LATEST REVIEW STUDIES OF IMPROVE THE EFFICIENCY OF SOLAR PANEL BY USING WATER COOLING METHOD

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Abstract

Solar energy is becoming another for the limited conventional fuel resources. One of the simplest and most direct applications of this energy is the conversion of solar radiation into heat, that used for in water heating systems. A commonly used solar collector is the flat-plate. A lot of research has been conducted in order to analyze the flat-plate operation and improve its efficiency. There is an increasing demand for the solar collectors, especially the flat-plate liquid solar collector. Therefore, an extensive research has been done to model the flat-plate solar collectors operation and to predict the performance of different types solar collector. An effective way of improving efficiency and reducing the rate of thermal degradation of a photovoltaic (PV) module is by reduced operating temperature of its surface. This can be achieved by cooling the module and reducing the heat stored inside the PV cells during operation. The system is used for irrigation purposes, consists of a PV module cooled by water, a submersible water pump, and a water storage tank. Cooling of the PV panel is achieved by introducing water trickling configuration on the upper surface of the panel. The cold water can be stored in a tank which is connected to a pump in order to circulate the water around the panel. The experimental rig is produced to investigate and evaluate PV module performance with the proposed cooling technique. Due to the heat loss by convection between water and the PV panel's upper surface, an increase in system output is achieved at peak radiation conditions. Long-term performance of the system is estimated by integrating test results in a c transient simulation package using radiation site and ambient temperature data. A simulation results of the system's annual performance indicated that an increase of 5% in delivered energy from the PV module can be achieved during dry and warm seasons.

KEYWORDS: Flat Plate Solar, Photovoltaic (PV) Module, Water pump.

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1. INTRODUCTION

In all over the world, energy is an essential for human. Energy is classified into two different categories, which are non-renewable energy and renewable energy. As development outcomes of world economy the world can't continue to depend on fossil fuels (natural gas, oil and coal). Most of the world's energy is generated from fossil fuels. The reserves of fossil fuels are limited lead to the cost of fossil fuels is day by day increasing. Renewable energy sources are becoming important as significantly benefits. Among all the renewable energy sources, A PV energy is a very efficient solution for renewable energy because of no pollution, abundance and completely free of cost. PV energy is energy that comes from the sun converts into electricity. Now a day the PV system is likely recognized and widely using in electric power applications. This is because it can be produced direct current electrical energy without any environmental harm when is exposed to solar radiation. Very low PV cell conversion electrical efficiency is one of the main obstacles that face the operation of the PV panel is. This is also a key obstacle of scientists and researchers to improve the electrical efficiency of PV cells. The power output yield by the PV system depends on several climatic factors such as the solar radiation, the operating temperature of the state of the PV panels (ageing, cell material, cleanliness, etc.) . The efficiency of PV plant is not only strongly depended on solar radiation, but also depends on the operating temperature of PV panels. The cause of low PV cell conversion electrical efficiency is overheating due to excessive solar radiation and high operating temperatures. This is because the PV panel only 15 % of sunlight energy converts into electricity to the rest converted into heat. To obtain increased electrical efficiency, the PV panel needs to be cooled by removing the excess heat from the cell assembly in some. Different research and studies have been present to increase the electrical efficiency of PV panel. The common PV panel cooling methods are water cooling, air cooling, and heat pipe cooling. As panel temperature increases output voltage of solar panel decreases so cooling of panel is necessary for improvement of efficiency. Hybrid Photovoltaic/Thermal (PV/T) solar system is one of the most popular methods for cooling the photovoltaic panels now a days . The hybrid system consists of a solar photovoltaic panels combined with a cooling system. Water is transfer around the PV panels for cooling the solar cells, and the warm water leaving the panels pump back to water tank. Warm water mixed with cool water of tank. It is concluded that the cooling system could solve the problem of overheating the PV panels due to excessive solar radiation and maintain the efficiency of the panels at an acceptable level by the least possible amount of water.DC motor water pump and small diameter nozzles are used to perform water layer along PV module upper surface. There are three main advantages of applying this technique is a drop in cell temperature, an increase in incident radiation due to radiation refraction by water, and continued surface cleaning by water flow. However, the drawback of the system is the power required by the pump to circulate cooling water.

Structure of the solar cell

In conventional solar cells, the electrical field is created at the junction between two regions of crystalline semiconductor having contrasting types of conductivity (Figure 3). If the semiconductor is silicon, one of these regions (n-type) is doped with phosphorus which has five valence electrons (one more than silicon). This region (the p-type) is doped with boron, having three valence electrons (one less than silicon). The concentration of holes is greater. The large difference in concentrations from one region to the other causes a permanent electric field directed from the n-type region towards the p-type region. This is the field responsible for separating the additional electrons and holes produced when light shines on the cell.

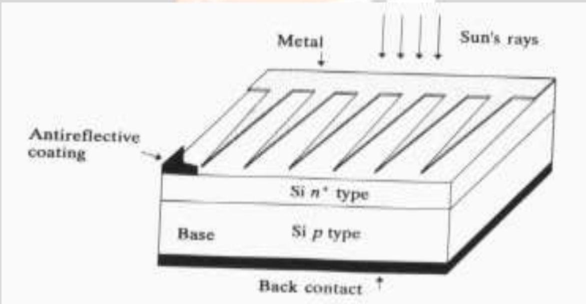


Figure 1: The p-n junction

2. LITERATURE REVIEW

2.1 Review of Papers

Y.M.Irwan, W.Z.Leow, M.Irwanto(2015) "Indoor Test Performance of PV Panel through Water Cooling, Method" He had describes the comparison of the performance of the PV panel with and without the water cooling mechanism by using solar simulator. The DC water pump is attached on the front side of the PV panel to spray water over the surface of PV panel. Moreover, the effect of spraying water over the PV panel on reduces the operating temperature of PV panels and reflection of PV panel. This water cooling mechanism has been used for measuring the performance of PV panel for different parameters such as operating temperature, voltage output, current output and power output. The performance of PV panel depends on the environmental factors, which is solar radiation and operating temperature. These environmental factors will be reduced the electrical efficiency of PV panel due to increase in operating temperature of PV panel. The solar simulator is set up on a steel frame is used to lift all the halogen lamp bulbs. The halogen lamp bulbs act as a natural sunlight. Four sets of average solar radiation at the test surface of the solar simulator are measured as 413, 620, 821 and 1016 W/m². A DC water pump is used to overcome the problem of low efficiency of PV panel with water flow over the front surface of PV panel. This water cooling mechanism is one way to enhance the efficiency of PV panel for maintaining a low operating temperature during its operation period. The experimental results mentioned that the decrement of operating temperature and increase the power output of the PV panel with water cooling mechanism based on different fixed of solar radiation. The water spraying can be reduced heat on the front surface of the PV panel[1]

Rizwan Arshad, Salman Tariq, Muhammad Umair Niaz , Mohsin Jamil(2014)"Improvement in Solar Panel Efficiency Using Solar Concentration by Simple Mirrors and by Cooling"–In this paper he have studied crystalline solar panel made of silicon semiconductor was used for this experiment. An iron made frame was designed with space for solar panel and for three mirrors. In this experimental technique active cooling system was used for improving efficiency of PV module. A PVC plastic pipe with holes at the bottom was fixed over the solar panel frame which was further fed from a rubber pipe from a water tank which was filled by an electric motor. One mirror from above and two from sides were reflecting solar radiation on the solar panel which was placed in the middle. This technique can be named as four sun technology also. Concentrated photovoltaic technology (CPV) uses optics such as mirrors and lens to focus sunlight on solar cells for the sake of generating electricity. CPV has advantage over no concentrated photovoltaic as less number of solar cells are required for the same power output. Along with duration and intensity of sunlight, temperature also has great effect on the performance of PV module as high temperature significantly reduces output power. This research paper explains a practical approach to enhance the efficiency of solar panel by the use of mirrors and cooling mechanism. These reflectors are cheap, easy to handle, simple enough to use and need no extra equipment or devices to use. But CPV operate efficiently in concentrated light as long as the solar cells are kept cool by means of some heat sinks. Experimental results indicate appreciable enhancement in overall output of solar panel. Experimental readings obtained from a) without reflectors and without cooling b) with reflectors and without cooling c) with reflectors and with cooling are compared. Corresponding results obtained from different conditions showing improvement in efficiency up to 32%in case (b) and 52% in case (c) are tabled and plotted.[2]

K.A. Moharram, M.S. Abd-Elhady, H.A. Kandil, H. El-Sherif(2012)"Enhancing the performance of photovoltaic panels by water cooling" In this paper using water as a coolant is found to be more effective than using air. Thus, the objective of this research is to build a water-based cooling system to solve the solar cells overheating problem with the minimum amount of water and energy. To minimize the amount of water and energy needed for cooling of the PV panels, a heating rate model is used to determine how long it takes to heat up the panels to the maximum allowable temperature limit that can lead to the maximum energy yield. The heating rate model is based on the operating conditions, i.e., solar radiation, ambient temperature, and ambient temperature at sunrise. Based on this model, it can be determined when to start cooling of the PV panels. A mathematical model is developed to determine how long it will take to cool the PV panels to the normal operating temperature. This model will be named as the cooling rate model throughout the paper. The cooling rate model is used to minimize the cooling time needed for the PV panels, as a means of minimizing the amount of water and energy needed for cooling. The heating rate and the cooling rate models are validated experiment -tally. The MAT is determined based on the heating rate and the cooling rate models, such that it can lead to the maximum energy yield. The objective of the research is to minimize the amount of water and electrical energy needed for cooling of the solar panels, especially in hot arid regions, e.g., desert areas in Egypt. A cooling system has been developed based on water spraying of PV panels. A mathematical model has been used to determine when to start cooling of the PV panels as the temperature of the panels reaches the maximum allowable temperature (MAT). A cooling model has been developed to determine how long it takes to cool down the PV panels to its normal operating temperature, i.e., 35 ^{o}C, based on the proposed cooling system. Both models, the heating rate model and the cooling rate model, are validated experimentally. Based on the heating and cooling rate models, it is found that the PV panels yield the highest output energy if cooling of the panels starts when the temperature of the PV panels reaches a maximum allowable temperature (MAT) of 45^{o}C. The MAT is a compromise temperature between the output energy from the PV panels and the energy needed for cooling.[3]

Chen Hongbing, Chen Xilin, Li Sizhuo, Chu Sai(2012) "Experimental Study on the Energy Performance of PV-HP Water Heating System" In this paper were studied the effect of solar radiation, inlet water temperature and water flow on the electrical and thermal efficiencies of the system. Heat pipes were equipped on the back of the PV panels, a heat collector which was connected to the condensational end of the heat pipe was installed at the top of PV panel, forming a heat pipe photovoltaic/thermal solar water-heating system. Circulating water flew past the heat collector, absorbed the heat from condensational end of the heat pipe for domestic water heating and PV panel cooling both sides. It was expected to achieve better cooling effect relatively in this passive way and better electrical and thermal performance of the PV modules.[4]

Swapnil Dubey, Jatin Narotam Sarvaiya, Bharath Seshadri,**(2012)**"Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World A Review"– In this paper, a brief discussion is presented regarding the operating temperature of one-sun commercial grade silicon based solar cells/modules and its effect upon the electrical performance of photovoltaic installations. Generally, the performance ratio decreases with latitude because of temperature. However, Regions with high altitude have higher performance ratios due to low temperature, like, southern Andes, Himalaya region, and Antarctica. PV modules with less sensitivity to temperature are preferable for the high temperature regions and more responsive to temperature will be more effective in the low temperature regions. Silicon remains the material of choice for photovoltaic's because of its abundance, non-toxicity, high and stable cell efficiencies, the maturity of production infrastructure and the deep and widespread level of skill available in relation to silicon devices. Rapidly decreasing module prices mean that area-related balance of systems costs are an increasing proportion of photovoltaic systems price. This places a premium on efficient cells. In recent years there have been large improvements in mass production of high quality wafers, the ability to handle thin wafers, maintenance of high minority carrier lifetimes, surface passivation, and minimization of optical losses, device characterization and in other areas. Many of these improvements are viable in mass production. The upper limit of silicon solar cell efficiency is 29%, which is substantially higher than the best laboratory

(25%) and large-area commercial (24%) cells. Cell efficiencies above 25% appear to be feasible in both a laboratory and commercial environment. Such a cell will have minimal bulk recombination due to a combination of a thin substrate with a very high minority carrier lifetime; superb surface passivation; small-area electrical contacts consistent with low contact recombination, free carrier absorption and contact resistance; excellent optical control through the use of texturing, antireflection coatings and rear surface reflectors; low edge recombination assisted by the use of thinner wafers, larger cells and edge passivation; and sufficient metal coverage to minimize resistive losses. This paper will survey current work in high performance silicon solar cell design and fabrication, and discuss approaches to efficiency improvements.[5]

Nikhil Gakkhar, M.S.Soni, Sanjeev Jakhar,(2012) "Analysis of water cooling of CPV cells mounted on absorber tube of a Parabolic Trough Collector" – This paper present the thermal performance of multi junction solar panel with concentration liquid cooling on both sides of the panel. The water is allowed to flow from inside as well as outside of receiver, thus reducing the temperature of the panel significantly.Thethermal model predicts the temperature variation of the cell along its length, which given the improved efficiency of the panel. The model is simulated considering the geometrical, optical and thermal aspect of receiver tube in MATLAB. The temperature trend obtained in the radial direction decreases from outward to inward. From outer glass envelope surface at 313 K, the temperature of inner most fluid reaches to 309 K. Across the length, the results show increases in temperature trend. This paper focuses on the impact of sprinkling and refrigerant based cooling methods of photovoltaic modules on actual performance, the duration of cooling and the quickness of the impact of cooling in comparison with mono crystalline photovoltaic modules without cooling. The obtained endings were analyzed both from technical and economic aspects. Based on the parameters of the regression model used in this study (r¼0.61), it can be concluded that a1°C increase of air temperature in the examined range (18–29 °C) improves actual performance by 1.58 W and cooling is probably necessary at higher temperatures. On more cloudy days, the expected performance is 9.8 W lower on average (P¼0.001).In both experiments, there was an obvious negative correlation between module temperature and actual performance under constant radiation conditions. On more sunny days, one unit change in temperature resulted in a performance change of 1.2–1.3% (R2¼0.87–0.95), while more

cloudy days resulted in less close correlation and a much lower change of temperature (0.8–0.9%) (R2
¼0.70–0.81). The following conclusions can be drawn in relation to the two examined cooling methods: The actual performance of the sprinkling method is higher than that of the other two alternatives (by19% and 25% in the case of the control method and by 13% and 18% in the case of refrigerant based cooling, depending on the day of measurement).After deducting the electricity needed for sprinkling cooling, the electric performance was still 12%better on average, using 22.5 L water per day on average. In the case of the refrigerant based cooling method, the produced extra energy was less than the electricity need of the heat exchanger itself; therefore, this method obviously seems to be unviable both from energetic and economic aspects.[6]

Rupali Nazar (2011)"Improvement of efficiency of solar panel using different methods"–In this paper he have studied PV cells are usually connected together to make PVmodules, consisting of 72 PV cells, which generates a DC voltage between 23 Volt to 45 Volt and a typical maximum power of 160 Watt, depending on temperature and solar irradiation. Solar panel efficiency depends on various factor such as solar intensity (brighter the sunlight, the more there is for the solar cell to convert), temperature, dust which decreases the efficiency of panel etc. Solar energy incompletely natural, it is considered a clean energy source. So the study on improving the efficiency of solar panel is very necessary In this paper he have discuss various methods of efficiency improvement of solar panel. We can improve efficiency of solar panel by using solar tracker with panel which continuously tracks sunlight throughout the day to get maximum solar energy. Second method to improve the efficiency is dust cleaning. Dustis barrier between sunlight and solar panel. Third method is cooling technique. As panel temperature increases output voltage of solar panel decreases so cooling of panel is necessary for improvement of efficiency. Other method is anti-reflecting coating for solar panel, which improve efficiency of panel. Aim of this paper is to increase the efficiency and power output of the solar panel.[7]

Saad Odeh & Masud Behnia (2010)"Improving Photovoltaic Module Efficiency Using Water Cooling"-The surface cooling technique of the PV module was developed in this study to improve the performance of a PV powered water pumping system. An arrangement of pipe fittings was used to allow water flow under gravity on the PV module upper surface. The system, which is used for irrigation purposes, consists of a PV module cooled by water, a submersible water pump, and a water storage tank. Cooling of the PV panel is achieved by introducing water trickling configuration on the upper surface of the panel. An experimental rig is developed to investigate and evaluate PV module performance with the proposed cooling technique. The experimental results indicated that due to the heat loss by convection between water and the PV panel's upper surface, an increase of about 15% in system output is achieved at peak radiation conditions. Long-term performance of the system is estimated by integrating test results in a commercial transient simulation package using site radiation and ambient temperature data. The simulation results of the system's annual perform -ance indicated that an increase of 5% in delivered energy from the PV module can be achieved during dry and warm seasons. An effective way of improving efficiency and reducing the rate of thermal degradation of a photovoltaic (PV) module is by reducing the operating temperature of its surface. This can be achieved by cooling the module and reducing the heat stored inside the PV cells during operation. In this paper, long-term performance modeling of a proposed solar-water pumping system is carried out.[8]

Ahmed Amine Hachicha, Chaouki Ghenai, Abdul Kadir Hamid(2010) "Enhancing the Performance of a Photovoltaic Module Using Different Cooling Methods"**-**Experiments were conducted using three cooling methods: back cooling, front cooling and double cooling (combining both methods). Temperature and electrical performance were tested during one hour at solar noon when the radiation and ambient temperature are higher. The evolution of temperature of the panel and the maximum power point using different cooling methods. It can be seen from that the performance of the PV panel is enhanced using different cooling methods by reducing the cell temperature and increasing the maximum power point. Tested the improvement of efficiency of PV module by applying many techniques. They designed a system consisting of cooling unit and sun tracking unit. The cooling unit is an electronic controller circuit that excites DC pump-to-pump water and form water film on the PV surface, by a signal from a temperature sensor that sends the signal once temperature of PV exceeds 35°C. It saves energy as well as water. Temperature effect on the performance of a photovoltaic module is one of the main concerns that face this renewable energy, especially in hot arid region, e.g. United Arab Emirates. Overheating of the PV modules reduces the open circuit voltage and the efficiency of the modules dramatically. In this work, water-cooling is developed to enhance the performance of PV modules. Different scenarios are tested under UAE weather conditions: front, back and double cooling. A spraying system is used for the front cooling whether a direct contact water system is used for the back cooling. The experimental results are compared to non-cooling module and the performance of the PV module is determined for different situations. The experimental results show that the front cooling is more effective than the back cooling and may decrease the temperature of the PV module significantly.[9]

Saurabh Mehrotra, Pratish Rawat, Mary Debbarma and K. Sudhakar(2009) **"**Performance of a solar panel with water immersion cooling technique"**-**The concept of this work is to improve the performance of a solar panel using immersion cooling technique with water as the coolant. The work aims at increasing the electrical efficiency of the panel by submerging it in water. In this study, electrical parameters of solar cell were calculated which showed that the cooling factor plays an important role in the electrical efficiency enhancement. Solar cell immersed in water was monitored under real climatic conditions; cell surface temperature can be controlled from 31-39 .C. Electrical performance of cell increases up to great extent. It is a conductive liquid which when decomposes into its ions may affect the electrical efficiency as the ions will also have a current. So deionized (DI) water is preferred as it has low viscosity and high thermal capacity.[10]

2.2 Comments on reviewed papers

The recent upsurge in the demand of PV systems is due to the fact that they produce electric power without hampering the environment by directly converting the solar radiation into electric power. Solar energy is completely natural; it is considered a clean energy source. So the study on improving the efficiency of solar panel is very necessary In above paper discuss various methods of efficiency improvement of solar panel. We can improve efficiency of solar panel by using solar tracker with panel which continuously tracks sunlight throughout the day to get maximum solar energy. Second method to improve the efficiency is dust cleaning. Dust is barrier between sunlight and solar panel. Third method is cooling technique. As panel temperature increases output voltage of solar panel decreases so cooling of panel is necessary for improvement of efficiency. Other method is anti-reflecting coating for solar panel, which improve efficiency of panel. As said before, instead of air as the coolant of the panel, water can be used in order to absorb more heat and to cool the panel more effectively.

This system which is using a fluid as the coolant is called hybrid. It transforms the sun's radiation to electrical energy and simultaneously absorbs the heat from the panel. By this way, the panel is working in lower temperatures (higher efficiency), and the heat produced can be used for covering a part of thermal requirements of a building, for example preheating the water used for hot water applications.

3 THE PROBLEMS EXISTING

3.1Problem Statement

Conducting materials consist of free electrons and some electrons are held tightly by the nucleus of atoms. When irradiance increases, more packets of photons strike the pane land this energy is absorbed by the atoms and electrons and they collide with each other emitting more electrons from the atoms and thus raising the temperature. Increase in temperature leads to increase in resistance to the flow of current. Efficiency is also dependent on temperature. At high temperature output performance of solar panel reduces as compared to a lower temperature. .

3.2Objective

Solar panels can diminish and produce less power when exposed to high temperatures. The objective of this experiment was to develop an efficient method of cooling down solar panels to increase their lifetime, as well as power production/efficiency.

3.3 Scope

The solar industry's structure will rapidly evolve as solar reaches grid parity with conventional power between 2016 and 2018. Solar will be seen as a viable energy source, not just as an alternative to other renewable sources but also to a significant proportion of conventional grid power. The testing and refinement of off grid and rooftop solar models in the seed phase will help lead to the explosive growth of this segment in the growth phase.

4. DESIGN OF WATER COOLING PANEL

4.1 General theory of PV cells

The conversion of the energy carried by electromagnetic radiation into electrical energy is a physical phenomenon known as the photovoltaic effect. Solar cells are without doubt the most important type of device for carrying out such conversion. When sunlight falls on semiconductor materials (e.g. silicon), the photons making up the sunlight can transmit their energy to the valence electrons. Silicon is representative of the diamond crystal structure. Each atom is covalently bonded to each of its four nearest neighbors. That is, each silicon atom shares its four valence electronic with the four neighboring atoms, forming four covalent bonds. Silicon has atomic number 14, and the configuration of its 14 electrons is 1s22s22p63s23p2 . The core electrons, 1s2, 2s2 and 2p6, are very tightly bound to the nucleus and, at real-world temperatures, do not contribute to the electrical conductivity. At absolute zero, as N silicon atoms are brought together to form the solid, two distinct energy bands are formed-the lower, "valence" band and the upper, "conduction" band. The valence band has 4N availability energy states and 4N valence electrons and is therefore filled. Conversely, the conduction band is completely empty at absolute zero. Thus the semiconductor is a perfect insulator at absolute zero.

As the temperature of the solid is raised above absolute zero, energy is transferred to the valence electrons, making it statistically probable that a certain number of the electrons will be raised in energy to such an extent that they are free to conduct electrical charge in the conduction band. These electrons are called intrinsic carriers. The amount of energy necessary to bridge the valence and conduction bands is referred to as the forbidden gap or energy gap E.g., which is 1.12 eV at room temperature for silicon.

Each time a photon breaks a bond, an electron becomes free to roam through the lattice. The absent electron leaves behind a vacancy, or hole, that can also move through the lattice as electrons shuffle around it. The movement of the electron and holes in opposite directions generates an electric current in the semiconductor. The current can carry on through an external circuit, allowing the energy absorbed from the light to be dissipated in some useful way. To separate the electrons from the holes and prevent the bonds from reforming, an electrical field is used. It provides a force propelling the electrons and holes in opposite directions. The result is a current in the direction of this field.

The main characteristics that distinguish photovoltaics from other renewable are:

• Direct production of electrical energy, even in very small scale of few Watt or mWatt

• They are easy to use. In certain small applications they can be installed directly from the user

• They can be installed in city centers without offending aesthetically the environment

• They can be combined with other sources of energy (hybrid systems)

• They can be expanded in order to meet higher demands

• Their operation has minimum noise production as well as no emissions

• Their operation life can be large with minimum maintenance

• They require high investment cost

4.2The four main types of silicon photovoltaic cells

The four general types of silicon photovoltaic cells are:

•Single-crystal silicon.

•Polycrystalline silicon (also known as multicrystal silicon).

•Ribbon silicon.

•Amorphous silicon (abbreviated as "aSi," also known as thin film silicon).

Single-crystal silicon

Most photovoltaic cells are single-crystal types. To make them, silicon is purified, melted, and crystallized into ingots. The ingots are sliced into thin wafers to make individual cells. The cells have a uniform color, usually blue or black

Polycrystalline silicon

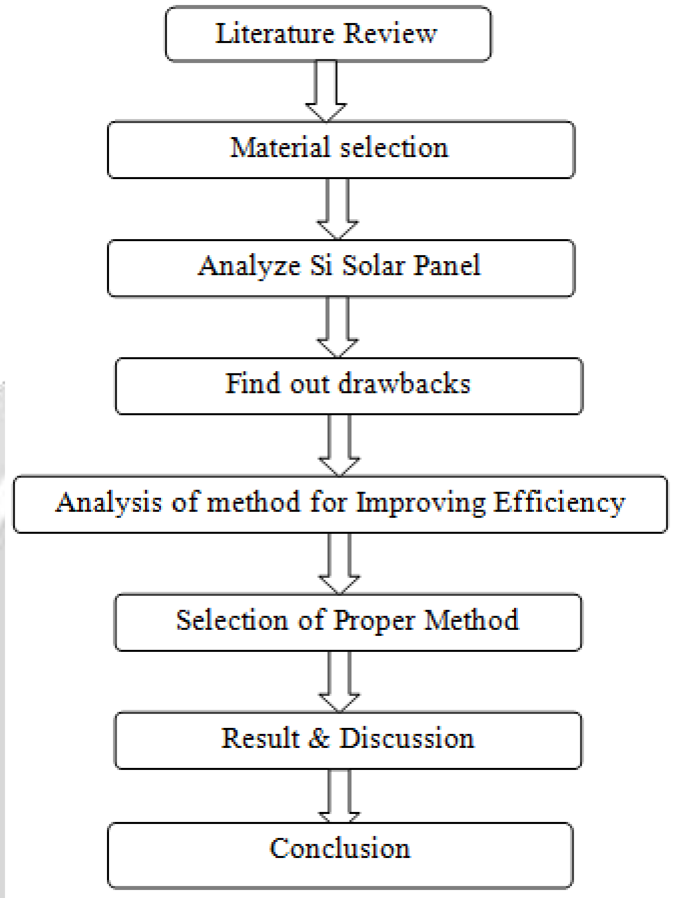
Polycrystalline cells are manufactured and operate in a similar manner. The difference is that a lower cost silicon is used. This usually results in slightly lower efficiency, but polycrystalline cell manufacturers assert that the cost benefits outweigh the efficiency losses. The surface of polycrystalline cells has a random pattern of crystal borders instead of the solid color of single crystal cells.

Ribbon silicon Ribbon-type photovoltaic cells are made by growing a ribbon from the molten silicon instead of an ingot. These cells operate the same as single and polycrystalline cells. The anti-reflective coating used on most ribbon silicon cells gives them a prismatic rainbow appearance.

Amorphous or thin film silicon

The previous three types of silicon used for photovoltaic cells have a distinct crystal structure. Amorphous silicon has no such structure. Amorphous silicon is sometimes abbreviated "aSi" and is also called thin film silicon. Amorphous silicon units are made by depositing very thin layers of vaporized silicon in a vacuum onto a support of glass, plastic, or metal. Since they can be made in sizes up to several square yards, they are made up in long rectangular “strip cells." These are connected in series to make up "modules.

5. METHODOLOGY



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