REVIEW ARTICLE

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Multi Crystalline Silicon Solar Cell based GISPVT integrated with Solar Photovoltaic Thermal Air Collector

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Abstract

The impact of increased CO2 in environment is a major factor of climate change and has cascading effects on ecosystem, human societies and agriculture. Increased CO2 levels can affect crop yield and food security. This paper aims to examine the carbon credit of a greenhouse integrated solar photovoltaic thermal (GiSPVT) system that uses Multi crystalline solar cell material with semitransparent SPVT collectors for control environment while promoting the friendly atmosphere. GiSPVT-integrated air collectors supply thermal and electrical energy, which is used to regulate the structure's humidity and temperature.

Keywords: Air collector, Solar cell, CO2, LCCE, Multi crystalline silicon.

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Introduction

The world's population may rise to about 8.5 billion in 2030, 9.7 billion in 2050, and then peak at over 10.4 billion in the 2080s, according to the most recent UN predictions [1,2]. Therefore, the annual food supply needs to sustainably balance the demands of the total population. The annual production of cereals, for example, needs to rise from 2.1 billion tonnes to above 3 billion tonnes in order to maintain pace [2]. Otherwise, this will undoubtedly lead to the world's worst economic crisis. This encourages agricultural scientists and stakeholders to look into the different obstacles that crop production faces and create plans to overcome them while utilizing the most resources and technologies possible to achieve the intended outcome [3]. Thus, the concept of sustainable agriculture is introduced. In the agriculture industry, sustainability is about finding a balance between boosting economic growth, reducing adverse environmental effects, and enhancing productivity [4]. The purpose of sustainable agriculture practices is to maximize the existing soil energy fluxes, nutrients, water cycles, beneficial soil organisms, and pest control systems. Existing procedures and flows can be used to prevent or lessen environmental harm [5]. These techniques also aim to produce food that is high in nutrients and free of impurities that could be harmful to human health. The need to replace fossil fuels has increased in response to the climate change brought on by their excessive use for thousands of years in an effort to lessen its negative impacts. Renewable energy like solar, wind ,biomass have become a new alternative.

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Due to rapid increase in population, contaminated environment and limited land area, there is a need to increase the yield from the available agricultural land to fulfill the demand as well as to protect the crop from extreme weather conditions. Thus, there is an immediate requirement to update traditional crop-growing methods and implement cutting-edge technology so that agricultural output can be increased [6]. Employing a greenhouse integrated solar photovoltaic thermal system (GiSPVT) to regulate the interior condition inside structure is one of the newer technologies and also promotes the renewable energy. The primary benefit of this method is that the crop is grown in a controlled environment and the generated solar energy may be used to install additional electrical needs like fans and lighting, turning into a self-sustaining system, which is advantageous in rural locations where grid connectivity is limited. Photovoltaic panels are installed on an inclined roof, produces the necessary thermal and electrical energy to keep the greenhouse at ideal temperature, humidity and sunlight while simultaneously screening the crops from harsh climate in order to maximize annual production. The materials used to construct the greenhouse affect its lifespan [7-9]. Different solar cell materials affect the GiSPVT's performance and electrical energy production. Selection of the material for optimal operation is extremely important considering the size, type of crop, geographical location etc. Moreover, the usage of renewable energy has proven a boon to mitigate atmosphere's rising CO2 level, which rose from 270 ppm to 415 ppm after World War II. Also increase is rapid industrialization and population density worsens this condition. Therefore, to maintain clean environment and energy conservation is crucial on a global platform. [10-14]. Few researchers reviewed the advancement made in the previous years in the field of monocrystalline, polycrystalline and thin-film PV and perovskite solar cells. Lee et. al [15] had examined the variations in the thermal environment and microclimate inside single-span greenhouses with a single sheet of glass, polycarbonate (PC), and plastic film. During the winter season, the PC covered greenhouse proved to be the most advantageous for controlling the heating impact at night. However, it was discovered that the glass-covered greenhouse worked best for controlling the cooling effect during the summer. The PC-covered greenhouse had the least change in thermal load leveling values, indicating its superiority in terms of energy conservation and environmental control. Makolli et.al. [16] has shown that increasing the proportion of renewable energy (RE) in the grid mix can affect energy performance metrics like energy payback time (EPBT). Energy performance is often demonstrated with EPBT. In addition to other energy-producing technologies, it can be used to compare the energy performance of different PV module and system configurations. Hosenuzzaman et.al. [17-19] emphasizes that the material used in PV cells is a significant parameter in the determination of electrical efficiency. The acceptability of a solar energy system depends on several criteria, such as affordability, dependability, and durability. Module installation requires less room and fewer materials as communication efficiency increases. The present paper aims to analyze the performance of multi crystalline silicon based GiSPVT system integrated with series connected air collectors by evaluating different energy matrices like EPBT, EPF and LCCE. The thermal modeling of the system is carried out using mc-Si solar cell. The total electrical energy generated by the system is evaluated to calculate the energy matrices of the system. Further, the impact of CO2 emission and mitigation on environment by using the proposed system has been calculated.

Solar Cell Materials

Earlier photovoltaic (PV) solar cells consisted of thin silicon wafers that converted sunlight directly into electrical energy. Modern photovoltaic technology operates on the principle of electron–hole pair generation within a semiconductor junction formed by two differently doped layers, namely p-type and n-type materials. Based on the materials used in their fabrication, solar cells are broadly classified into different generations. First-generation (wafer-based) solar cells represent the earliest and most widely used PV technology, primarily due to their high power conversion efficiencies. Silicon wafer–based cells are further divided into two categories: monocrystalline silicon solar cells, which are fabricated from a single crystal of silicon, and polycrystalline (or multicrystalline) silicon solar cells, which are produced from multiple silicon crystals. Second-generation solar cells are thin-film–based technologies, including amorphous silicon (a-Si) solar cells. These cells are comparatively more economical than first-generation wafer-based silicon solar cells. The classification of solar cell materials is illustrated in Fig. 1.

First Generation Solar Cell Materials (Wafer Based)

First-generation solar cells are fabricated using silicon wafers and are broadly classified into monocrystalline and multicrystalline (polycrystalline) silicon solar cells. Monocrystalline silicon solar cells are manufactured from a single crystal of silicon, whereas multicrystalline silicon solar cells are produced from multiple silicon crystals bonded together to form a single cell, as illustrated in Fig. 2. Monocrystalline silicon solar cells typically exhibit efficiencies in the range of 17–18%, while efficiencies of about 12–14% have been reported for multicrystalline silicon solar cells [11]. In the present study, a multicrystalline silicon (mc-Si) solar cell–based system is considered to evaluate the overall lifetime efficiency and the payback time of the system.

Second Generation Solar Cell Materials (Thin film solar cells)

Most thin-film solar cells, including amorphous silicon (a-Si), are categorized as second-generation solar cells. These

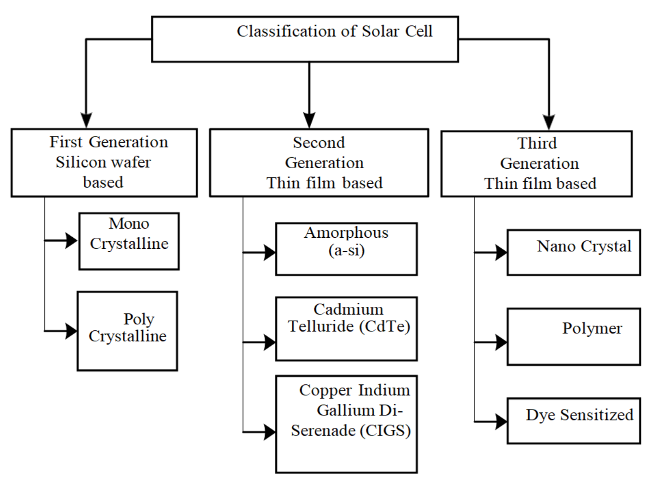

Fig. 1: Classification of Solar Cell Materials

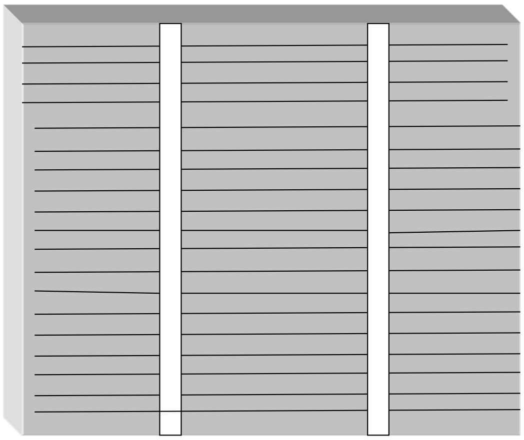

Fig. 2: Multi crystalline solar cell

technologies are more economical than first-generation silicon wafer–based solar cells and can be manufactured at relatively low processing temperatures. Thin-film solar cells typically exhibit efficiencies in the range of 4–8%.

Cadmium telluride (CdTe) solar cells are based on a direct band-gap crystalline semiconductor, which enables efficient light absorption and results in higher efficiencies compared to a-Si solar cells. A CdTe solar cell is generally fabricated by sandwiching the CdTe layer with cadmium sulfide to form a p–n junction diode, achieving efficiencies in the range of 9–11%. Compared to CdTe thin-film solar cells, copper indium gallium selenide (CIGS) solar cells demonstrate higher efficiencies, typically in the range of 10–12% [11].

Third Generation Solar Cell Materials

Nanocrystal- or quantum dot (QD)–based solar cells are composed of semiconductor materials derived from transition metal groups, synthesized in the nanocrystal size range. Typically, these nanocrystals are dispersed in a solution and subsequently deposited as a coating onto a silicon substrate. Polymer solar cells are generally flexible in nature due to the use of polymer-based substrates. Dye-sensitized solar cells (DSSCs) utilize dye molecules positioned between different electrodes to facilitate light absorption and charge transfer [11].

Working Principle Of The Proposed System

Fig. 3 gives the cross-sectional view of GiSPVT system integrated with Air Collectors. The proposed system is the combination of GiSPVT system and semi-transparent photovoltaic (SPVT) air collectors. To maximize solar insulation, an uneven-shaped greenhouse with a south-facing roof is employed. The PV modules made of multi crystalline silicon (mc-Si) are utilized. There are two different gains available at the room, first directly through the non-packing space, and second indirectly through the PV modules' backs. To minimize heat losses from the back, a semitransparent photovoltaic (SPV) module is put above a blackened absorber that is insulated from rear of the absorber. Thirty collectors

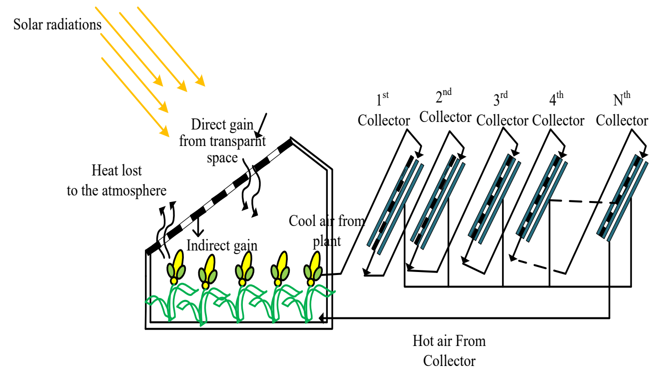

Fig. 3: Cross sectional view of GISPVT system integrated with air collectors

are linked in series in the present system. The first SPVT air collector receives ambient air through its input, which is subsequently heated and releases thermal energy from the blackened surface onto the moving air. For additional heating, the second SPVT air collector's intake is connected to the first SPVT air collector's outlet, and so on up to the nth SPVT air collector. The GiSPVT system's bottom receives the output of the nth collector. Thus, the temperature within the GiSPVT room get increased.

Analysis of Proposed System

The following formulae are derived to determine the monthly and annual variations in solar cell temperature (Tcell), room air temperature (Troom), and crop temperature (Tcrop) based on the operation of the system described above and the Hottel-Whillier-Bliss equations [14]:

$$\overline{T_{sc}} = \frac{\tau_g \beta(\alpha_c - \eta_0)\overline{I(t)} + U_{t,ca}\overline{T_a} + U_{b,cr}\overline{T_{ra}}}{U_{b,cr} + U_{t,ca}} = \frac{\tau_g \beta(\alpha_c - \eta_0)\overline{I(t)} + U_{t,ca}\overline{T_a}}{U_{b,cr} + U_{t,ca}} + \frac{U_{b,cr}}{U_{b,cr} + U_{t,ca}}\overline{T_{ra}} \quad (1)$$

$$\overline{T_{ra}} = \frac{(\alpha\tau)_{eff} A_{RS}\overline{I(t)} + \left[U_{ra1} A_{RS}\overline{T_a} + h1 A_P T_P + \sum_{i=1}^{5} A_i U_i \overline{T_a}\right]}{\left[U_{ra1} A_{RS} + h1 A_P + \sum_{i=1}^{5} A_i U_i\right]} \quad (2)$$

$$\bar{T}_f = \frac{1}{t}\int_0^t T_f\,dt = \left\{\frac{\left[\{\tau_g^2(1-\beta) + PF_2(\alpha\tau)_{eff}\} A_{RS}\overline{I(t)} + \tau_g \sum_{j=1}^{3} A_j \bar{I}_j\right]}{\left[(UA)_{wa} + \sum_{k=1}^{5} A_k U_k\right]} + \overline{T_a}\right\}\left(1 - \frac{1 - e^{-at}}{at}\right) + T_{f0} \quad (3)$$

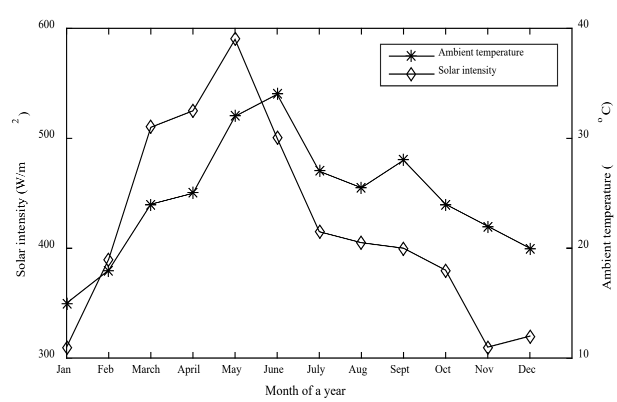

Fig. 4: Monthly average variation of solar radiation and ambient temperature of an Indian climatic condition

The monthly variation of ambient temperature ( ) and solar radiation (I (t) in W/m2) must be known in order to calculate the monthly variation of , , and . The monthly average change of ambient temperature and solar radiation (W/m2) for a composite Indian climate condition is shown in Fig. 4. Using equations (1-3), the monthly fluctuation of , , and may be obtained from the data as shown in Fig. 4. As it is clear from Fig. 4, solar intensity is low in the month of January and December.

Assessment of Energy Matrices

Energy matrices, including life cycle conversion efficiency (LCCE), energy production factor (EPF) and EPBT have been estimated to assess the performance of the system[20]. If the energy required to manufacture the system exceeds the energy the system can generate throughout its lifetime, it makes no sense. Total amount of electrical energy produced by the system is estimated. The annual electrical energy produced by the GiSPVT system and the annual electrical energy produced by semitransparent collectors are added together to get the total electrical energy produced annually.
Total electrical energy generated/year = 68722kWh

This has been estimated using data in Fig.4 and the temperatures of solar cell, room and inside air temperature.

Embodied energy of the overall system

Ein = Embodied energy of GiSPVT+ Embodied energy of mc-Si module +embodied energy of 30 SPVT collectors.

Ein = 27954.7 +(168*646) +26097.1 = 162579.8 kWh

EPBT is the ratio of total embodied energy to total annual energy of the system. It should be as low as possible. For the considered system,

$$EPBT = \frac{Ein}{Annual\ Energy} = 162579.8/68722 = 2.36 Years \quad (4)$$

EPF is ratio of annual energy times life time of the system to the embodied energy. For the considered system, total life span is 30 years. For a economical system, this value should be large (Parasaram, 2021).

$$EPF = \frac{Annual\ Exergy * life\ span}{Ein} \quad (5)$$

= 68722*30/ 162579.8 =12.6

Life cycle conversion efficiency (LCCE) is the ratio of effective energy obtained and available solar energy in the life time of system and it is defined as,

$$LCCE = \frac{Annual\ Exergy * life\ span - Ein}{Yearly\ solar\ radiation * life\ of\ the\ system} \quad (6)$$

= 68722*30- 162579.8/2.4752*168 =25.57%

CO_2 Emission and Mitigati

It is well known that 1.01 kg of CO2 emission takes place while producing 1kWh of electrical energy at a coal-based thermal power plant. Furthermore, transmission, distribution and wiring losses are 40% and 20%, respectively [21]. The CO2 emission by embodied energy at the plant is given as follows:

$$CO2\ emission/\ year = \frac{Ein}{Life\ Time} * 2.10 \quad (7)$$

=7.59Tones

CO2 emission for the whole life is estimated as=227.934Tones

Total thermal energy is the sum of thermal energy obtained by GiSPVT and thermal energy obtained by air collectors, the CO2 mitigation of system to environment can be evaluated as;

CO_2mitigation/year=$Ex_{yearly*}$2.1kWh (8)
= = 108.75 Tones
CO_2 mitigation for entire life= CO_2 mitigation/year *life time
= 3262.5Tones

The net CO2 mitigation over the life time (in tones) of the proposed system also considers the effect of carbon dioxide emission by embodied energy (Ein) and is expressed is as,
CO_2 (net tones) = ($Ex_{yearly} \times$ total life- E_{in}) $\times 2.1 \times 10^{-3}$ (tones)
=3034.2 tones

If carbon credit rate CCR = $10/ tone, then total carbon credit earned by GiSPVT-SPVT in whole life is as= CCR*CO2 net tones =10*3562.6 tones =30342$

Carbon credit earned per year=30342/30 =₹80,912

Therefore, the system is capable of saving around ₹ 81,000 and considered as economical system.

Considering the conversion rate in Indian scenario and If 1$=80 ₹ Carbon credit earned in life time = Carbon credit earned per year x × total life = ₹ 24, 27,360/-

In overall lifetime, the farmers are capable of generating crops in controlled environment but also are beneficial in saving the environment. Where the grid is not connected, the system is generating electrical energy, saving environment, aiding government initiative and even generating crop independent of outside climatic condition. Overall, this system is recommended and a boon for farmers and villagers.

Conclusion

GiSPVT system integrated with SPVT collectors has shown a potential application in the agriculture sector with a significant amount of carbon credit earned in whole life span. The GiSPVT system based on multi-crystalline silicon (mc-Si) solar cells has a 30-year lifespan and high efficiency of 25.27% and an EPBT of 2.36 years. It mitigates 3262.5 Tones of carbon in its entire life span thus reduces the carbon foot print and promotes the ecofriendly environment. Beside this it also generates the extra revenue by carbon credit it generates around ₹80,912 per year and ₹ 24,27,360 in its entire life span. It has become a boon for the farmers.

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