Solar Thermal System Integration Studies to Determine the Influence on Solar Photovoltaic Module Efficiency

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Abstract

The performance and deterioration of solar photovoltaic cells are significantly influenced by the temperature of the solar cell. Numerous academics and manufacturers have studied the relationship between solar cell temperature and photovoltaic module efficiency. The merging of solar photovoltaic and solar thermal is attempted in this study. The study has been focused on developing an optical filter that uses water as an optical filter to integrate solar photovoltaic modules with solar thermal systems. The system has undergone research and fabrication. In compared to a single solar module, the PV/T system has a better efficiency and lower photovoltaic module temperature. The input temperature, ambient temperature, solar radiation, relative humidity, wind speed, flow rate, and other factors all affect how efficient a PV/T system is. The research has chosen input temperature, solar radiation, and ambient temperature out of a variety of characteristics. In order to prevent hot spots on the photovoltaic module, the research of concentrating PV/T system with water-based optical filter for the concentration of solar rays V-trough has been employed in this work.

Keywords: *solar cell, Temperature, Efficiency, Photovoltaic and optical filter.*

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1. Introduction

The scenarios are diverse perspectives on the future that may be utilised to investigate, implement, and decide potential future developments. The key metric for measuring a country's progress is energy [1]. More developed countries have higher per capita consumption. Due to worries about the environment, geopolitics, and the economy, as well as the uneven regional distribution of natural resources, the world's current energy scenario is unsustainable [2]. Coal is the primary energy source in India, accounting for 60.7% of the nation's total energy production. In India, nuclear power produces around 2% of the nation's energy [3]. Only 14.8% of India's large and economically feasible hydropower potential has been used for the production of electricity, while renewable energy sources account for 13.7% of the total.

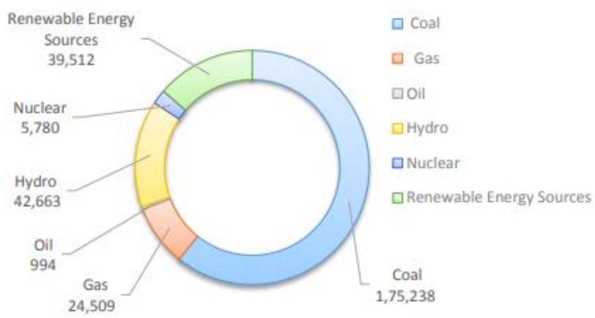

Figure.1. Sector wise installed capacity of power plant in India

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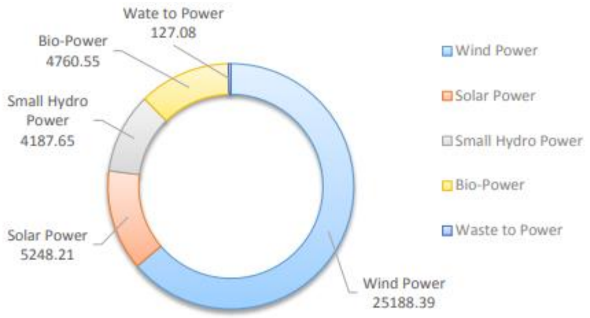


Figuer.2. Sector wise installed capacity of renewable energy power plant in India

India is ranked fifth with 60600 Mt of coal reserves, while the United States holds the top spot with 237295 Mt. Of the 209745 bcm of natural gas in the globe, Russia possesses the biggest amount at 47750 bcm [4]. The USA has the biggest installed nuclear power capacity in the world (98903 MW), while the global total is 364078 MW. The greatest installed hydropower capacity in the world, at 231000 MW, is in China [5]. The world's installed wind power capacity is 238049 MW, with China having the biggest installed capacity at 62364 MW. The greatest solar PV installation in the world is in China with 43530 MW, followed by India with 6997 MW and a total installed capacity of 256000 MW.

A physical system's energy is its ability to carry out tasks. The whole electromagnetic spectrum is covered by the sun's radiant radiation [6]. This spectrum, which is referred to as "solar radiation," is constrained between 280 nm to 4000 nm due to air interference. The electromagnetic waves from the sun's energy travel across space [7]. The planet continually gets 1.8 x 1017 W of solar radiation at the top of its atmosphere. However, only 50% of it makes it to the earth's surface [8]. Reduced solar radiation is present on Earth's surface as a result of phenomena including light absorption, scattering, and reflection as it travels through the atmosphere (Fig.3). Solar energy is a low density energy source by definition.

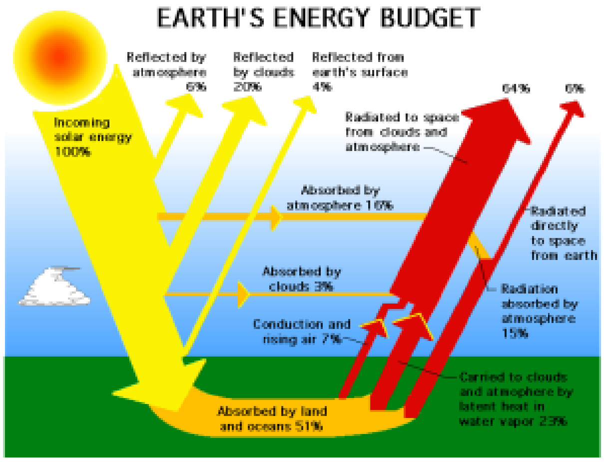


Figure.3. Earth's energy budget (Credit: Image courtesy NASA's)

The amount of radiation generated overall that reaches the planet is really little. Nearly every sort of energy utilised today has its indirect source in the radiation that does reach the planet [9]. Nuclear fission and fusion as well as geothermal energy are the exceptions [10]. Even fossil fuels are descended from the sun; they were once living organisms whose existence was reliant on the sun [11]. Solar power may directly provide a large portion of the energy needed by the planet. Even yet, indirect energy provision is still possible.

The quantity of solar radiation received by a surface that is constantly kept perpendicular (or normal) to the rays that arrive in a straight line from the direction of the sun at its present location in the sky is known as direct normal irradiance (DNI). Generally, maintaining a surface normal to incoming radiation will allow us to increase the quantity of irradiance it receives yearly [12]. Both concentrated solar thermal plants and installations that follow the location of the sun are particularly interested in this amount.

Three processes make up the solar cell's operation. Sunlight photons strike the solar panel and are absorbed by semiconducting components like silicon [13]. An electric potential difference results from the separation of negatively charged electrons from their atoms. To remove the potential, current begins to flow through the substance, and the electricity is collected. The electrons are only permitted to flow in one direction because of the unique composition of solar cells [14]. Solar energy is transformed into an useable quantity of direct current (DC) power using a solar cell array.

Varying materials have varied prices and different efficiency. Materials for effective solar cells must have properties that are compatible with the light spectrum. Some cells are designed to effectively transform the solar light wavelengths that reach the earth's surface. Some solar cells, nevertheless, are also designed to absorb light from sources beyond the earth's atmosphere [15]. It is often possible to utilise light-absorbing materials in a variety of physical arrangements to benefit from various light- and charge-separation techniques. Mono-crystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium selenide/sulfide are among the materials now utilised in photovoltaic solar cells. Crystalline silicon, sometimes referred to as "solar grade silicon," is by far the most widely used bulk material for solar cells and is denoted by the group abbreviation c-Si. The resultant ingot, ribbon, or wafer is a variety of categories of bulk silicon divided by crystallinity and crystal size [16]. The history of silicon technology development and predictions made about where silicon technology is expected to go in the next ten years have been the subject of much discussion and debate (Swanson, 2006). The obstacles that have prevented the development of rival technologies are then explored, along with the actions that must be done to overcome them.

Since every grain in a mono-crystalline silicon cell is the same size, it is known as such. Using the Czochralski technique, mono-crystalline silicon cells are constructed. Because mono-crystalline silicon solar cells are costly, they are made from cylinder-shaped ingots and have circular shapes that are then squared off at the sides [17]. As a result, these kinds of solar panels feature a space between the solar cells' corners. Both the Czochralski technique and the casting of multi-crystalline ingots in massive crucibles are being used to create silicon ingots. Casting is the more popular and considerably less expensive method. The productivity of casting furnaces has significantly risen, and their ownership costs have decreased. On the other hand, czochralski growth is often carried out in a manner similar to that of IC ingot production [18]. IC ingots must meet significantly stricter specifications than solar. Therefore, there is a lot of opportunities for cost savings in the Czochralski growth process. Many businesses are actively looking for jobs in this field. Additionally, there are ribbon technologies that completely omit the sawing stage and are doing rather well (Swanson, 2006).

Figure.4. Mono crystalline solar cell

The term "polycrystalline solar cell" refers to a solar cell comprised of several crystal grains. It was created using square silicon ingots that were cast. Although less effective than single crystal silicon cells, poly-Si cells are less costly to build [19]. Data from the US Department of Energy indicate that owing to their greater price, polycrystalline silicon is sold more often than monocrystalline silicon. Production of polycrystalline silicon: The present silicon scarcity has made polysilicon more prominent [20]. The majority of the current polysilicon manufacturing facilities were constructed to support the microelectronics sector. The scrap materials and sometimes extra capacity from these facilities have traditionally been used by PV. All of this is going to drastically alter. Numerous brand-new polysilicon factories are now being built to meet the specific needs of the PV sector. All across the globe, including the US, Germany, Russia, China, and Japan, they are found (Swanson, 2006).

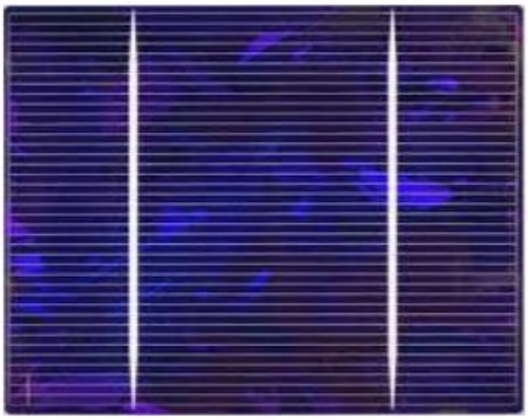


Figure.5. Multi-crystalline or poly-crystalline

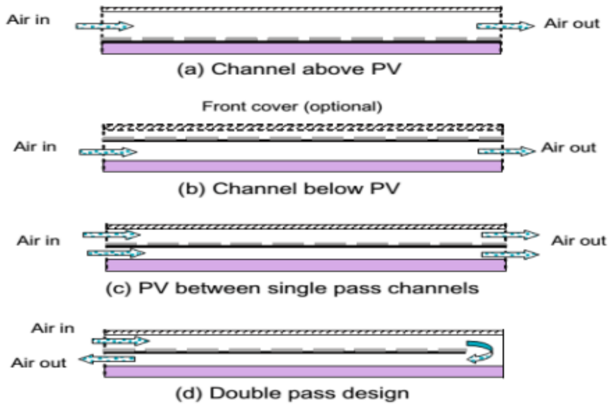
Polycrystalline silicon also includes ribbon silicon, which is produced by pouring molten silicon onto thin, flat sheets; as a result, it acquires a polycrystalline structure and does not need cutting from an ingot [21]. Its efficiency is lower than that of a poly-crystalline solar cell, but it uses less material and has a manufacturing cost that is around half that of a completed crystalline silicon solar module. Researchers have also worked on silicon solar cells with a string ribbon and a 17.8% efficiency (Kim et al., 2003; Yelunduret al., 2006) tie ribbons Vertical sheet growth is used to create Si wafers, which results in low-cost Si owing to the high feedstock utilisation rate and lack of wafer etching and ingot sawing [22]. A record-breaking 16.2% efficiency cell was created a few years ago utilising photolithographic methods (Hanoka, 2001). The creation of a material with even greater potential is the subject of much investigation.

Despite being a relatively new technology, organic solar cells promise to be much less expensive (than thin-film silicon) and to provide returns more quickly. These cells can be treated from solution, opening the door to a straightforward roll-to-roll printing method that might enable low-cost, mass manufacturing [23]. Thin films (usually 100 nm) of organic semiconductors, such as polymers like polyphenylenevinylene and small-molecule substances like copper phthalocyanine (a blue or green organic pigment), carbon and fullerene derivatives, are used to create organic solar cells and polymer solar cells. When compared to inorganic materials, conductive polymers have not yet attained high energy conversion efficiencies [24]. The maximum NREL (National Renewable Energy Laboratory) certified efficiency has reached 8.3% for the Konarka Power Plastic, although it has improved fast in the previous several years. These cells may also be advantageous in certain situations when mechanical flexibility and disposability are crucial. These devices vary from inorganic semiconductor solar cells in that the electrons and holes produced when photons are absorbed are not separated by a p-n junction's strong built-in electric field. An organic device's active area is made up of two materials, one of which serves as an acceptor and the other as an electron donor [25]. The charges usually stay coupled in the form of an exciton when a photon is transformed into an electron hole pair, which normally occurs in the donor material. They are then separated when the exciton diffuses to the donor-acceptor contact. The effectiveness of such devices is often constrained by the short exciton diffusion lengths of most polymer materials [26]. Performance may be enhanced via nano-structured interfaces, which can sometimes take the form of bulk hetero-junctions. Flexible solar cells include polymer solar cells. They may take on a variety of shapes, such as organic solar cells (also known as plastic solar cells) or organic chemistry photovoltaic cells that harness polymers to create electricity from sunlight. In order to make solar cells, other kinds of more stable thin-film semiconductors may also be coated on various kinds of polymers. Research on this relatively new technology is ongoing in universities, government labs, and several businesses worldwide (Mayer et al., 2007). Chemical vapour deposition (usually plasma-enhanced, PE-CVD) is mostly used to deposit silicon thin film cells from silane gas and hydrogen gas. This may produce amorphous silicon, frotocrystalline silicon, nanocrystalline silicon, or microcrystalline silicon, depending on the deposition settings. Recent studies are being conducted on the use of nanotechnology to solar PV cells (Sethiet al., 2011). Due to the issue of global climate change and the growing interest in renewable energy, the solar cell sector has seen rapid growth in recent years [27]. Any solar technology's success depends in large part on cost. To produce substantial amounts of power, today's solar cells are just too inefficient and costly to produce. However, possible developments in nanotechnology may pave the way for the creation of solar cells that are less expensive and somewhat more effective. In the realm of solar energy, nanotechnology has already shown enormous advances. Solar cell efficiency may be improved by nanotechnology, but the technology's potential for lowering manufacturing costs is far greater. The goal of developing PVs based on CdTe, CuInGaSe (CIGS), CuInSe (CIS), and organic materials is to lower the cost per watt, even if it means losing conversion efficiency and dependability.

2. Literature Survey

Because of the oil crisis in the 1970s, renewable energy has seen a true worldwide renaissance today, making it highly promising. One of the most promising forms of renewable energy is solar energy. Hybrid photovoltaic/thermal (PV/T) energy conversion is a relatively new and promising technique for the generation of both thermal and electrical energy concurrently, among other uses for solar energy. The photovoltaic modules' temperature rises as a result of the solar energy received but not converted into electricity, decreasing the electrical efficiency of the modules [28]. The power output of conventional crystalline silicon PV power plants is reduced by -0.3 to -0.5% K-1 by higher cell temperatures in PV modules. Wilshaw et al., Wilshaw et al., Emery et al., King and Eckert, 1996. Therefore, modelling and control of heat transport are crucial because electrical-yield losses at high working cell temperatures may be significant. Therefore, PV cooling—which may be accomplished by water or air heat extraction—is required to maintain electrical efficiency at a tolerable level [29]. A straightforward and affordable technique to remove heat from PV modules is forced or natural air circulation. 2005's Y. Tripanagnostopoulos et al. Photovoltaic (PV) and solar thermal components/systems are combined to create photovoltaic/thermal hybrid solar systems, which may generate both energy and heat from a single integrated component or system. In other words, solar energy is used as a component of the thermal absorber. PV/T integration may be done in several ways. The options include flat-plate or concentrator kinds, glazed or unglazed panels, natural or forced fluid flow, freestanding or building-integrated features, mono-crystalline/poly-crystalline/amorphous silicon (c-Si/pc-Si/a-Si) or thin-film solar cells, among many more. As a result, there are a variety of installations that may be used, including PV/T air and/or water pre-heating systems, PV integrated heat pumps for hot water delivery, and actively-cooled PV concentrators that employ affordable reflectors. To maximise the total advantages, design choices must be made about the kind of collector, the thermal to electrical yield ratio, and the solar portion [30]. The operating mode, working temperature, and efficiency of the system are all influenced by these factors. The properties of both the electrical yield and the thermal yield are fundamentally altered by the combination of a PV and a thermal collector in one design (H. A. Zondaget al, 2002). As an alternative to conventional PV modules, the first PV/T solar systems employing air or water heat extraction were studied (Kern E C et al, 1978; Hendrie SD, 1979; Florschuetz L W, 1979; Raghuraman P, 1981). Even an unique transparent type module-based PV/T model was examined (Lalovic B, 1986–1987). Later, the notion of employing PV modules for both electrical and thermal conversion of solar radiation emerged from the practicalities and modelling outcomes of liquid type PV/T systems. The most significant recent research on water-cooled PV/T systems are those on one-two and three-dimensional models for PV/T prototypes with water heat extraction (Zondag HA et al., 2002) and systems with water circulation in channels linked to PV modules (Zondag HA et al., 2003). When solar radiation is concentrated, the electrical and thermal output of hybrid PV/T systems may be improved. To do this, flat (Sharan SN et al, 1985; Al Baali AA, 1986) or curved (Brogren M et al, 2000; Brogren M et al, 2002) reflectors were recommended to be mounted atop PV/T modules. At the University of Patras, PV/T systems with and without an extra glass cover were experimentally evaluated [15]. Design ideas, prototype fabrication, and test results for water- and air-cooled PV/T systems were given. The environmental benefit of PV/T systems was further supported by a comparison of those systems to conventional PV and thermal systems. The specific energy band gap below which electricity conversion is impossible has a threshold photon energy that corresponds to the threshold photon energy of a solar cell [16]. Longer wavelength photons solely release their energy as heat in the cell; they do not produce electron-hole pairs. Depending on the solar cell type and operating circumstances, a typical PV module transforms 4–17% of the solar energy received into electricity. In other words, a majority of the solar energy that is incident is transformed to heat (after deducting the reflected portion). Extreme cell operating temperatures of up to 500C above the surrounding environment may result from this. If the heat stress persists for an extended length of time, there may be two unfavourable effects: I a reduction in cell efficiency (-0.3 to -0.5% K-1 increase for c-Si cells), and (ii) irreversible structural damage to the module. Numerous relationships between the relevant meteorological factors, cell operating parameters, and cell temperature and efficiency are compiled here (Skoplaki E et al, 2009). The electrical generation may be increased by using a fluid stream, such as air or water, to cool the solar cells[8]. Reusing the heat energy the coolant removed is theoretically the superior design, however. The energy yield per area of panel (or façade in the case of installation that is incorporated into a structure) may thus be increased. These are the incentives pushing PV/T hybrid solar technology forward.

Most of the time, these kinds of systems are employed with non-concentrating systems. Theoretical and experimental evaluations of several PV/T air collector designs have been conducted, according to previous research investigations. All are primarily characterised by their airflow patterns, including the flow of air in single-pass and double-pass configurations above, below, and on both sides of the absorber. The air-type product design offers a straightforward and cost-effective method of cooling PVs, and the air may be heated to various temperatures through forced or natural flow. Due to improved convective and conductive heat transfer, forced circulation is more effective than natural circulation, but the necessary fan power lowers the net electricity gain. There has been a thorough examination of the total performance analysis of flat plate PV/T air collectors. As shown in Figure 6, four common designs are taken into consideration, with the air moving either over, beneath, or on both sides of the absorber in a single pass (Model III) or double pass (Model IV). Versions I and II have a single rectangular channel, but the other models have two similar channels above and below the absorber, separated in Model III but linked in Model IV by a tight return curve [19]. The Model I collector performs the worst under identical operating circumstances, according to the findings of numerical simulations, whereas the other models show equivalent thermal and electrical output gains. However, the Model III collector, followed by the Models IV and II, requires the least amount of fan power. Additionally, it is shown that selective characteristics are unsuitable for these PV/T collectors since they reduce the amount of PV energy produced, particularly at low flow rates.



Figuer.6. Some common PV/T air collector design

It has been investigated how well photovoltaic PV modules working with air ducts in India's composite environment operate. PV/T collectors' thermal models have been created. created an experimental setup that demonstrates that there is a reasonable level of agreement between theoretical and experimental data for the thermal models of Model I. Additionally, it is stated that the PV module's use of thermal energy has greatly improved the PV/T system's total thermal efficiency. Results indicate that the availability of thermal energy in addition to electrical energy has increased the PV/T system's overall efficiency by 18%. (Tiwari et al, 2006). An analysis and implementation of two low-cost heat extraction improvements in the channel of a PV/T air system to increase thermal output and PV cooling to maintain an acceptable level of electrical efficiency. The proposed techniques in the PV/T air arrangement include using a thin flat metal sheet hung in the centre or a finned rear wall of an air channel. The performance of the PV/T air system is improved by the recommended improvements, according to experimental and theoretical findings. 80 percent overall efficiency is attained (J.K. Tonui et al, 2007). The performance of a double pass solar PV/T air heater with fins has been thoroughly analysed. To increase the efficiency and rate of heat transmission, the fins are positioned perpendicular to the direction of airflow. Figure.7. depicts the double pass PV/T solar collector in cross section with (a) and without (b) fins. The air heater's top channel receives air, which then moves in the opposite direction to the bottom channel. According to the calculations, the fins in the lower air channel on the absorber surface enhance the area where heat can be transferred to the air and boost both thermal and electrical efficiency. Additionally, the expanded fin area significantly lowers the cell temperature. The cell temperature, which is influenced by solar irradiation, intake air temperature, airflow rate, and packing factor, has a substantial impact on electrical efficiency (R. Kumar et al, 2011).

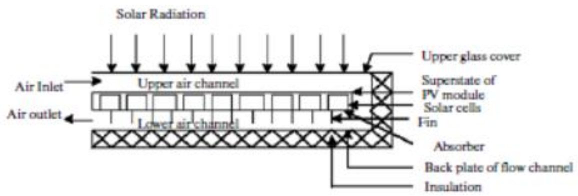


Figure.7. Double pass solar PV/T air heater with fins

Additionally, a novel double pass PV/T air collector design with fins and a compound parabolic concentrator has been researched. Figure 8 illustrates the collector design idea. Direct solar heating occurs when air enters via the top channel created by the glass cover and photovoltaic panel. It then moves into the lower channel created by the PV panel and the rear plate. The PV cells get concentrated solar energy from the compound parabolic concentrators. The PV panel's back has fins that improve system efficiency by increasing heat transmission to the air. To ascertain the collector's electrical and thermal efficiency at different working temperatures, steady state operation tests were conducted inside.

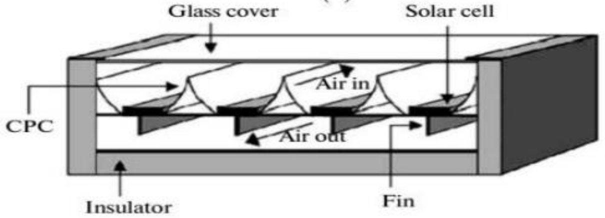


Figure.8. Double pass PV/T solar collector with CPC and fins

The best way to use solar cells is to only direct onto them the portion of the solar spectrum for which high conversion efficiency can be attained. Radiation outside of this range may be recovered by directing it to a second receiver, such as a thermal, chemical, or a separate PV band-gap receiver. The incident beam is separated into PV and thermal spectral components, as shown in Figure 9, and this is the basic idea behind PV/T solar hybrid systems. All-dielectric and metal-dielectric multilayer filters (M.A.C. Chendo et al., 1987), heat reflectors (D.E. Soule et al., 1986), refraction or prism spectrum splitting (J.P. Penn, 2002), holographic filters (J.E. Ludman et al., 1997), fluorescent methods (F. Galluzzi et al., 1984), and liquid absorption filters are among the main (M. Sabry et al,2002). the method of spectrum splitting in which a filter divides light into spectral components aimed at distinct cells with various band-gap energies (G.W. Masden et al, 1978).

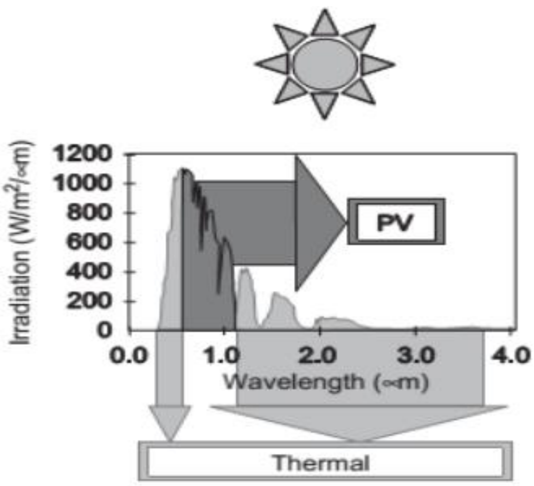


Figure.8. Splitting the solar spectrum into components for PV and thermal energy conversion

Many scientists have looked at the potential for employing PV/T collectors to produce electrical and thermal energy all around the world [23]. The many designs of PV/T systems with air, liquid, and optical filters/spectral beam splitting have been covered. We have shown that different PV/T system combinations may be employed for varied weather conditions. However, optical filtering/spectrally beam splitting is the most promising technology for PV/T systems since it has the benefit of allowing us to employ high temperatures for thermal systems without significantly heating solar PV.

3. Design Concept

Standard solar panels may be used to create concentrating PV/T systems, and they can be integrated with optical filters and V-troughs as illustrated in Figure 9. Above the solar panel, an optical filter has been installed. Here, an optical filter serves as a heat collector, while a V-trough boosts the amount of solar energy coming in. Because a V-trough is a non-imaging collector and may concentrate solar energy more evenly, it has been utilised for solar radiation concentration. The optical filter was made of a 3 mm glass sheet and was filled with regular Reverse Osmosis filter water. The conventional polycrystalline PV-panel with a glass/EVA/ARC/Si/EVA/PE-Al-tedlar casing is known as an opaque PV-panel. The performance of the optical filter-based PV/T system, which employs a flow channel as illustrated in Fig. 9, was calculated using a model created for this work. Through optical filters that absorb extra solar radiation, solar radiation enters the solar cell. The optimal water thickness depends on the solar cell's quantum efficiency. Water absorbed the sun radiation's energy, causing the temperature to increase by the time it emerged. Air is provided between the solar cell and the optical filter to prevent heat transmission between the two components. Electricity was produced using a typical solar module.

Material choice: We employed materials that are typically used in traditional PV laminates for the system design. For a fair comparison between the theoretical model and the actual model, ordinary silica glass is used in the thermal collector. The research employed a polycrystalline PV panel that contains the following layers: glass, EVA, ARC, Si, EVA, PE-Al, and tedlar. The sun's rays may be focused using a variety of imaging and non-imaging concentrating collectors. We have selected a non-imaging V-trough collector since solar cells need to be evenly illuminated.

Figuer.9. Non-imaging V-trough hybrid PV/T system with optical filter

For the purpose of calculating the effectiveness of the PV/T system design, a theoretical model has been established in this work. Solar radiation enters the optical filter, which absorbs the solar radiation that won't benefit the solar photovoltaic panel and lets the remaining energy pass through to the solar cell. According to Fig. 9, this optical filter matches the solar cell's quantum efficiency. Water has the ability to absorb some infrared and ultraviolet rays. The characteristic of an optical filter was covered in the section above, and this section will cover both thermal and electrical efficiency. It is assumed that the air mass of the solar radiation is 1.5. The sun spectrum numbers were derived from Sachin et al(2014) .'s estimate of the filtered solar radiation, which took into account the glass's transmission (ASTM G173-03, 2014, "Standard Tables for Reference Solar Spectral Irradiances," Accessed in April 2014). The heat balance equation for each layer of the PV/T collector is solved to create the steady-state thermal model. We first described the optical filter, then performed temperature analyses on the PV and water channels, and then evaluated the PV/T system's thermal and electrical efficiency. The useable energy generated by it and the effectiveness of the PV/T system are the outcomes of the measurements and calculations. The many V-trough designs may be divided into three categories: seasonal tracking, one axis north-south tracking, and diurnal tracking. Here, a V-trough with a concentration ratio of 2 has been created and built.

4. Quantum efficiency of crystalline solar cell

The solar cell's temperature rises as some of the incident solar energy is turned into electrical energy and some of it is transformed into thermal energy. The efficiency of the solar cell decreases by -0.0045% per 0C when the temperature of the solar cell increases (F. Sarhaddiet al, 2011). Withdrawing the heat energy from the module will boost the efficiency of PV systems. These systems are often referred to as hybrid PV/T (PV/T) systems. The thermal energy may be removed from the solar cell using a number of techniques. Heat may be extracted using air, water, or both. PV heating is mostly caused by solar radiation that is received but not converted into electricity, and cooling photovoltaic cells is thought to be important to maintain an acceptable level of electrical efficiency. One method of cooling the PV system involves bringing the working fluid into close contact with the system and eliminating any surplus heat that results. Due to the greater output temperature from the thermal system, this form of design forces a tradeoff between the PV cell temperature and efficiency losses. In concentrated solar PV/T systems, when irradiance on the receiver is high and operating temperatures are forced to be moderate, in the range of 30-100 0C, the performance tradeoff is even more obvious (Robert A Taylor et al, 2012). One potential answer to the problems mentioned above is the use of water as an optical filter. We made an effort to maximise the water's thickness before solar radiation hit the photovoltaic module as an optical filter. Optical filters have been used in several hybrid solar PV/T systems. The majority of optical filters are constructed from solid materials or from thin layers of materials. The camera, electronics, lights, optical sensors, etc. all require these optical filters. However, optical filters in solar PV/T systems have not received much attention. 53.85% VIS, 41.53% IR, and 4.62% UV make up the solar spectrum. The crystalline solar cell makes use of some UV, all visible light, and some IR. The solar light with the highest quantum efficiency in crystalline solar cells is between 300 nm and 1190 nm in wavelength, and it contains approximately 86% of the solar energy present in the solar spectrum. The remaining energy is converted to heat, which raises the temperature of the solar PV cell. Therefore, it is necessary to filter out sun spectrum wavelengths exceeding 1190 nm. The IR portion of the solar spectrum, which heats the solar cell, is removed using water as an optical filter for the solar spectrum. Concentrated solar energy strikes an optical filter and an infrared component, passes through water, and finally strikes the crystalline photovoltaic cell in Figure 10.

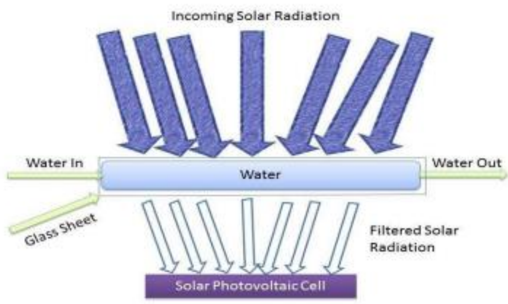


Figure.10. Working of optical filter

Since the band gap of the silicon solar cell is 1.12 eV, photons should ideally not have enough energy to transfer electrons from the valance band to the conduction band below the band gap (above the 1100 nm wavelength). Due to Si's indirect band gap semiconductor nature, there is no abrupt cut-off at 1100 nm. Since glass absorbs the majority of the light at short wavelengths below 300 nm, the quantum efficiency of a silicon solar cell under glass is virtually nil. The cell becomes close to the ideal at mid-wavelengths. The quantum efficiency returns to zero at long wavelengths (1190 nm), as seen in Figure 11.

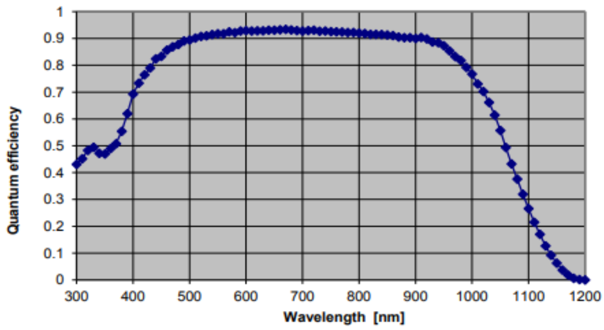


Figure.11. Quantum efficiency of Si solar cell

Incoming solar energy, as seen in Figure.10, travels through a rectangular tube of soda-lime glass that is about 3 mm thick before entering the water. Therefore, it is crucial that we take into account the transmission characteristic of soda-lime glass that is 3 mm thick. Figures 12 and 13 show the absorption coefficient and transmission of 3 mm soda-lime glass, respectively (M. Rubin and E.D. Palik, 1985). It may be deduced from Figure.14 that wavelengths less than 300 nm cannot travel through glass. Similar to this, wavelengths greater than 4600 nm do not penetrate soda-lime glass that is 3 mm thick.

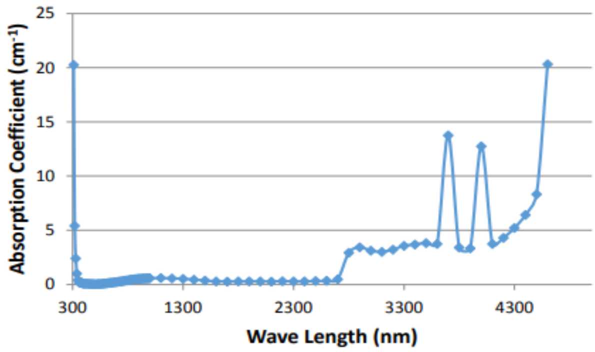


Figure.12. Absorption coefficient (cm-1) of soda-lime Glass

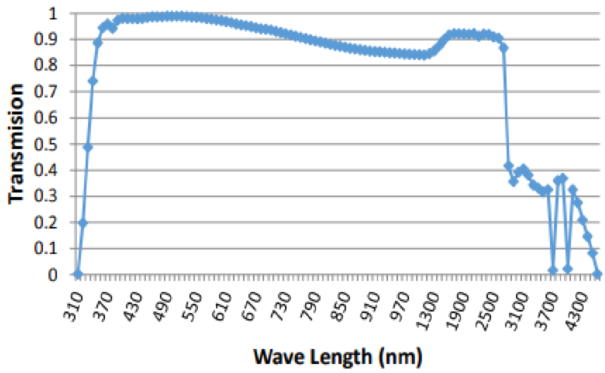
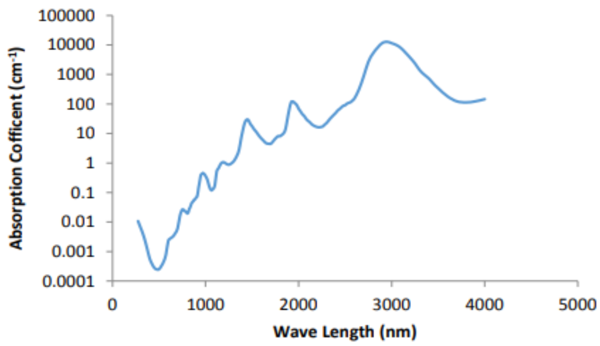


Figure.13. Transmission of soda-lime glass (3mm thickness)



Figuer.14. Water absorption coefficient

5. Results and Discussion

In this work, we have investigated the variation of the solar radiation spectrum without water filtration, with water filtration, and for different water thicknesses, namely 0.25 cm, 0.50 cm, 0.75 cm, (Gueymard C, 2004; Gueymard C et al, 2002). Figures.14 to Figures.16 show the variance of the unfiltered solar spectrum, the filtered solar spectrum for different water thicknesses from 0.25 cm to 2.00 cm, and the quantum efficiency.

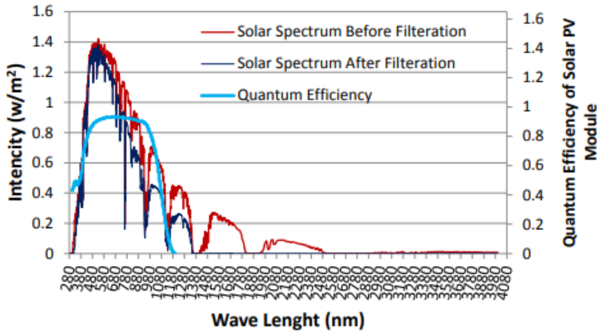
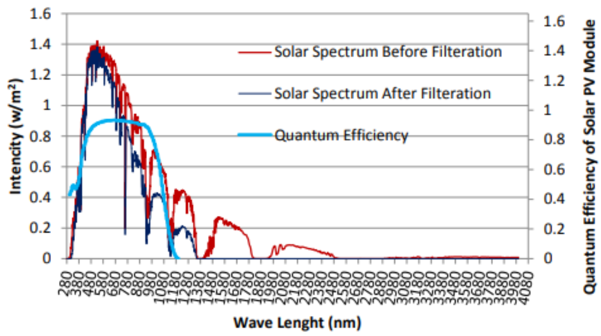
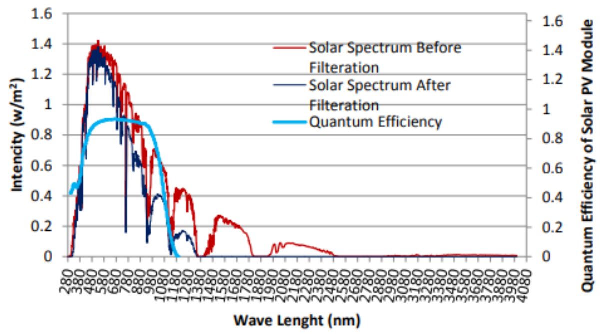


Figure.14. Comparison of solar radiation with quantum efficiency of solar PV module before filtration and after filtration at 0.25 cm water depth



Figuer.15. Comparison of solar radiation with quantum efficiency of solar PV module before filtration and after filtration at 0.50 cm water depth



Figuer.16. Comparison of solar radiation with quantum efficiency of solar PV module before filtration and after filtration at 0.75 cm water depth

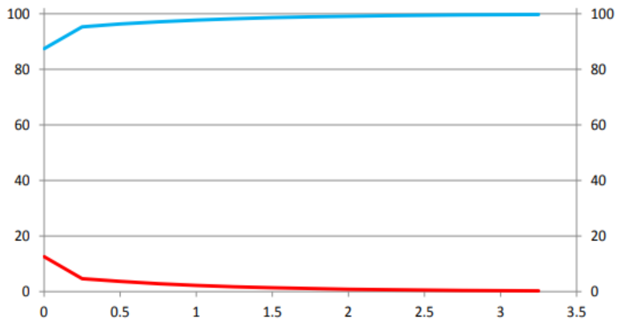


Figure.17. Percent of energy available after the filtration from the glass and water, which is available for solar photovoltaic module in the range of 300 nm and above

The aforementioned graphs clearly show that as water depth increases, solar energy on the side of infrared radiation is absorbed by the water and is thus increasingly responsible for heating the solar cell. Additionally, some of the solar light below 1190 nm is absorbed by the water. An essential factor in the filtering of IR and UV is the thickness of the water in the optical filter. Other factors taken into account include the transmissivity of the optical filter's glass, the reflectivity of the V-trough, and the tracking of the V-trough collector. The water-based optical filter comes to mind since it is a cheap material that can be utilised right away for other applications and because several studies have already been conducted for PV/T systems with various modes. Understanding how sun spectrum absorption varies with water thickness would seem to be crucial for studying this kind of system.

6. Conclusion

With the aid of the standard data, an effort has been made in this study to determine the ideal thickness of the optical filter based on the theoretical method. As this paper demonstrates, it is a good idea to use water, a cheap material, as an optical filter in PV/T systems with concentration. The experimental set-up for such a system was created with a 2.00 cm water depth. The paper include on the experimental findings. In PV/T systems, especially those with concentration, using optical filters to harness the energy of the incoming solar radiation for thermal purposes is a promising alternative that has to be further investigated and, if commercially feasible, implemented in such systems.

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