours or Amp-hours (Ah).

Types of Solar Cells

Solar cells are usually made from silicon, the same material used for transistors and integrated circuits. The silicon is treated or "doped" so that when light strikes it electrons are released, so generating an electric current. There are three basic types of solar cell. Mono crystalline cells are cut from a silicon ingot grown from a single large crystal of silicon whilst poly crystalline cells are cut from an ingot made up of many smaller crystals. The third type is the amorphous or thin-lm solar cell.

Amorphous Solar Cells

Amorphous technology is most often seen in small solar panels, such as those in calculators or garden lamps, although amorphous panels are increasingly used in larger applications. They are made by depositing a thin lm of silicon onto a sheet of another material such as steel. The panel is formed as one piece and the individual cells are not as visible as in other types. The efficiency of amorphous solar panels is not as high as those made from individual solar cells, although this has improved over recent years to the point where they can be seen as a practical alternative to panels made with crystalline cells. Their great advantage lies in their relatively low cost per Watt of power generated. This can be o set, however, by their lower power density; more panels are needed for the same power output and therefore more space is taken up.

FIG 1.2 Amorphous Solar Cells

Fiq.1.3 shows an image of amorphous solar cell

Crystalline solar

Cells are wired in series to produce solar panels. As each cell produces a voltage of between 0.5 and 0.6 Volts, 36 cells are needed to produce an open-circuit voltage of about 20 Volts. This is sufficient to charge a 12 Volt battery under most conditions. Although the theoretical efficiency of mono crystalline cells is slightly higher than that of poly crystalline cells, there is little practical difference in performance. Crystalline cells generally have a longer lifetime than the amorphous variety.

FIG 1.4 Crystalline Solar Cell

Fiq.1.3 shows an image of crystalline solar cell

ADVANTAGES OF SOLAR POWER

- Solar energy is a clean and renewable energy source.
- Once a solar panel is installed, solar energy can be produced free of charge.
- Solar energy will last forever whereas it is estimated that the world's oil reserves will last for 30 to 40 years.
- Solar energy causes no pollution.
- Solar cells make absolutely no noise at all. On the other hand, the giant machines utilized for pumping oil are extremely noisy and therefore very impractical.
- Very little maintenance is needed to keep solar cells running. There are no moving parts in a solar cell which makes it impossible to really damage them.
- In the long term, there can be a high return on investment due to the amount of free energy a solar panel can produce, it is estimated that the average household will see 50% of their energy coming in from solar panels.

DISADVANTAGES OF SOLAR POWER

- Solar panels can be expensive to install resulting in a time-lag of many years for savings on energy bills to match initial investments.
- Electricity generation depends entirely on a countries exposure to sunlight; this could be limited by a countries climate.
- Solar power stations do not match the power output of similar sized conventional power stations; they can also be very expensive to build.
- Solar power is used to charge batteries so that solar powered devices can be used at night. The batteries can often be large and heavy, taking up space and needing to be replaced from time to time.

Environmental Impacts of Solar Power

The sun provides a tremendous resource for generating clean and sustainable electricity without toxic pollution or global warming emissions.

The potential environmental impacts associated with solar power — land use and habitat loss, water use, and the use of hazardous materials in manufacturing — can vary greatly depending on the technology, which includes two broad categories: photovoltaic (PV) solar cells or concentrating solar thermal plants (CSP).

Chapter 2

Battery Types

The number of times a battery can be discharged is known as its cycle life, and this is what determines its suitability for use with solar cells. Car batteries are the most common type of lead-acid battery, but will survive only 5 or 10 cycles

1. Lead Acid Batteries can contain a large amount of electrical energy which they are capable of discharging very quickly if any form of conductor is placed across their terminals.

2. Lead acid batteries contain Sulfuric Acid which is corrosive.

3. Lead Acid batteries give off hydrogen when they are being charged, which when mixed with air is explosive, and can be ignited by a small spark.

Figure 2.0 Battery Types.

Fiq.2.1 shows an images of leisure and lead acid battery

Lead acid Batteries

are unsuitable for our purposes. For solar applications a battery needs to be capable of being discharged hundreds or even thousands of times. This type of battery is known as a deep-cycle battery, and some of the many die rent types are explained here.

Leisure batteries

Leisure batteries or caravan batteries are usually the cheapest type of deep-cycle battery. They look similar to a car battery but have a die rent plate construction. Their capacity is normally in the range of 60 to 120 Ah at 12 Volts, making them most suitable for smaller systems. The cycle life of leisure batteries is limited to a few hundred cycles, meaning that they are most suitable for systems which will not be used every day, such as those in caravans or holiday homes.

Traction Batteries

The term traction battery relates to all batteries used to power electric vehicles. This can mean anything from a mobility scooter to a fork-lift truck, so encompasses capacities from 30 or 40 Ah to many hundreds. The smaller traction batteries are usually 6 or 12 Volt units; where the largest are single 2 Volt cells. Traction batteries are ideal for solar power applications, as they are intended to be fully discharged and recharged daily. The larger traction batteries can withstand thousands of discharge cycles. There are also batteries known as semi-traction batteries, which can be thought of as higher quality leisure batteries, exhibiting a greater cycle life. Marine batteries also fall into this category.

Figure 2.2 Traction Batteries

Fiq.2.1 shows an image of traction batteries

Sealed Batteries

There are many types of sealed lead-acid batteries, ranging from those of 1 or 2 Ah to single cell traction batteries of hundreds of Amp-hours. The advantages of sealed batteries are obvious; they need no maintenance and are spill-proof. They do have disadvantages however; they are more expensive than other battery types, they require more accurate charging control and can have a shorter life, especially at high temperatures. Sealed batteries are most appropriate where the solar power system will need to operate for long periods without maintenance.

Figure 2.3 Sealed Battery

Fiq.2.2 shows an image of sealed battery

Charge Controllers

Most stand-alone solar power systems will need a charge controller. The purpose of this is to ensure that the battery is never overcharged, by diverting power away from it once it is fully charged. Only if a very small solar panel such as a battery saver is used to charge a large battery is it possible to do without a controller. Most charge controllers also incorporate a low-voltage disconnect function, which prevents the battery from being damaged by being completely discharged. It does this by switching o any DC appliances when the battery voltage falls dangerously low.

FIG 2.4: Controller Types.

Fiq.2.3 shows an image of controller to ensure that the battery never overcharges

Controller Types

Solar charge controllers are specified by the system voltage they are designed to operate on and the maximum current they can handle. The system voltage is usually 12 or 24 Volts, or occasionally 48 Volts. The maximum current is deter-mined by the number and size of solar panels used. A single panel would need a controller of between 4 and 6 Amps rating, while larger arrays may need controllers of 40 Amps or more. Dice rent settings are needed if sealed batteries are used to prevent the loss of electrolyte through gassing. The example controller shown is available with ratings of 8, 12, 20 and 30 Amps, and automatically selects between 12 and 24 Volts.

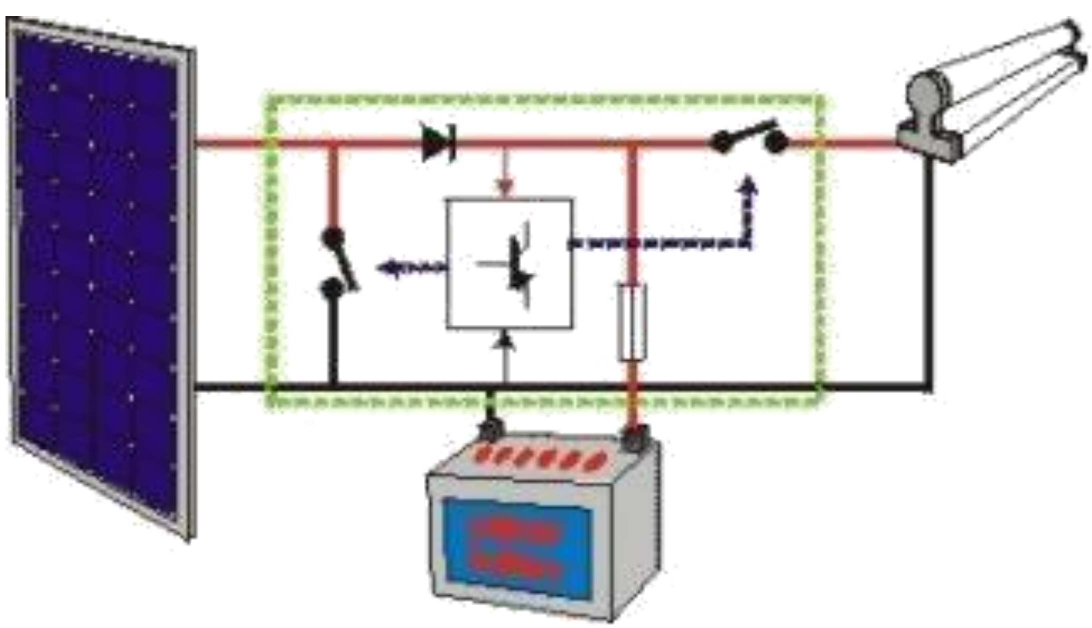
Working Principles

The principle behind a solar charge controller is simple. There is a circuit to measure the battery voltage, which operates a switch to divert power away from the battery when it is fully charged. Because solar cells are not damaged by being short or open-circuits, either of these methods can be used to stop power reaching the battery. A controller which short-circuits the panel is known as a shunt regulator, and that which opens the circuit as a series regulator. Optionally there may also be a switch which automatically disconnects the power from the appliances or loads when the battery voltage falls dangerously low. This is known as a low-voltage disconnected function.

Chapter 3

Solar Inverter:

We see many people using Solar inverters these days which proves that its necessity has been increased in the current years. A Solar inverter is similar to a normal electric inverter but uses the energy of the Sun i.e. solar energy. A solar inverter helps in converting the direct current into alternate current with the help of solar power. Direct power is that power which runs in one direction inside the circuit and helps in supplying current when there is no electricity. Direct currents are used for small appliance like mobile e phones, MP3 players, IPod etc. where there is power stored in the form of battery. In case of alternative current it is the power that runs back and forth inside the circuit. The alternate power is generally used for house hold appliances. A solar inverter helps devices that run on DC power to run in AC power so that the user makes use of the AC power. If you are thinking why to use solar inverter instead of the normal electric one then it is



Fiq.3.1 Shows An Image Of Solar Inverter

because the solar one makes use of the solar energy which is available in abundant from the Sun and is clean and pollution free.

Solar inverters are also called as photovoltaic solar inverters. These devices can help you save lot of money. The small-scale grid one have just two components i.e. the panels and inverter while the off grid systems are complicated and consists of batteries which allows users to use appliances during the night when there is no Sunlight available. The solar panel and the batteries that are placed on rooftops attract Sun rays and then convert the Sunlight into electricity. The batteries too grab the extra electricity so that it can then be used to run appliances at night.

Working Principle of Solar Inverter:

Now after knowing what a solar inverter is, let's talk about its working. Solar panels produce direct electricity with the help of electrons that are moving from negative to positive direction. Most of the appliances that we use at home work on alternative current. This AC is created by the constant back and forth of the electrons from negative to positive. In AC electricity the voltage can be adjusted according to the use of the appliance. As solar panels only produce Direct current the solar inverter is used to convert the DC to AC.

An inverter produces square waves or a sine wave which can be used for running lights, televisions, lights, motors etc. However these inverters also produce harmonic distortion. Expensive inverters make use of lots of steps to produce a sine wave and thus are found in residential solar inverters. Basically inverters should be a large one so that it supplies enough power to all the necessary appliances.

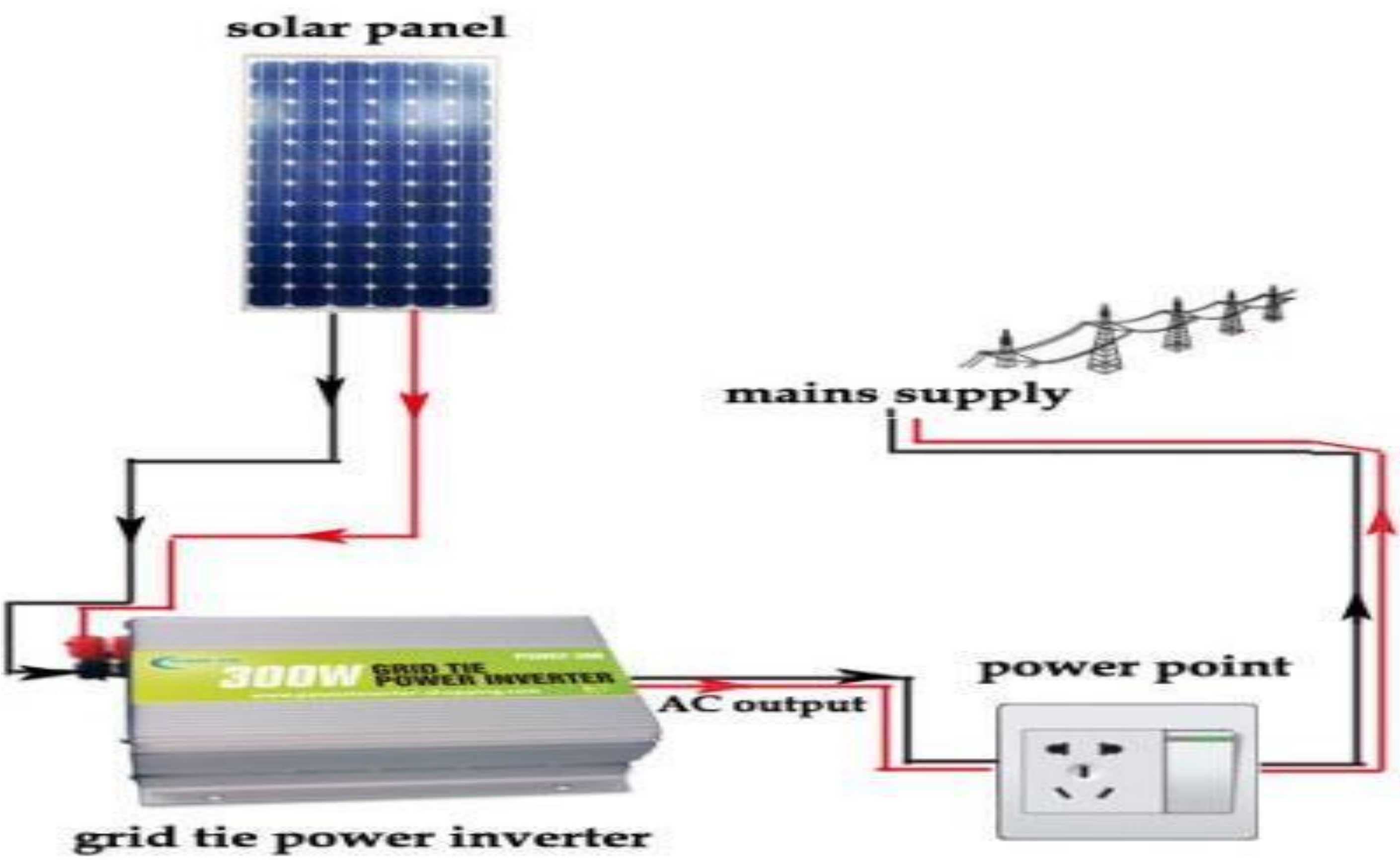
An inverter s easy to buy but choosing the right solar inverter for your appliance is more important. Thus you must always consult a solar professional before buying on. We know that the energy derived from sun is solar energy which is one of the cleanest sources of energy. Also it can be used to provide lighting to houses.

You can make us of the photovoltaic tiles that attract energy from Sun and converts it into a clean form of electricity which can be used to light, houses, industries and companies. The cells of photovoltaic consist of positive and negative silicon that is placed underneath a slice of glass. When the protons of the Sunlight hit the PV cells they knock the neutrons present in the silicon. Now the negative charged neutrons get attracted to the silicon but then are held inside a magnetic field. The wires attached on the silicon catch hold of these neutrons and while connecting to the circuit, current is formed. This then gives space for direct electricity and for converting that into alternate electricity an inverter is used so that the house appliances can run. As mentioned before major of the house appliances work on alternate current hence an inverter is used to convert DC to AC.

Solar power apart from making your home appliances work can also be used to heat water and swimming pools too.

How to Make a Solar Inverter?

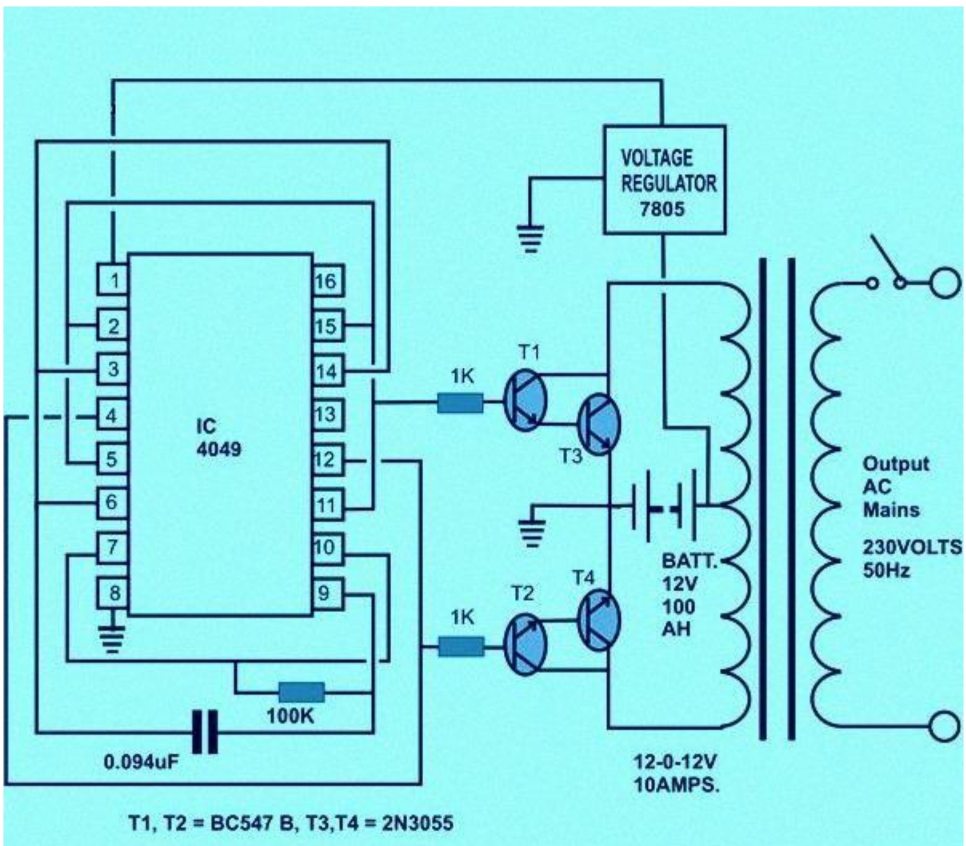
The energy derived from Sun is a renewable one and is totally free of cost. We have learnt how the solar inverter helps in providing electricity and now we shall learn how a solar inverter is made. A solar panel is capable enough to convert the heat or energy of the Sun into direct current.



Fiq.3.2 shows an image how a solar panel is capable enough to convert the heat or energy of the Sun into direct current

Solar Inverter Design:

To easily understand the construction of a solar inverter lets discuss the following construction sample:-

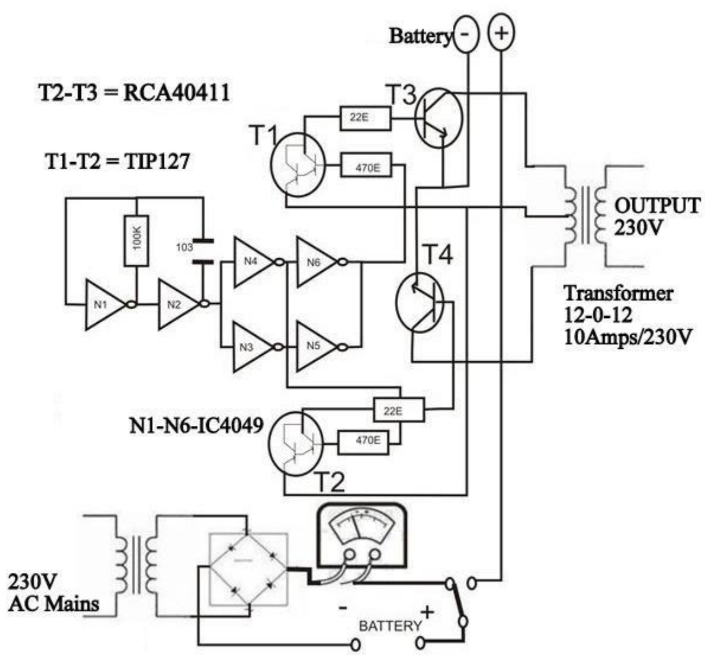


Fiq.3.3 shows an image of how to design solar inverter

1. According to the circuit diagram initially do the assembling of the oscillator part which consist of the small components & IC. It is finely completed by interrelating the part leads itself and fusing the joints.
2. Now place the power transistors into the acutely pierced aluminum heat sinks. This is crafted by cutting aluminum sheet into specified sizes and bending their sides, so that it can be hold tightly.

3. Make use of mica isolation kit to fix transistors in the aluminum heat sink, evade short circuiting & direct contact of the transistors from ground & each other.
4. Fasten the heat sink congregation to the bottom of a properly ventilated, strong, thick gauge metal enclosed space.
5. Also fasten the power transformer next to the aluminum heat sinks by making use of screw & bolts.
6. Now join the suitable points of the assembled circuit board & power transistors on the aluminum heat sinks.
7. At last connect the power transistor’s productions to the subsequent winding of the power transformer.
8. End the assembly by fastening and interlocking the outer electrical fittings such as switches, mains cord, fuses, sockets, and the battery inputs.
9. A voluntary solar power supply circuit and a transformer may be added within to charge the battery when necessary (check diagram).

Solar Inverter Circuit Diagram:



Fiq.3.4 shows solar inverter circuit diagram

To understand well how to construct a solar inverter, it is vital to study how the circuit operates through with the help of following steps:

- N1 & N2 gates of IC 4049 are employed as an oscillator. It carries out the key role of providing square waves to the inverter division.
- N3 to N6 gates are employed as buffers so that the circuit is not dependent on load.
- Continuously changing voltage from the buffer phase is useful to the bottom of the current amplifier transistors T1 & T2. These transistors perform in harmony with the practical changing voltage and boost it to the bottom of the output transistors T3 & T4.
- These producing power transistors swing at a full oscillation, providing the total battery voltage.
- This energy produced is from solar panel & is employed to power the output load.

Solar Inverter Advantages:

After knowing in detail what a solar inverter is and how different useful it is to make appliances work at residential and industrial levels we must discuss about the many advantages of the device.

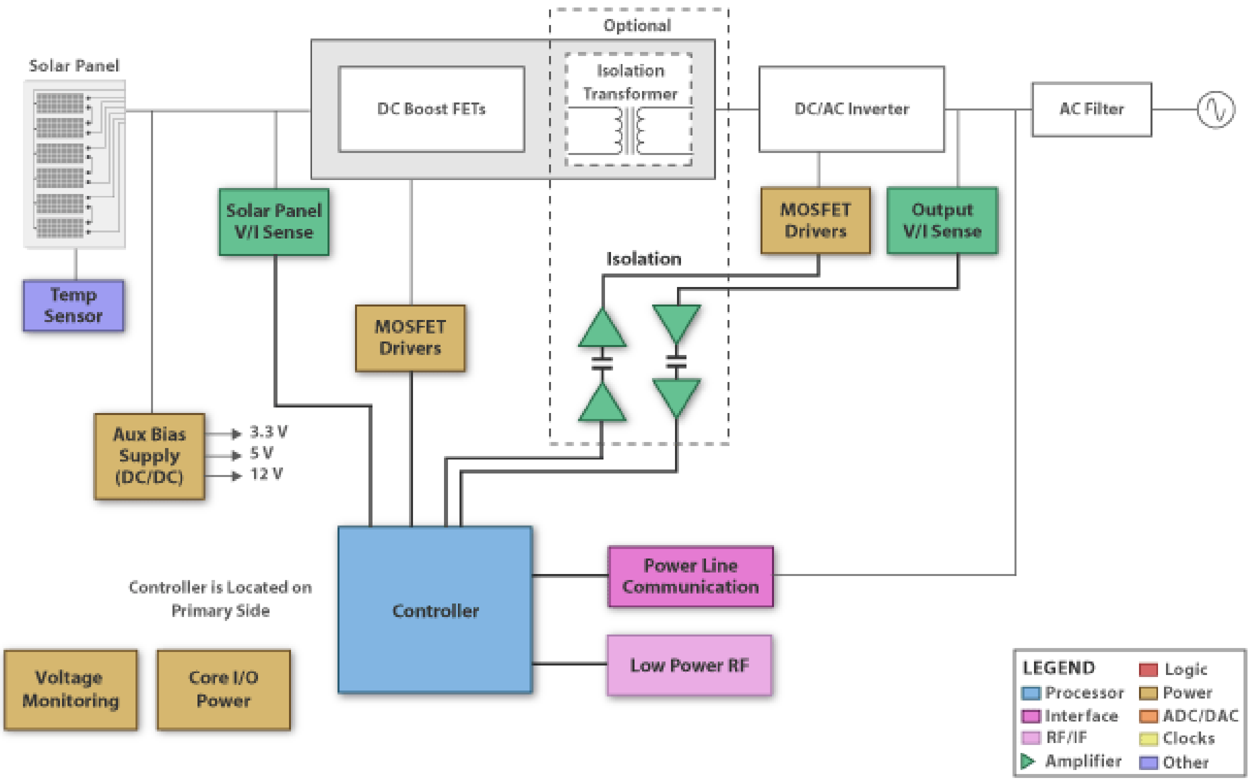
- Solar energy has always helped in reducing global warming and greenhouse effect.
- Also use of solar energy helps in saving money many people have started using solar based devices
- A solar inverter helps in converting the Direct current into batteries or alternative current. This helps people who use limited amount of electricity.
- There is this synchronous solar inverter that helps small homeowners and power companies as they are large in size
- Then there is this multifunction solar inverter which is the best among all and works efficiently. It converts the DC power to AC very carefully which is perfect for commercial establishments

- This inverter is cost effective i.e. less expensive than generators
- Apart from solar inverters there are other devices too that make use of solar energy namely, solar cooker, heater.
- Solar inverters are the best way and they are better than the normal electric ones. Also their maintenance does not cost much money

Solar Inverter Disadvantages:

- Initially you need to shell out a lot of money for buying a solar inverter
- It will work effectively and produce direct current only when the Sunlight is strong.
- The solar panels that are used to attract Sunlight requires lots of space
- The device can work efficiently only if the presence of the Sun is strong.
- Solar Inverters can work when there is no Sunlight but provided their battery is charged fully with the help of Sunlight.

After counting on some of the disadvantages of solar inverter we can state that when a device is very useful at some point of time it too requires proper maintenance and when it comes to a solar device the equipment of solar energy is must. So buy a solar device only if you have plenty of solar energy available.



Fiq.3.5 shows solar devices and the equipments of solar energy

Chapter 4

Maximum Power Point Tracking (MPPT)

A MPPT, or maximum power point tracker is an electronic DC to DC converter that optimizes the match between the solar array (PV panels), and the battery bank or utility grid. To put it simply, they convert a higher voltage DC output from solar panels (and a few wind generators) down to the lower voltage needed to charge batteries.

Maximum Power Point Tracker Solar Charge Controllers

A basic charge controller simply performs the necessary function of ensuring that your batteries cannot be damaged by over-charging, effectively cutting off the current from the PV panels (or reducing it to a pulse) when the battery voltage reaches a certain level.

Fiq.4.1 shows a basic charge controller simply performs the necessary function of ensuring that your batteries cannot be damaged by over-charging

DIFFERENCE BETWEEN SINGLE AND DUAL MPPT:-

Single Inverter Attribute	Single MPPT	Dual MPPT
Allow connecting arrays with different solar azimuth angles	No*	Yes
Allow connecting arrays with different solar tilt angles	No*	Yes
Allow connecting arrays with different string lengths	No*	Yes
Allow connecting strings of dissimilar modules	No*	Yes
Allow connection more than two strings without combiner fusing	No**	Yes
Provide better monitoring granularity	No	Yes
* Can be done but results in low harvesting efficiency, lower harvested energy ** Violates NEC requirements. Dual MPPT provides two channels and code allows two strings per input without need for fusing		

Table: 4.1 shows difference between single and dual mppt

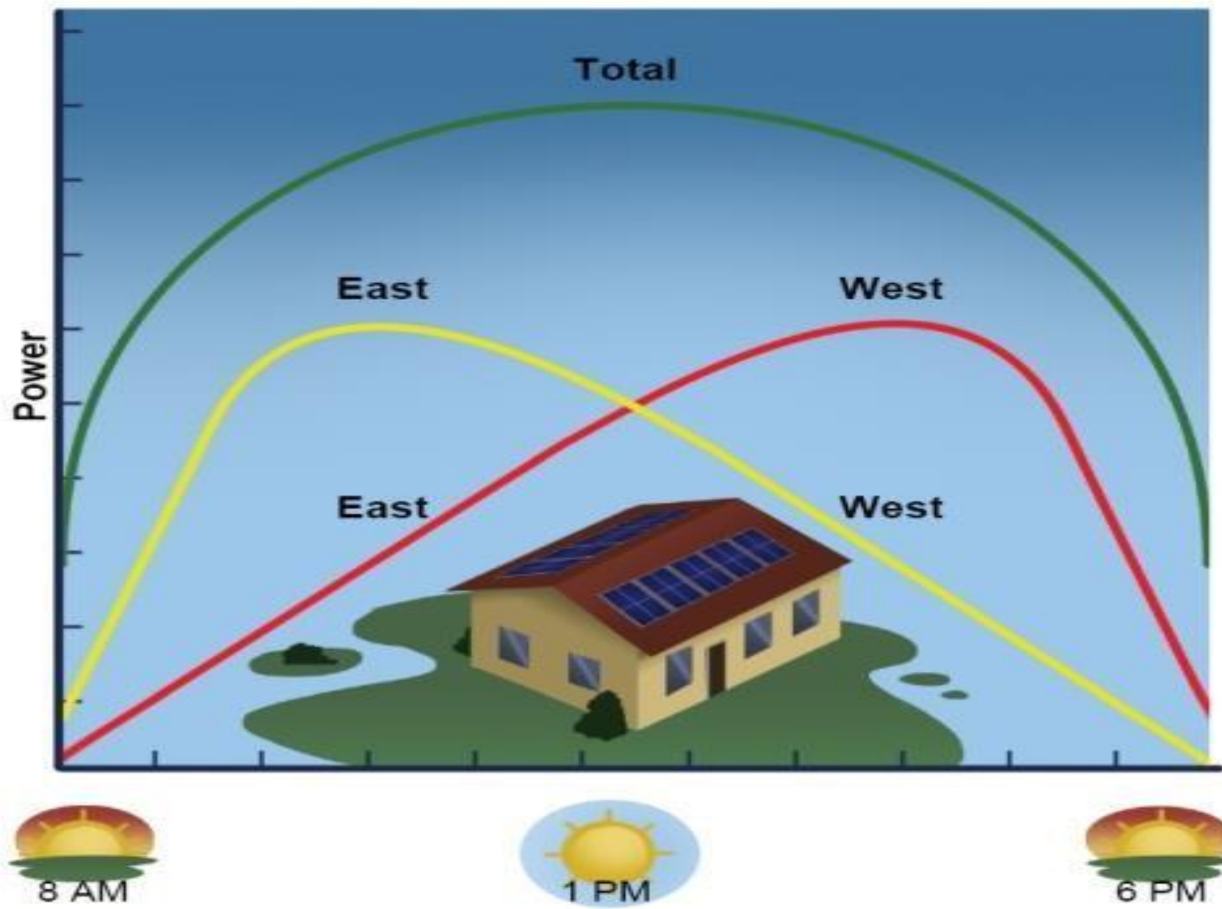
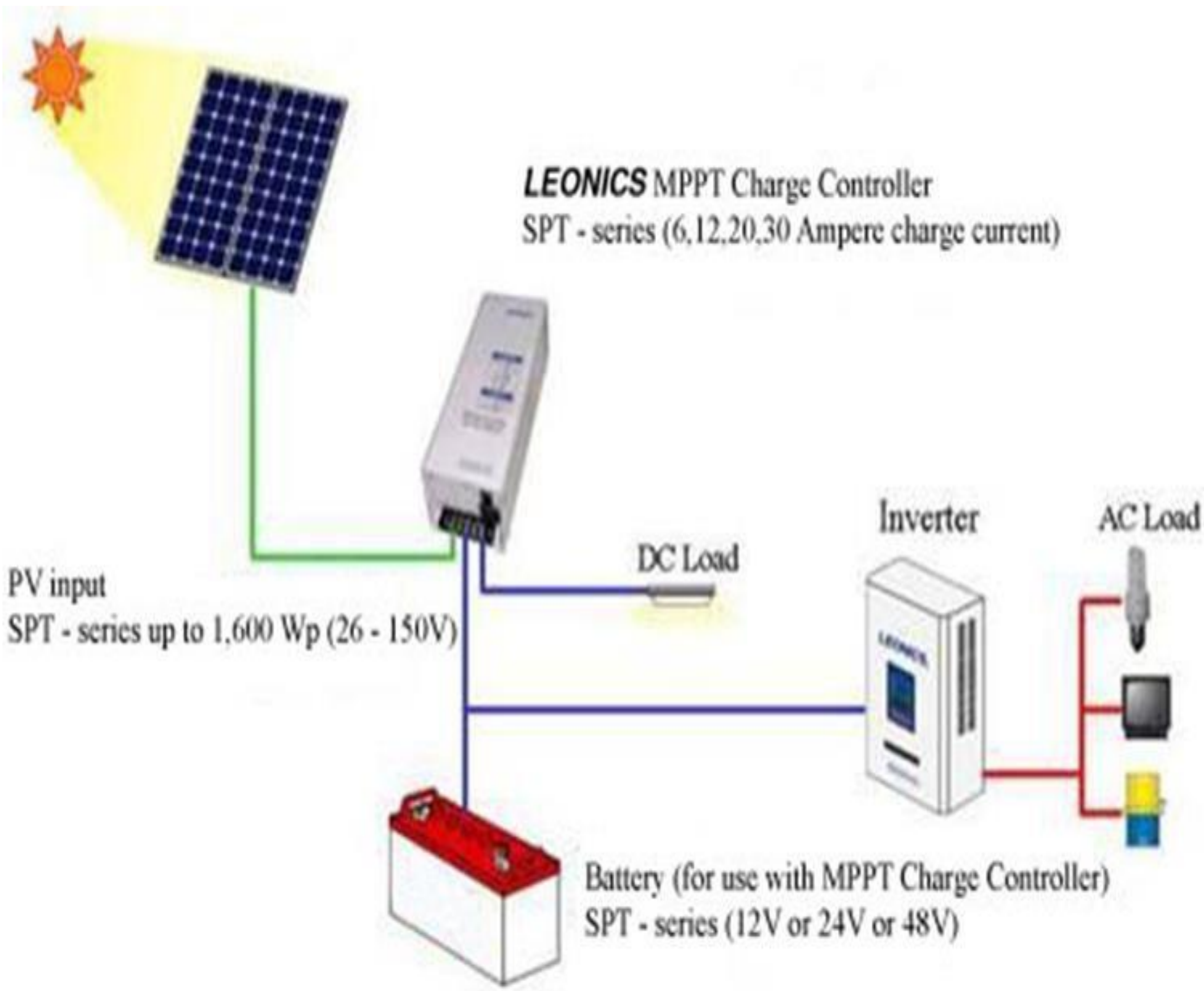


Fig.4.2 shows PV systems with all strings facing the same direction

Additionally, even for PV systems with all strings facing the same direction, using the dual MPPT function is a better choice. Assume a system has four strings all on a flat roof. If a single MPPT channel is used to connect these to the inverter in addition to requiring an external combiner if one string is damaged or subjected to higher soiling rates or shading issues, this would affect the output of the entire array and result in a lower overall energy harvest.

MPPT AND MONITORING

Single MPPT channel inverters can only provide monitoring data at the entire array level. Whether one, two or four strings, data collection will be based on the overall array input. With independent dual MPPT channels, the inverter can provide monitoring information at the MPPT channel level.



Fiq.4.3 shows an image of maximum power point tracker and monitoring

A FAST AND RELIABLE APPROACH FOR MAXIMUM POWER POINT TRACKING

Fiq.4.4 shows a fast and reliable approach for maximum power point tracking

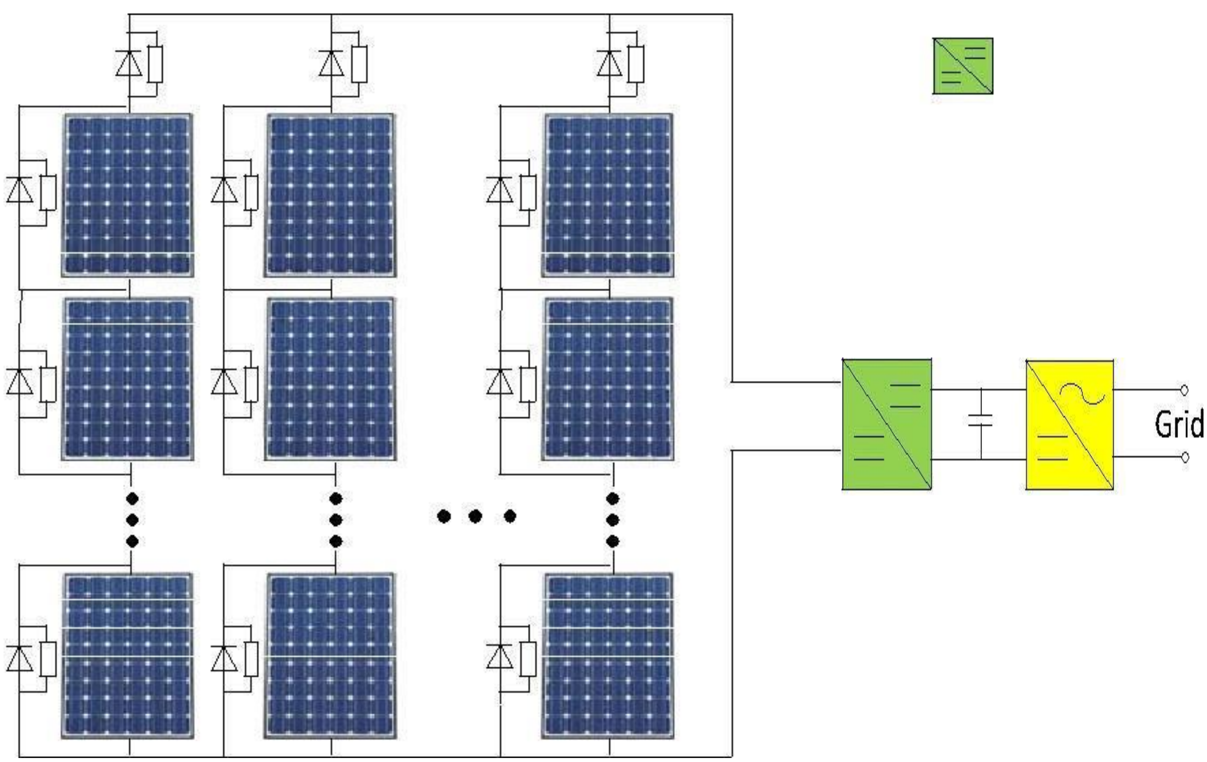
PV generation systems have two major problems: the conversion efficiency of electric.power generation is very low (9-17%) especially under low irradiation conditions; the amount of electric power generated by solar arrays changes continuously with weather conditions. the power delivered by a pv system of one or more photovoltaic cells is dependent on the irradiance, temperature, and the current drawn from the cells. in general, there is a unique point on the i-v and p-v curve, called the maximum power point (mpp), at which the entire pv system operates with maximum efficiency and produces its maximum output power. The location of the mpp is not known, but can be located, either through calculation models or by searching algorithms. to maximize the output power of a pv system, continuously tracking the maximum power point of the system is necessary.

There are many different approaches to maximizing the power from a pv system. These range from using simple voltage relationships, to more intelligent and adaptive based algorithms.

Typical mppt techniques that have been proposed in the literature include the short-circuit current method open-circuit voltage method perturb and observe (p&o) methods incremental conductance (ic) methods and adaptive p&o method and intelligent and fuzzy logic methods these techniques vary between each other in many aspects, including simplicity, convergence speed, system stability, and mpp tracking effectiveness. The primary challenges for maximum power point tracking of a solar PV array include: 1) how to get to a mpp quickly, 2) how to stabilize at a mpp, and 3) how to smoothly transition from one MPP to another for sharply changing weather conditions. In general, a fast and reliable MPPT is critical for power generation from a solar PV system.

Extracted Power Characteristics of a PV System

A grid-connected solar PV system consists of three parts (Fig): an array of solar cells, power electronic converters, and an integrated control system [44, 45]. The control system of a solar PV array contains two parts: one for MPPT and the other for grid interface control. Both control functions are achieved through power electronic converters. In general, the dc/dc converter implements the MPPT function while the dc/ac converter performs the grid interface control.



Fiq.4.5 shows A grid-connected solar PV system consists of three parts (Fig): an array of solar cells, power electronic converters, and an integrated control system

THE EFFECT OF TEMPERATURE

Temperature affects solar cell characteristics primarily in the following two ways: directly via *T* in the exponential term in and indirectly via its effect on the reverse-diode saturation current *I0* and the photo-generated current *IL*. The dependence of the reverse-diode saturation current *I0* on temperature for a silicon solar cell is:

$q\ E_g$

$I_0 \quad K\, T^3 \quad e^{m\, k\, T}$

where *K* is the approximate constant with respect to temperature, *Eg* is the band-gap energy of the semiconductor (eV), *m* is the diode ideality constant, *k* is Boltzmann constant, and *T* (K) is the temperature of the p–n junction. The photo-generated current *IL* is also influenced by the temperature too as the following: Terminal voltage. During a day, solar irradiation and temperature fluctuates overtime causing the MPP of the PV array changes continuously. Consequently, the PV system operating point must be adjusted constantly to maximize the energy produced.

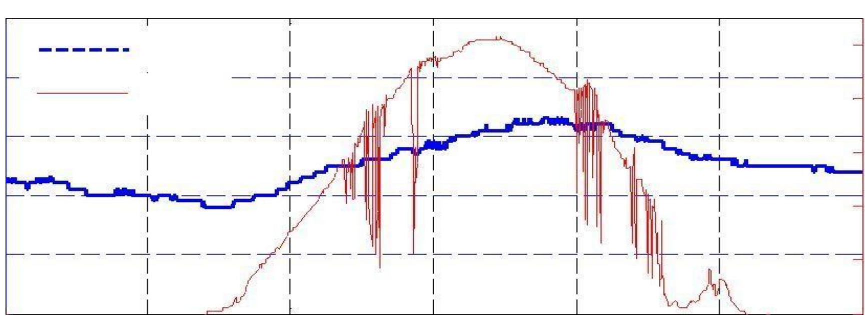
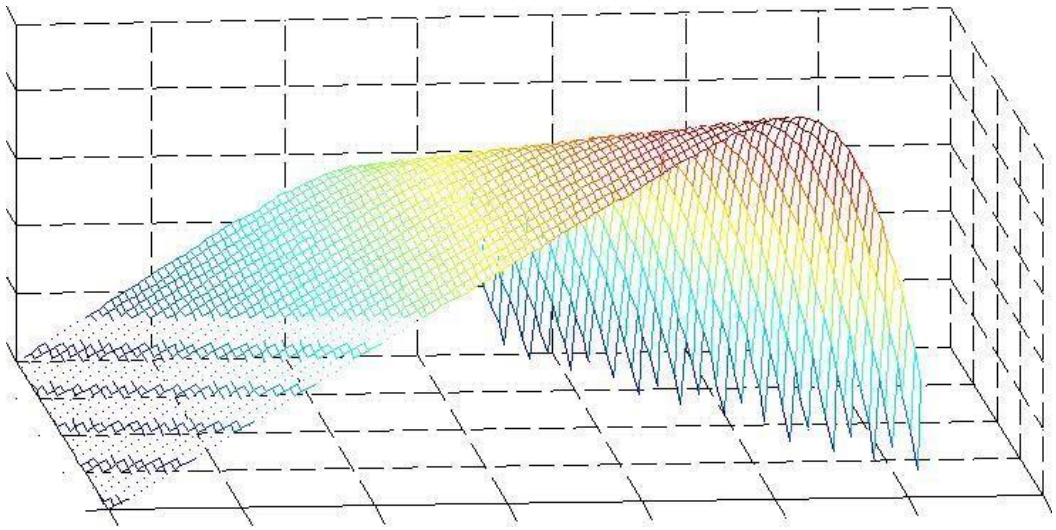


Fig. 4.6 shows Temperature affects solar cell characteristics primarily in the following two ways



Fiq.4.7 shows in conventional adaptive MPPT methods, the perturbation value changes during the hill climbing process

TRADITIONAL ADAPTIVE MPPT METHODS

In conventional adaptive MPPT methods, the perturbation value changes during the hill climbing process [50, 55]. Typical adaptive P&O methods use power derivative information to determine the next perturbation operation. It is based on the observation that the derivative is positive on the left side of the MPP, zero at the MPP, and negative on the right side of the MPP Thus, a scaling factor (SF) perturbation strategy is developed as shown by in which M is a constant coefficient and the multiplication of M with the derivative determines an adaptive adjustment of the duty ratio in the next perturbation cycle. Hence, the duty ratio adjustment is scalable rather than fixed. Similar to the IC method, the perturbation stops theoretically when the MPP is reached.

$$d(k) \quad d(k \quad 1) \quad M \frac{dP_a}{dV_a}$$

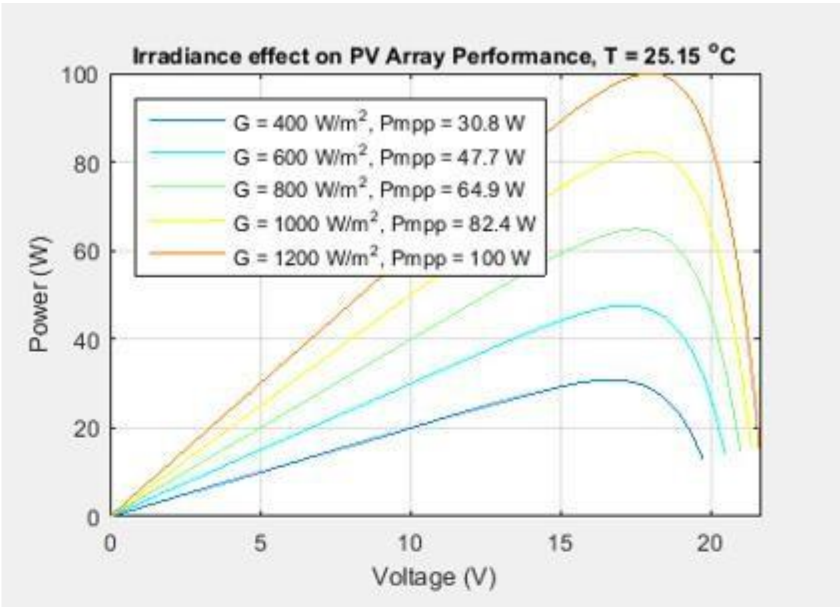
Another conventional adaptive duty ratio strategy is based on a proportional-integral (PI) control mechanism The error signal to the controller is generated by comparing dP_a / dV_a with a zero power derivative reference value. The duty ratio of the dc/dc converter is

Regulated continuously until the MPP is reached, i.e., $dP_a / dV_a \quad 0$.

Implement Maximum Power Point Tracking (MPPT) algorithms for photovoltaic systems using MATLAB and Simulink

Engineers developing solar inverters implement MPPT algorithms to maximize the power generated by photovoltaic (PV) systems. The algorithms control the voltage to ensure that the system operates at “maximum power point” (or peak voltage) on the power voltage curve, as shown below.

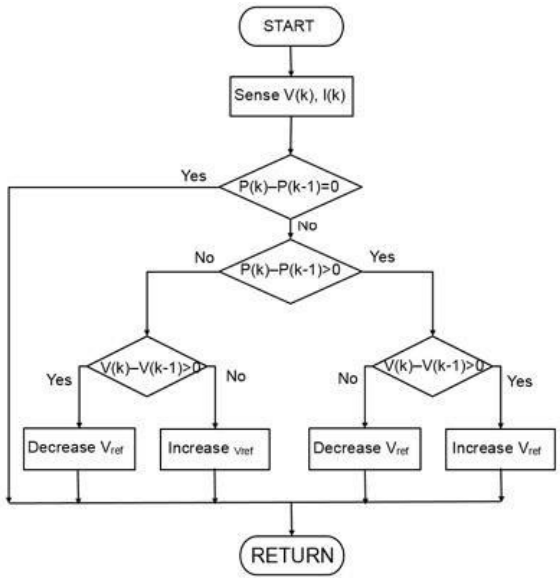
MPPT algorithms are typically used in the controller designs for PV systems. The algorithms account for factors such as variable irradiance (sunlight) and temperature to ensure that the PV system generates maximum power at all times.



Fiq.4.8 temperature to ensure that the PV system generates maximum power at all times.

THE THREE MOST COMMON MPPT ALGORITHMS ARE:

1. **Perturbation and observation (P&O):** This algorithm perturbs the operating voltage to ensure maximum power. While there are several advanced and more optimized variants of this algorithm, a basic P&O MPPT algorithm is shown in the next page.



Fiq.4.8 shows algorithm perturbs the operating voltage to ensure maximum power

2. **Incremental conductance:** This algorithm, shown below, compares the incremental conductance to the instantaneous conductance in a PV system. Depending on the result, it increases or decreases the voltage until the maximum power point (MPP) is reached. Unlike with the P&O algorithm, the voltage remains constant once MPP is reached.

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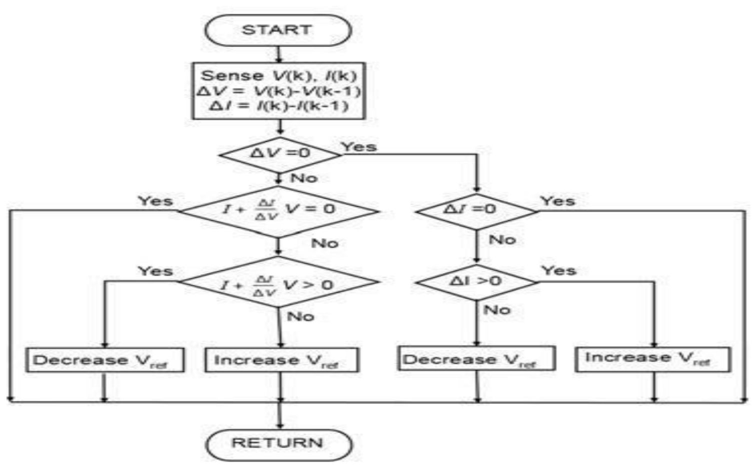


Fig 4.9 shows algorithm, shown below, compares the incremental conductance to the instantaneous conductance in a PV system

3. **Fractional open-circuit voltage:** This algorithm is based on the principle that the maximum power point voltage is always a constant fraction of the open circuit voltage. The open circuit voltage of the cells in the photovoltaic array is measured and used as in input to the controller.

How a Maximum Power Point Tracker Works:

The Power point tracker is a high frequency DC to DC converter. They take the DC input from the solar panels, change it to high frequency AC, and convert it back down to a different DC voltage and current to exactly match the panels to the batteries. MPPT's operate at very high audio frequencies, usually in the 20-80 kHz range. The advantage of high frequency circuits is that they can be designed with very high efficiency transformers and small components. The design of high frequency circuits can be very tricky because the problems with portions of the circuit "broadcasting" just like a radio transmitter and causing radio and TV interference. Noise isolation and suppression becomes very important.

There are a few non-digital (that is, linear) MPPT's charge controls around. These are much easier and cheaper to build and design than the digital ones. They do improve efficiency somewhat, but overall the efficiency can vary a lot - and we have seen a few lose their "tracking point" and actually get worse. That can happen occasionally if a cloud passed over the panel - the linear circuit searches for the next best point, but then gets too far out on the deep end to find it again when the sun comes out. Thankfully, not many of these around anymore.

The power point tracker (and all DC to DC converters) operates by taking the DC input current, changing it to AC, running through a transformer (usually a toroid, a doughnut looking transformer), and then rectifying it back to DC, followed by the output regulator. In most DC to DC converters, this is strictly an electronic process - no real smarts are involved except for some regulation of the output voltage. Charge controllers for solar panels need a lot more smarts as light and temperature conditions vary continuously all day long, and battery voltage changes.

Smart power trackers

All recent models of digital MPPT controllers available are microprocessor controlled. They know when to adjust the output that it is being sent to the battery, and they actually shut down for a few microseconds and "look" at the solar panel and battery and make any needed adjustments. Although not really new (the Australian company AERL had some as early as 1985), it has been only recently that electronic microprocessors have become cheap enough to be cost effective in smaller systems (less than 1 KW of panel). MPPT charge controls are now manufactured by several companies, such as Outback Power, Anthrax XW-SCC, Blue Sky Energy, Apollo Solar, Midnight Solar, Morningstar and a few others.

How to calculate the annual solar energy output of a photovoltaic system

The global formula to estimate the electricity generated in output of a photovoltaic system is:

$$E = A * r * H * PR$$

E = Energy (kWh)
A = Total solar panel Area (m^2)
r = solar panel yield (%)
H = Annual average solar radiation on tilted panels (shadings not included)
PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9, default value = 0.75)

r is the yield of the solar panel given by the ratio: electrical power (in kWp) of one solar panel divided by the area of one panel
Example: the solar panel yield of a PV module of 250 Wp with an area of 1.6 m^2 is 15.6%

PR: PR (Performance Ratio) is a very important value to evaluate the quality of a photovoltaic installation because it gives the performance of the installation independently of the orientation, inclination of the panel. It includes all losses.

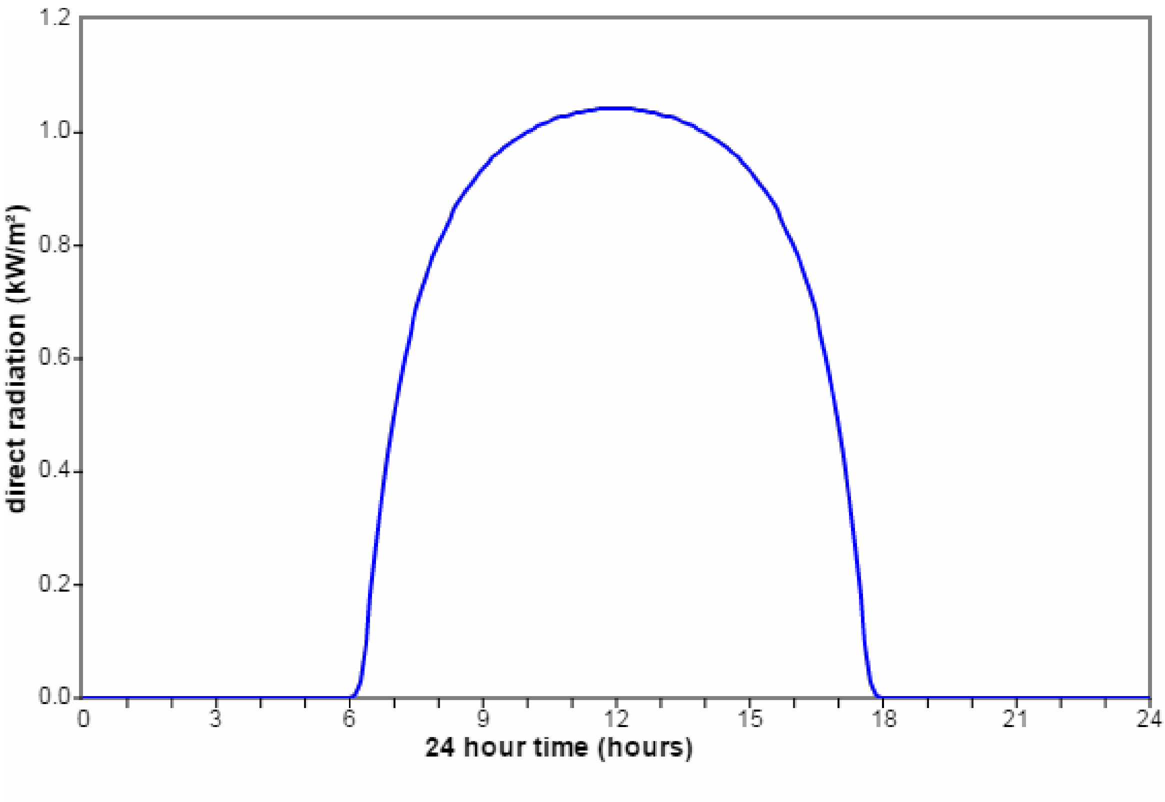
Example of losses details that gives the PR value (depend on the site, the technology, and sizing of the system) :
- Inverter losses (4% to 15 %)
- Temperature losses (5% to 18%)
- DC cables losses (1 to 3 %)
- AC cables losses (1 to 3 %)
- Shadings 0 % to 80% !!! (Specific to each site)
- Losses weak radiation 3% to 7%
- Losses due to dust, snow... (2%)
- Other Losses (?)

Based on the equation of the sun's position in the sky throughout the year, the maximum amount of solar insolation on a surface at a particular tilt angle can be calculated as a function of latitude and day of the year. These calculations are also essential in using experimental data from sunshine hour recorders. The following animations calculate the daily solar irradiance, the solar insolation and the number of hours during the day which the sun is shining. They do not include local weather effects and so these theoretical graphs are not used in system sizing or prediction of operation. A description of each graph is given in the caption underneath.

Sunrise: 6:0 Sunsets: 18:0

Latitude: 0° North

Day: 1 (Jan 1)

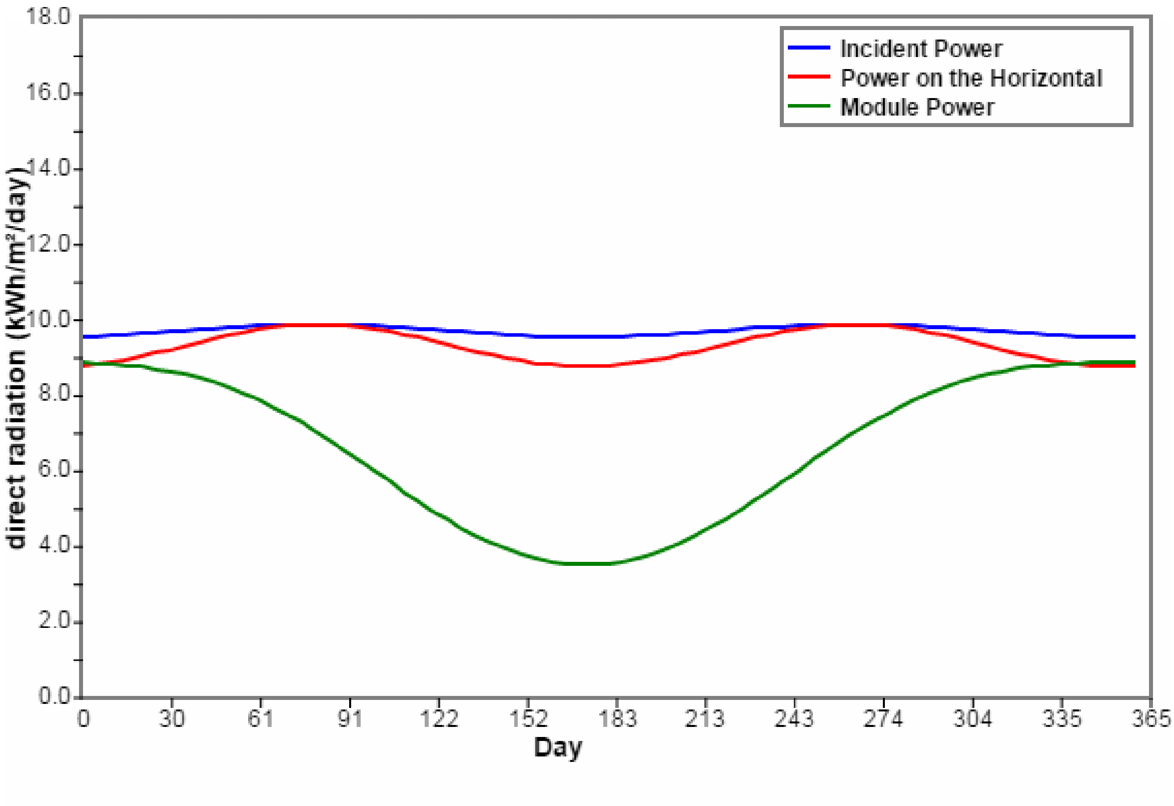


Fiq.4.10 The graph shows the intensity of direct radiation in W/m² throughout the day

The graph shows the intensity of direct radiation in W/m² throughout the day. It is the amount of power that would be received by a tracking concentrator in the absence of cloud. The time is the local solar time. Set the latitude to your location and then adjust the day slider to see how much radiation there is for each day of the year.

Latitude: 0° North

Array Tilt: 45°



Fiq.4.11 shows the amount of power that would be received by a tracking concentrator in the absence of cloud.

The average daily solar insolation as a function of latitude. The three curves are the incident solar insolation, the horizontal solar insolation and the solar insolation on a titled surface as defined in the page Module Tilt. The daily insolation is numerically equal to the number of sun hours in a day. The module is assumed to face the equator so that it faces South in the northern hemisphere in North in the southern hemisphere. As the latitude is adjusted through zero going across the equator, the module faces in the opposite direction. The graph changes suddenly at the equator since the module is now facing in the opposite direction.

Latitude: 0° North

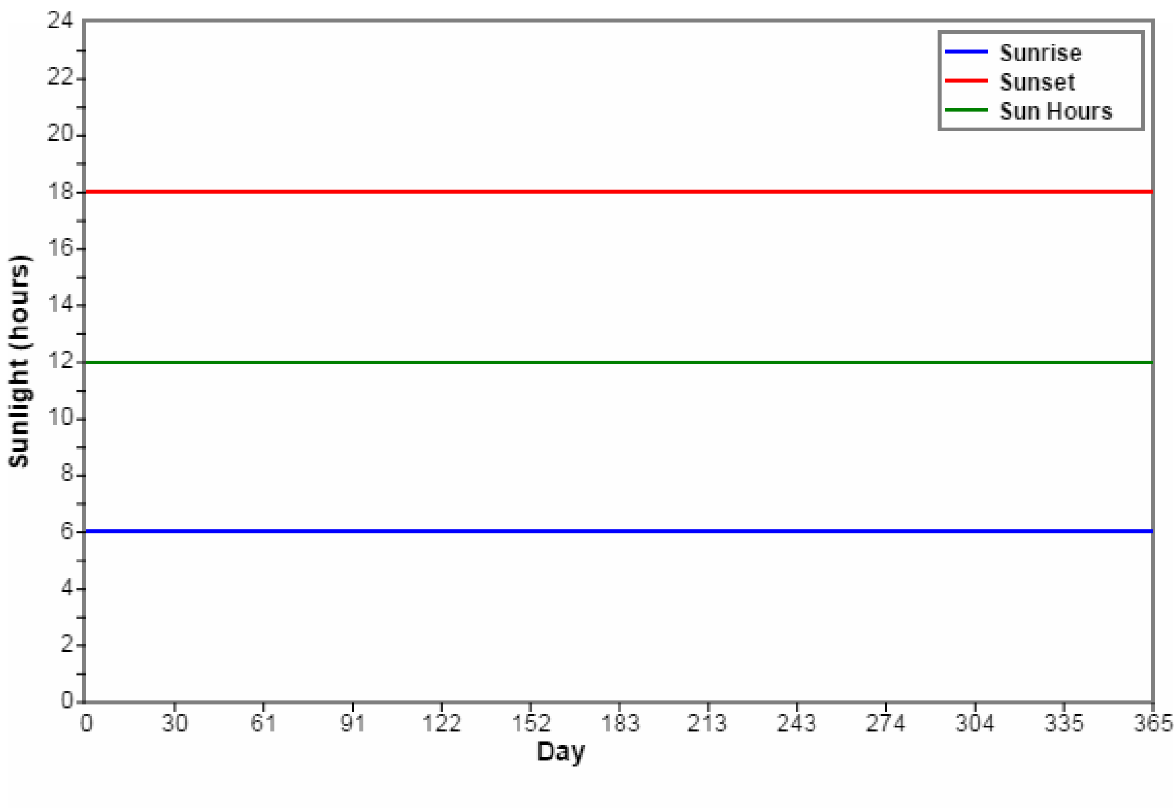


Fig 4.12 shows the average daily solar insolation as a function of latitude.

CONCLUSIONS AND FUTURE WORK

Contributions of the Dissertation

This dissertation demonstrates solar photovoltaic energy generation and conversion from devices to grid integration.

Firstly, this dissertation investigates solar PV system performance under uneven shading and dissimilar conditions, especially using both simulation tools and Newton-Raphson algorithm to study and cross-verify the I-V and P-V characteristics of shaded and sunshade cells. It is found that a traditional PV module with one single shaded cell is the most hazardous condition to affect proper function of a PV module. Its observed that, with bypass diodes, the performance of PV device is more complicated and different from the traditional understanding of the PV I-V and PV characteristics and each PV cell with a bypass diode will have the most significant improvement in the performance of a PV module/array under uneven shading.

Secondly, this dissertation provides a fast and robust MPPT technique and compares it with typical conventional MPPT algorithms used in solar PV industry. Through both software and hardware simulation, it is concluded that the proposed MPPT approach has the least oscillation and the highest stability. Both the sampling rate affects and variable solar irradiance levels are considered in the comparison. The comparison between the traditional and proposed adaptive methods shows that the hyperbolic processing of the derivation is important for high performance of a solar PV system.

Thirdly, this dissertation compares the energy extraction characteristics of a solar PV system for different converter schemes, including central, string and micro converter configurations especially uneven shadings. It is concluded that the central converter based PV system with properly built-in bypass diodes is an effective and economic approach to improve efficiency, performance, and reliability of a PV system.

Last but not least, this dissertation discusses control designs of grid-connected photovoltaic system with ESUs and how to coordinate all the electrical devices in the whole system by the control of power electronics. In the proposed method, GCC is operated at VQ mode to maintain a stable dc-link voltage and adapt to the reactive power command, PVCC is designed to implement the MPPT of PV array, and ESUs connected converters control are conceived to achieve the power balance of the whole system. A comprehensive computational simulation study demonstrates that the proposed control structure can effectively supply the desired reactive and active power to the grid and achieve the stability of dc-link voltage through power electronic converters coordination. Additionally, the proposed coordinated control has also been modified and tested in other applications considering single-phase DQ control and ramp rate control. The simulation results present an effective performance in these two applications.

Limitations and Future Work

In ramp rate control of gird-connected PV system with ESUs, it is noted that a dynamic ramp control design instead of fix ramp is necessary for a practical control in the future work because of volatile solar radiation.

Also, it is not yet considered how to keep ESUs at an appropriate level of charging/ discharging when implementing ramp rate control. The parameters of ESUs in this dissertation are given ideally to verify the effectiveness of ramp rate control without optimizing the cost. It is important to design economically considering factors that can limit the real power output including the maximum power generation/ absorption of the ESUs, ESUs current limit, ESUs state of charge. With great certainty, we can say that the demand for development and improvement of grid-integrated renewable energy will remain.

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