High Efficient Renewable Power Generation using Bi-Conical Flask Technology

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Abstract—In order to ensure the widespread use of solar photovoltaic technology for terrestrial applications, cost per unit watt must be significantly lower. This work aims to make better use of the solar spectrum than conventional single-gap cells currently do. New concepts that strive for better utilization of Sun’s spectrum, hence better cell efficiency are under development. In multi-junction solar cells, better spectrum utilization is obtained by stack several solar cells. A record efficiency of over 39% has been achieved under 236 suns light concentration. Thermoelectric generators are solid-state energy converters that combine thermal and electrical properties to convert heat into electricity. The paper proposes a solar-energy conversion package which combined PV cell, thermoelectric conversion unit, and thermal heating system together. The possibility of using the full spectrum and including the waste heat are also described. The overall efficiency of the proposed system will be much higher than the existing systems. The space required for installation will be also reduced and also almost all the spectrum will be utilized. The power output and overall efficiency is described in detail.

Keywords- Multi-junction Cells (MJC); Photovoltaic (PV); Thermo Photovoltaic (TPV).

I. INTRODUCTION

The fundamental principle of converting the 5.2 kWh of solar energy that on average falls every day on every square meter in our geographical region 1 into electrical energy is relatively simple. The need for clean, renewable energy has placed enormous attention on solar power to provide the world’s energy, despite currently supplying only 0.1% of generated electricity [1]. Two approaches of power generation aim to utilize either the sun’s thermal energy or photon energies to excite the photoelectric effect in semiconductor materials. Photovoltaic’s can provide point-of-use power eliminating large scale distribution problems and expenses. Photovoltaic cells are commonly connected into large area, rigid solar panels used to cover upward-facing rooftops.

These systems require large volumes of high-purity mono- or polycrystalline silicon and provide power conversion efficiencies well below 20%. The high material cost and low output levels elevate the cost per Watt to over $5 which is currently four to five times higher than grid-based power generation 1. Tandem and multi-junction PV cells are constructed by layering semiconductors with different absorption characteristics to convert a larger portion of the incident solar spectrum. These devices can achieve efficiencies above 40%, however are small in physical area and cost orders of magnitude more than simple silicon cells [2].

The conventional single-gap solar cell makes poor use of the solar spectrum. On the one hand, sub-bandgap photons cannot be absorbed and exploited for the PV conversion. On the other hand, the absorption of high energy photons generates electron-hole pairs whose energy excess over the gap is wasted quickly through phonon emission. The most idealized single-gap solar cell would exhibit, under fully concentrated sunlight, a limiting efficiency of 40.7%. This inefficient exploitation of the solar spectrum is one of the reasons why the PV-generated electricity is not cheap enough to compete with fuel-based, hydroelectric and nuclear energies. There are, however, a variety of economical, political, social and ecological reasons that compel to look for a new generation of Solar spectrum converters which better use the full solar spectrum and are capable of enhancing the efficiency and reducing the cost of generated electricity.

II. RELATED WORK

Hiroyuki and Akira [3] presented a typical solar thermal power generating system, which comprised a light collecting optical system, a heat storage layer, a thermoelectric conversion layer, and a heat-exchanging layer. This system is suitable for small size power generation system. Omer and Infield [4] illustrated a design procedure and thermal performance analysis of a solar combined heat and thermoelectric power cogeneration system based on a two-stage solar-energy concentrator. The results showed that efficiency was very sensitive to the collector tracking misalignment angle, and the system could tolerate misalignment angles as high as 4° without significant thermal performance decrease.

It is well known that PV cells can only convert a small portion of solar energy into electric power, and a large amount of remaining solar radiation mainly produces heat energy. Therefore, a lot of effort has been expended to combine the PV and thermoelectric technology in an efficient and powerful way.
Figure 1. Illustration of the Multijunction Solar Cell

Figure 2. Schematic representations of a PN-couple used as TEC based on the Seebeck effect.

Most of these inventions are focused on the structure design. Hunt [5] presented a simple hierarchical structure, which had at least one thermoelectric module thermally attached to the PV module and could produce electricity both from the PV cell and thermoelectric module. Hecht proposed another solar-energy conversion package which combined PV cell, thermoelectric conversion unit, and thermal heating system together. Apart from that, making full use of solar radiation can also be achieved by performing a wavelength band division of solar light [6]. This method shows that solar radiation could be divided by wavelength band dividers and the energy can be produced from these bands.

III. SPECTRAL SPLITTING

The sun is a 5760K black body radiator depositing an average of 1372 W/m² on the earth’s surface [7]. The atmosphere causes specific ultraviolet and infrared spectral nulls due to absorption and scattering from water vapor, ozone, CO₂, clouds and dust. 97.5% of the resulting spectrum exists between 380nm and 2130nm [7]. The PV material should maximize its response to this very broadband illumination. Unfortunately, the photovoltaic effect requires specific photon energies above the material band gap to generate a photocurrent. Photons greater than the band gap contain too much energy and lead to excess heat from phonons while low energy photons cannot generate electron-hole pairs. This makes PV materials truly efficient at only one specific wavelength. The solar spectrum has an irradiance peak at 885nm, corresponding to an ideal 1.4eV material band gap [8]. Silicon is the most widely-used PV material, though has a band gap of 1.12eV shifting its absorption further towards lower energy infrared photons. III-V semiconductor compounds such as gallium arsenide (GaAs) with 1.42eV band gaps are better suited for single-junction solar cells, but provide only modest efficiency gains over silicon and add significant material costs [8].

IV. SYSTEM ARCHITECTURE AND DESIGN

A. Multi-Junction Solar Cells

A multi-junction solar cell consists of a stack of single-gap solar cells as illustrated in Fig. 1. The cell on top exhibits the broadest of the gaps, while the rest of the cells are ordered by decreasing gaps. Each cell absorbs those photons whose energy ranges its own gap and that of the cell on top of it. The limiting efficiency of a stack containing an infinite number of cells is 86.6% [9], much greater than that of the single-gap cell (40.7%). Currently, high-concentration MJCs seems to be the most realistic path to a better use of the solar spectrum, increasing the efficiency and decreasing the cost of PV-generated energy. MJCs can be manufactured by using two approaches: mechanically stacked, or monolithically (internally series connected) stacked cells. The advantage of monolithic series connected cells in comparison to mechanically stacked cells is the use of only one substrate, which reduces its cost at the expenses of increasing its complexity. Just as with the goal of reducing the cost, the monolithic approach has been the one chosen here. These more complex device structures can be grown using industrial-size MOVPE (Metal-Organic Vapour Phase Epitaxy) technology.

B. Thermoelectric Converters

Thermoelectric conversion is a Seebeck effect-based technology which can directly convert thermal energy to electricity through thermoelectric elements. A typical schematic model is shown in Fig. 2. By combining one end of two different semiconductors n type and p type, putting it at high temperature, and making the other end open circuit and under low temperature conditions, an open-circuit voltage will be generated at the cold end. Thermoelectric generators (TEG) are solid-state energy converters that combine thermal, electrical, and typically, also semiconductor properties to convert heat into electricity or electrical power directly into cooling. Basically, a TEG creates voltage because charge carriers in metals and semiconductors (in the generator) are free to move much like gas molecules, while carrying charge as well as heat. When a temperature gradient is applied to a TEG, the mobile charge carriers at the hot end tend to diffuse to the cold end. The build-up of charge carriers results in a net charge at the cold end, producing voltage. The relationship can be expressed as
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\eta = \frac{T_h - T_c}{\Delta T} = \frac{\sqrt{1 + Z T} - 1}{\sqrt{1 + Z T} + T_c/T_h}
\]

where \( \eta \) is the optimum efficiency, \( T_h \) is the absolute hot-junction temperature, \( T_c \) is the absolute cold-junction temperature, \( T \) is the mean absolute temperature, \( Z \) is the figure of merit, \( S \) is the Seebeck coefficient which is used to quantitatively describe the magnitude of generated thermoelectric voltage in response to the temperature difference, \( \rho \) is the specific electrical resistivity, and \( k_T \) is the specific thermal conductivity. As can be seen, the optimum efficiency of a thermoelectric converter is thermodynamically limited by the Carnot efficiency like all heat engines. To improve thermoelectric conversion efficiency, it should not only produce a larger temperature difference between the two ends of TEG but also tune the thermoelectric materials to have a large Seebeck coefficient, a large electrical conductivity, and a small thermal conductivity within the temperature range.

C. Thermo-Solar Power using Bi-conical flask method

Solar cells of the P-N junction type are sensitive to solar radiant energy of wavelength from 5,000 Å to 12,000 Å, and transform the solar radiant energy into electric energy, which is so-called photovoltaic effect. In addition, the solar radiant energy into solar cells is converted into not only electric energy but heat energy, which induces the temperature of solar cell rise unavoidably.

The rear temperature of the solar cells was much higher than the ambient temperature. The highest rear temperatures of the solar cells obtain more than 61°C, when the solar irradiance is about 744W/m\(^2\), at the ambient temperature 34°C. In other research, the rear temperature of solar cells even can reach more than 70°C in summer stronger sunlight. The temperature rise of solar cells is undesired, because it can reduce open circuit voltage, conversion efficiency and lifetime of solar cells. Fig. 3 shows the general block diagram of the system.

The unavoidable temperature rise of the solar cells makes it to be the usable heat source for TEG. TEG will be attached to the rear of solar cells to absorb the heat energy. Once the temperature difference comes into being between the hot-side and the cold-side, the TEG will produce electricity and become the additional power source for the load.

It is well known that photovoltaic cells can only convert a small portion of solar energy into electric power, and a large amount of remaining solar radiation mainly produces heat energy. Therefore, a lot of effort has been expended to combine the PV and thermoelectric technology in an efficient and powerful way. A Seebeck solar cell device, in which the materials used to form conductors in the n-type and p-type regions of the cells were chosen for their different thermoelectric characteristics. Therefore, electric power could be produced not only from the PV cells but also from the temperature gradient in the conductors resulting from solar radiation and waste heat generated in the PV cell. Multiple devices could be connected in series or parallel so as to enhance the output power.

The paper proposes a solar-energy conversion package which combined PV cell, thermoelectric conversion unit, and thermal heating system together as shown in Fig.4. Unlike the system described previously, the thermoelectric cell and PV cell in this system were separated, and the irradiated surface of the PV cell was treated with selective spectrum reflective coating to allow high conversion PV wavelength energy to be absorbed by the PV cells, while the rest of less effective wavelength radiation would be reflected to the thermoelectric cell surface to produce electricity from heat.

The duration of a PV cell is 10 years, which may be due to the contact to the external environment and also the heat generated from it. If this two are avoided then the efficiency and life of the cell can be increased. The paper proposes one such concept where the contact of the solar cell with external environment is cut off completely and PV cell is kept in a closed environment and also the heat generated from the cell is pumped out periodically. This keeps the efficiency of the solar cell at the maximum rate possible. The system consists
of a Convex-Concave arrangement for making the solar radiation to concentrate and also to split the concentrated beam. This arrangement is made up of low cost plastic lens which has high durability and robust when compared to crystalline lens.

The solar radiation after splitting falls on the copper pipes carrying normal water. The pipes are millimeter thickness and also they are arranged in a horizontal row perpendicular to the beam. The housing is made up of glass, to ensure the maximum amount of radiation around its walls. When the radiation falls on the glass, there is reflection which makes the light to again strike on the PV cell. The Solar cell is kept at the edge of the housing and setup is kept in such a way that maximum of solar radiation can fall on the solar cell. The thermoelectric cell is kept contradictory to the solar cell and at the rear of copper pipes. These two arrangements carry the heat from the solar cell and convert them into electricity. The water pipes are interconnected, so that water can be heated to maximum amount to produce steam. The steam generated can be used to run the turbine.

In addition, a Fresnel concentrator is used on other side which collects the radiation and concentrates at a mid point. Opposite side of the flask is provided with concave for splitting the beam of solar radiation from the concentrator. The low cost plastic lens is used at both sides for the concentration and splitting of the solar radiation. The thermoelectric cells absorbs nearly maximum amount of the heat from the solar cell, so that the PV cell can stay in the active region for more time. This ensures the more amount of energy extraction from the solar cell and also guarantees the life of it. Since and which had at least one thermoelectric module thermally attached to the PV module and could produce electricity both from the PV cell and thermoelectric module.

V. RESULT AND DISCUSSION

Thermoelectric(4x4) devices (16 PN couples) have been characterized for power generation with temperature differences up to 200K while $T_c$ was maintained constant at 30°C (303K). The open circuit voltage, short circuit current, the AC resistance, and performance driving a load are measured for a given temperature difference. These devices show consistently high power output per unit area, as is expected due to the short thermoelectric element thickness, L. Efficiency is directly proportional to the temperature difference ($\Delta T$) across the module. To achieve the highest operating efficiency possible, the distance between heat source and module should be close as possible, to maximize the temperature across the module.
The system overall efficiency is shown in Fig.8, which clears that the efficiency increases with No. of Sun. The steam generated in this system is connected together and given to the turbine as pre heated water. This additionally constitutes power to the source. From Fig. 9 and Fig.10, the output across the thermoelectric and solar cell can be analyzed for a day. The output shows that power will be maximum in the day noon and it gradually rises and falls in the morning and evening.

VI. CONCLUSION

The prototype of the system shows the overall efficiency dependence on the No. of Sun. It also shows how the PV cell absorbs the radiation in their bandwidth. If multi junction cell is used, then almost all the spectrum of light falling on the cell can be utilized without releasing it. The heat generated in the PV cell is used to generate power using thermoelectric cell, which is additional power generated from waste heat. The steam generated is also used to run the turbine. It is possible for thermoelectric cell to produce power even in the night, when there is difference of temperature.

REFERENCES