ISSN: 0974-2115
www.jchps.com Journal of Chemical and Pharmaceutical Sciences

Increased efficiency solar PV panel using integrated techniques

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ABSTRACT

The aim of the paper is to increase the efficiency of the solar panel by integrating several methods of efficiency improvement techniques in a single system to overcome the main drawbacks of current Solar PV Panels. Currently the efficiency of solar panels is very low. Currently the best achieved sunlight conversion rate (solar module efficiency) is around 21.5% in new commercial products. The efficiency of the panels is increased by using concentrators in the form of mirrors, used to focus the incoming light; optical Filters, to filter all types of rays except for visible radiation & dust cleaning technique. By integrating several techniques drawbacks can be overcome, and to increase the overall efficiency of the solar panel by around 40-50%.

INTRODUCTION

In solar technologies and innovations, one of the biggest issues is the photovoltaic panels or solar cells. These panels are made using various methods and depending on their production their efficiency and cost are determined. So far the cheapest solar cells are the thin film type which is used to make flexible panels. This process is cheaper but their efficiency is not that great. It also has the casting of existing silicon crystals into a panel which is the most predominant form of solar cell manufacture but this is more expensive and while efficiency may increase, the costs of these panels is very high. Another method is the creation of silicon crystals which is a manmade process of dissolving them and reforming them only to be thinly sliced and turned into a PV panel. These are the second most competent solar cell with efficiencies closing in on the 15% mark, but they are also consuming to produce which also means very expensive. The final type of solar cell is also the newest that is available to the general market. These PV panels are the most expensive. They are multiple layers of solar cells stacked on top of each other. The concentrated PV panels can have efficiencies in the range of 40% - 50% which is getting closer to what the world needs, but as stated before, their cost is extremely high; some of them costing well over $10,000 for a single cell that can fit in the palm of one's hand.

In most cases the cost of solar cells can be so great that is will not even cover the life expectancy of the cell which means it would cost more than using utility feeds. Power generated by solar cells is also considered by far to be the most expensive means of producing electricity. One cannot use solar cells at night time so either we have to store the energy at higher costs or turn to fossil fuels for this night time power production. And the solar cells only produce direct current and hence when coupled to the necessary inverter another 15% is lost.

Though solar cells have good promises; delivery of an efficient and inexpensive PV panel in this lifetime is too much. The solar cells are not the only way of producing electricity from the sun. While solar cells convert sun's light to produce electricity, solar thermal systems use the sun's heat to produce and is by far much more efficient. While in low light conditions, the heat is not much, the heat created by the sun can be stored in a number of mediums from graphite to molten salt which means that within no time the ability to store this energy all night long will be upon us.

PRINCIPLE OF SOLAR CELL WORKING

Two important steps are involved in the principle of a solar cell (R. Abd Elgani, M. H. M. Hilo, et al., 2013). These are: Creation of pairs of positive and negative charges (called electron-hole pairs) in the solar cell by absorbed solar radiation. The separation of the positive and negative charges by a potential gradient within the cell, for this to occur, the cell must be made of a material which can absorb the energy associated with the photons of sunlight. The energy (E) of a photon is related to the wavelength (λ) by the equation:

$$E = \frac{hc}{\lambda} \quad (1)$$

Where h is Plank's constant = 6.62 × 10−34 J.s, and c = velocity of light = 3 × 108 m/s.

Substituting these values, we get: $E = \frac{1.24}{\lambda}$ (2)

Where E is in electron-volt (eV) and λ is in μm. The only material suitable for absorbing the energy of the photons of sunlight are semiconductors like silicon, cadmium, gallium arsenide, titanium oxide, etc. In semiconductors, the electrons occupy one of two energy bands—the valence band and the conduction band. The valence band contains electrons at a lower energy level and is fully occupied by the electrons, while the conduction band has electron at a higher energy level and is not fully occupied, but only partially occupied. The difference between the energy levels of the electrons in the two bands is called the band gap energy. Photons of sunlight having energy E greater than the band gap energy Eg are absorbed in the cell material and excite some of electrons. These electrons then jump across the band gap from the valence band to the conduction band, leaving holes in the valence band. Thus electron hole pairs are created. The electron in the conduction band and holes in the valence band are mobile and not stationary. They can be separated and made to flow through an external circuit (thereby executing the second step of the photovoltaic effect) if a potential gradient exists within the cell. In semiconductors the potential gradient is obtained by making the cell as sandwich of two types, p-type and n-type (R. Abd Elgani, 2013). The energy levels of the conduction and valence bands in p-type are slightly higher than the corresponding levels in n-type. Hence when a composite of two or more types of material is formed, the electron jump occurs at the junction interface. This potential gradient is adequate to separate the electrons from the holes, and cause a direct electric current to flow in the external load.

POWER PRODUCTION

The solar panel produces a current depending on the surface area of the cell. Each cell produces a constant voltage of 0.6V, irrespective of its area. To measure the power produced in a solar, its voltage and current is measured separately. For this, the solar panel is connected across a rheostat as the load. An ammeter is connected in series with the load to measure the current produced by the panel and a voltmeter is connected parallel to the load to measure the voltage across it. By measuring the voltage and current, the power produced can be calculated. The formula for power is given by:

$$P = VI \qquad (3)$$

Where P = Power produced by the solar panel.
V = Voltage across the load.
I = Current flowing in the load.

Similarly the amount of load can be calculated by measuring power and using the voltage formula. As we know that according to ohms law,

$$I = V/R \qquad (4)$$

Hence, power can be expressed in terms of current as:

$$P = I^2R \qquad (5)$$

Or it can be expressed in terms of Voltage as :

$$P = V^2/R \qquad (6)$$

Where R = Resistance of the load (i.e. Rheostat in this case.)

INTEGRATED TECHNIQUES TO INCREASE EFFICIENCY

The efficiency of the solar panel is increased using:

A. **Concentrators:** Concentrators in the form of mirrors, used to focus the incoming light at the back of panel and increase the intensity of sun light falling on the plane. The performance of the solar panel with reflector depends mainly on three parameters namely tilt angle, length and reflectivity of the reflector (Anand, V.P., Khan, M.M., et al., 2014). Hence it is important to choose the optimum values of these parameters to attain maximum power output from the system. We have developed a model system to analyze the effect of reflector parameters on the overall power output.

B. **Optical Filters:** Optical Filters to filter particular frequency of light which decreases the heat loss in the panel due to the elimination of radiation of heat caused by the light of various wavelengths (Schoeman, 2013). In normal the sun light has different wavelengths. But only the visible Light of wave length 400nm to 700nm is best suited for the panels to produce the radiation less absorption. Thus by using integrated filters to filter the unwanted light will decrease the heat loss, which will simultaneously increase the power production.

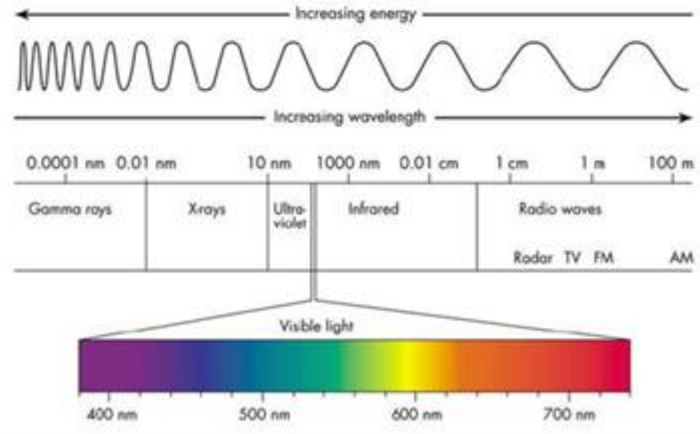

Figure 3.1

C. Dust Cleaning Techniques: As the solar panels are always exposed to the external environment, the panel get dust sedimentation which will reduces the power production (Hiroyuki Kawamoto, Takuya Shibata, et al., 2013). Thus Dust cleaning technique using automated wipers is also incorporated to increases the efficiency of the solar panel. Using these techniques, conversion rate of the solar panel can be increased upto 30-45%. As science dictates, we are trying to integrate as many techniques, to increase the efficiency to its maximum, to help humanity have a better future.

SYSTEM DESIGN

As shown in Figures 4.1 & 4.2, the system consists of a solar PV panel, which can absorb light on both its faces. The Solar Panel is mounted on a stand that consists of two mirrors, acting as reflector system. The Mirrors are positioned and angled in such a way that the light falling on it is reflected directly to the backside of the solar panel. Since the solar panel can absorb light on both sides, the light falling on the back face is also absorbed, and a current is produced. Since the reflector system consists of two mirrors, the amount of light falling on the panel is equivalent of light having the intensity of two suns. However, since the mirrors are not 100% perfect reflectors (as 100% reflection cannot be achieved by any substance) the equivalent intensity is less than that of two suns.

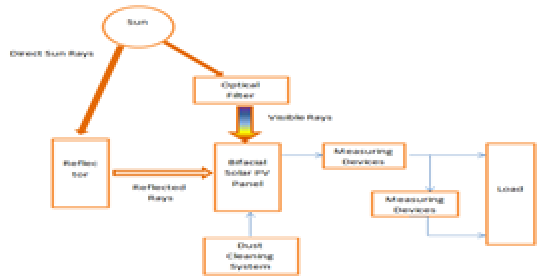

Figure 4.1

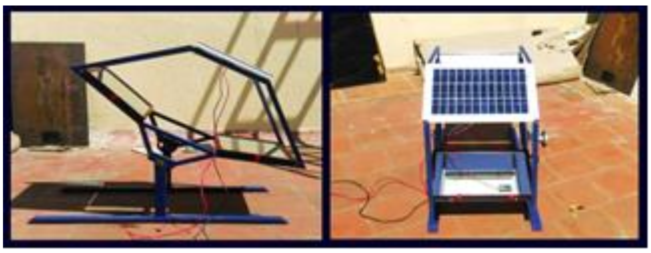

Figure 4.2

The top side of the panel doesn't get light coming directly from the sun. An intermediate layer of optical filter is used in the between for separation of light. The optical filter only allows light falling in the visible range to pass through, and the light in the other regions to be either absorbed or reflected back. The rays coming from the sun consists of 51% of Visible light, 41% of infrared light and 8% of Ultraviolet light. The light rays that produce electrical energy in a solar panel are only rays present in the visible region. Using the simulation, the angle of the reflectors to be used to perform perfect reflection without excessive light not getting wasted was measured and used.

The angle was found out using simple trigonometry and geometry as the distance between the panel and reflector could be varied. The right distance, that would not be too excessive as well as not to minimum was selected. The selected distance was 35cm. Since for perfect reflection without wastage, the light falling on the rightmost edge of the mirror must be reflected to the rightmost edge of the panel. Hence the exact angle of the reflectors was calculated and was verified by simulation.

The cleaning system consists of a longitudinal brush (a flat surface with soft bristle like projections) attached to a tracks coiled around a set of wheels, similar to the wheels of a tank. The wheels are connected to a motor that is controlled by an Arduino Uno circuit board. The rotation of the wheel makes the brush move up and down on the surface of the solar panel, wiping off the dust that has settled on the surface. The system has been programmed to operate at an interval of every 60 minutes. This ensures that the panel is cleaned in regular intervals and the cleaning does not disturb or affect the functioning of the solar panel. Similarly the cleaning system is positioned in such a way that its shadow does not fall on the solar panel during resting position.

The optical filter is a silicon-glass mixture placed above the solar panel at a distance of 10 cm. All the light falling on the front side of the panel is the light passing through the filter only.

SIMULATION

Using the softwares of TracePro & PVSyst, the model and design was tested. First a simple solar panel having the same dimensions and substance was simulated. The power produced by a 10 W panel, at conditions present at Chennai in the month of February was around 6 W.

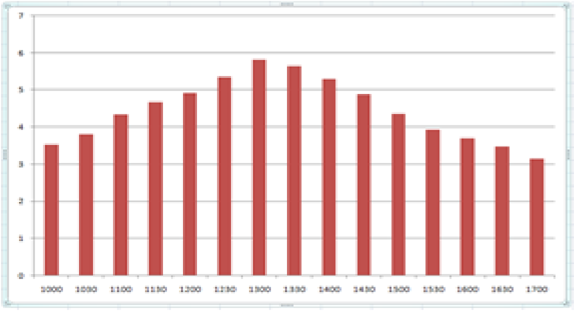

Figure 5.1

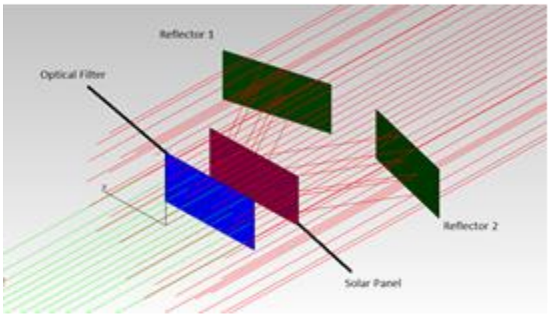

Figure 5.2

The peak power production of the solar panel, as seen in Figure 5.1, was found to be around the time of 12:30pm to 2pm. Since the maximum power produced was only 6W, the efficiency is very low. The software was used to simulate the reflector system.

The power produced using a single side and both sides were simulated (As seen in Figure 5.2 & Figure 5.3). There was an increase in efficiency almost two times.

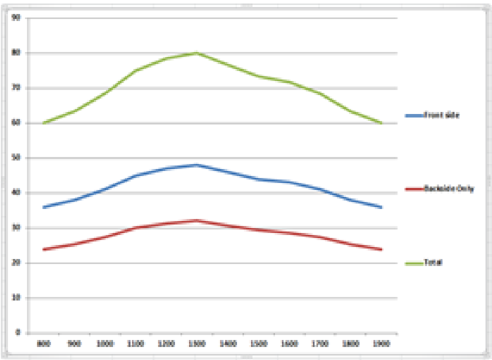

Figure 5.3

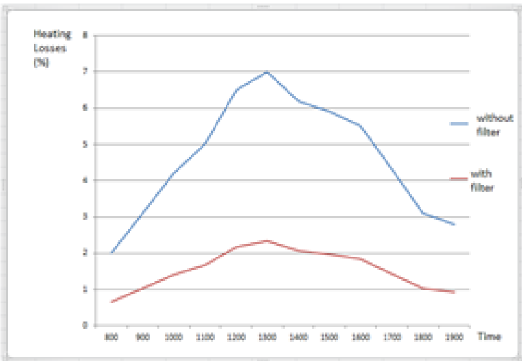

Figure 5.4

The heating loss for the system, as seen in Figure 5.4, while using the optical filter and without using the optical filter was calculated and measured in the simulation. The heating loss was found to be very less, almost negligible during the morning.

The loss in power production due to the accumulation of dust was also simulated in the PVSyst software. The weather and climatic conditions present were set to normal (i.e. without rain, storm, cyclone, etc.). The accumulation of dust over a period of seven days was simulated and the loss in power produced was measured.

CONCLUSION

The simulation of the system clearly shows that the present day solar panels have very low efficiency. The power produced is very low and can be increased using multi-fold. Similarly environmental conditions are also a factor in reducing the power production. Hence using the integrated techniques the power production for a single solar panel can be increased multi-fold. The reflective system itself increases the efficiency by almost two times. Using the optical filter and dust cleaning system the external losses can be reduced significantly as well.

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