Hybrid Solar Energy Harvesting System with Thermoelectric Generators

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Abstract: *A number of topics concerning solar thermoelectric (TEG) systems for heat and electric power production are presented in this introductory chapter. Starting with a historical background of people who have harnessed solar energy, this is followed by an overview of solar hot water systems (SHW). Given the fact that the focus of the present study is Combined Heat and Power (CHP), based on solar hot water (SHW) collector, photovoltaic (PV) cells and thermoelectric devices attached to SHW collectors are also discussed in this section. The aims and objectives of the present study are highlighted in this paper and, lastly, the thesis's structure is outlined. In this paper we will implement and analyze the hybrid energy generation using solar panel and TEG components. Here, heat from solar panel is given to the TEG &another side of TEG will be forced cool using water coolant. This temperature difference at both side of TEG will generate the EMF across the two terminal of TEG plate. Using this technical energy generate from TEG will be extra advantage with solar energy which will increase the system performance for energy generation. This system will also increase the energy to cost ratio effectively.*

Keywords: *Solar panel, Charging circuit, Voltage regulator, Battery, Thermoelectric generator*

INTRODUCTION

A number of topics concerning solar thermoelectric (TEG) systems for heat and electric power production are presented in this introductory chapter. Starting with a historical background of people who have harnessed solar energy, this is followed by an overview of solar hot water systems (SHW). Given the fact that the focus of the present study is Combined Heat and Power (CHP), based on solar hot water (SHW) collector, photovoltaic (PV) cells and thermoelectric devices attached to SHW collectors are also discussed in this section. The aims and objectives of the present study are highlighted in this chapter and, lastly, the thesis's structure is outlined.

Converting the energy from the Sun directly to electricity in an efficient way is of great interest. Photovoltaic devices (PV)can directly convert parts of the solar spectrum, but a significant part is absorbed as heat. In order to remedy this, a number of combined photovoltaic and heat recovery systems have been proposed recently. The most simple of these convert the heat energy directly to electrical energy using a thermoelectric generator (TEG). The latter utilizes the Seebeck effect to convert heat directly into electrical energy through the movement of charge carriers induced by a temperature span across the TEG.

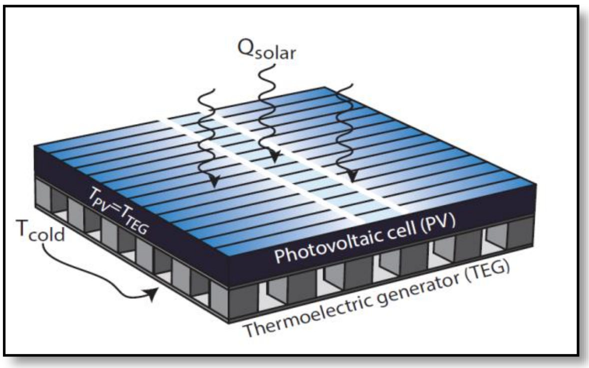

Fig.1. Basic working of hybrid solar thermo-Electric Generators

A more specific combined PV + TEG system that uses a wavelength separating device to separate the incoming solar radiation into two parts, up to 800 nm for the PV and longer wavelengths to the TEG, has also been proposed Zhang et al. [2005].An experimental realization, using a hot mirror and a near-infrared focusing lens was made by Mizoshiri et al. [2012], who observed an increase in total open circuit voltage of 1.3 % compared tothat of the PV alone. A similar system was also modeled where it was found that the TEGs contributed about 10 % of the output power in the hybrid system et al. [2012].

LITERATURE REVIEW

Benson and Jaydev et al [4] presented the idea of using thermoelectric generators in very large scale installations to produce useful amounts of electricity from low grade heat sources. One possibility was to use thermoelectric generators in an ocean Thermal Energy Conversion system. The proposed temperature difference was 5-25°C. It was shown that some commercially available thermoelectric materials have an acceptable figure of merit in this temperature range. It was assumed that performance of 20% of Carnot efficiency could be achieved from the thermoelectric devices. Other potential sources of energy that were discussed included geo-thermally heated ocean water(85°C),solar ponds(50°C),natural lake thermo-clines (10-20°C),and utility power plant waste heat(15C°C). Long term capital costs were taken into account in the discussion.

Lamley et al [5] presented an unusual application of a thermoelectric generator designed to produce power from the long wave infrared radiation leaving the surface of the earth. This project involved generation power for a high altitude, long duration communication platform. Energy would be collected by radiation from the earth's surface, and rejected by radiation into space. A thin-film thermoelectric device configuration was devised and tested. A total temperature difference of 58°C was used in the design. Benson and Tracy et al [6].Discussed the development and use of thin-film thermoelectric generators for use with low grade thermal energy applications such as those discussed in Benson and Jayadev[4]. Chen, J. [7] performed the thermodynamic analysis of a thermoelectric generator powered by direct solar radiation. Four classes of important irreversibility's were identified and their effects were included in the analysis. These irreversibility's included: Finite rate heat transfer between the device and the surroundings. Heat leaks internal to the device, Ohmic heat production, and heat losses in the solar collector. The main conclusions of the analysis established performance limits for solar powered thermoelectric devices.

A.Steinhuser et al [8].Presented extensive investigations and have shown that there is still considerable potential for optimization, particularly concerning the gas burner and the connection of the thermoelectric modules to the heat source, and given the example that the total efficiency value and, in particular, the exhaust emission of the thermoelectric converter can be improved by using a large area burner or a catalytic burner. The Proposed system can also be used as the power supply for other facilities remote from the grid, such as environmental measurement stations, aviation safety equipment and traffic guiding systems. The economics of the proposed plant has been investigated in details.

Analysis of all cost relevant parameters of the reference hybrid system shows that the thermoelectric generator size needs to be reduced as much as possible. Also the reference system has been compared with all relevant supply alternatives; PV battery system is always the cheapest solution for a small load, if site is located in tropical areas, but not in temperate zones. The fossil fuelled generators are too expensive due to their O&M costs. It is proved that the proposed hybrid system is cost competitive with pure thermoelectric generators, and the system also guarantees an higher reliability and avoids 2.4T CO2 annually. Narong Vatcharasathien et al. [9] Developed a design methodology for solar-thermoelectric power generation using TRYNSYS software which is an extremely powerful tool. The result do not show high system performance however, they demonstrate well the feasibility of this concept for power generation in Thailand. The result derived lay a foundation for further investigation of solar-thermoelectric power generation at large scale. W.G.J.H.M. Van Sark [10] Developed a model to determine the combined efficiency of photovoltaic and thermoelectric converter. The result show that adding a TE converter to the backside of a PV module can lead 8-23% increase in efficiency, depending on the type of module integration, and assuming TE material with afigure of merit value of Z=0.004K-1. The efficiency increase depends on the assumption that the backside is sufficiently cooled and is at ambient temperature. M.M.M. Daud et al[11] developed a prototype panel which utilizes solar radiation and heat from the sun to generate electricity, by using PV cells and TE modules. It is shown that the efficiency of PV thermal can be increased upto 0.79% without cooling system and 1.84% with integration of cooling system from traditional PV panel at 600w/m2 of solar radiation. Result also show that at 868 w/m2 solar radiations, the prototype panel with liquid cooling can improve efficiency up to 3%. Also with the use of high efficiency of SiGe QW or PbTe QD TE module could contribute to electricity with overall higher efficiency.

PROBLEM STATEMENT

The Solar Panel when used for electricity generation degrades its lifespan due to excess temperature which cannot be controlled The excess heat which is dissipated by the solar panel cannot be utilized thus it is wasted. The Solar Panels are exposed to excess amount of temperature due to which it starts degrading its lifespan.

The successful project work should deliver a hybrid solar panel that would be able to produce hot water and electrical power. The hybrid solar panel would have with a payback time less than 5 years. The objective of the Hybrid Solar Panel project is to integrate the thermoelectric generators (TEGs) together with hot water producing solar panels. TEG cells use the excess heat from the solar panels, that otherwise would be wasted, to produce electrical power. In this way, each household will have solar panels on the roof that make hot water for domestic use and heating. When the demand for hot water in the house is met, the TEGs in the same panels will start producing electricity using the solar heat.

RECENT DEVELOPMENTS IN THE SOLAR THERMOELECTRIC SYSTEMS

There are good effort on the research area of Solar TEG from quite long ago, even lately become more attractive especially after the recent progress in the field (Kraemer et al., 2011). For instance Chen (1996) reported a calculation technique based on thermodynamic analysis to determine the best performance of a solar-driven thermoelectric generator. While Rockendorf et al. (1999) have carried out a comparative study of the performance of a solar TEG and a solar PV, where both systems were used for combined heat and power application. It was found that the thermal and electric efficiency of the solar thermoelectric generators are approximately 45% and 3.2%, respectively, whereas that of a PV/T system reaches 10% for electricity production. Accordingly, they concluded that solar thermoelectric system will only be of interest for special applications and purposes. However, their conclusion was drawn from a special case where the geometry of thermoelectric module was fixed and the geometrical influence had been neglected. Juanicó and Rinalde (2009) present another economic comparison between PV and TEG solar panels, based on a field study examining the provision of lighting for isolated homes in rural of Argentina. They find that the panel with TEG produces electricity at a lower cost, even though both panels are similar in terms of construction cost. This difference is due to a greater flexibility of TEGs to operate with any thermal source, such as the chimney of a stove, while PV is restricted only to operation during periods with sufficient sun light. . Omer and Infield designed and produced a two-stage solar TEG system using a concentrated collector. The design has been demonstrated to provide efficient solar concentration without the need for frequent tracking adjustment. The system has been successfully employed in a small combined heat and thermoelectric power generation unit. It was found that the major heat loss from the system was due to radiation more than convection, and the overall heat loss coefficient were related to the pressure level and the tilt angle (Omer & Infield 2000). Significant efforts have been made to achieve the improved performance of rooftop solar thermoelectric systems with focuses on implementing different designs of collectors and identifying the best position / orientation for the TEG collectors. The failure to observe such an action is likely to result in unsatisfactory performance. He et al. (2012) reported an experimental solar TEG system based on a glass evacuated-tubular solar collector as shown in Figure 2.18, A TEG placed in between a hot copper plate and a water flow channel. The study concludes that the optimum power output obtained when the load resistance is larger (not equal) than TEG internal resistance, this was at the condition of constant temperature difference across a thermoelectric module, this finding is different from what previously stated, which is the maximum power output can be achieved when the TEG resistance and the load resistance are equal in value. They also reported that both the thermal and electrical efficiencies of the proposed module decrease with an increase in the cold water temperature (input water), as the electrical efficiency is decreased by 23%, and the thermal efficiency also decreased by 10% when the input water temperature was increased from 25°c to 55°C.

SCOPE OF WORK

Photovoltaic thermal hybrid solar collectors, also known as hybrid PV/T (PVT) or solar cogeneration systems are power generation technologies that convert solar radiation into usable thermal and electrical energy. Such systems combine a solar cell, which converts sunlight into electricity, with a solar thermal collector, which captures the remaining energy and removes waste heat from the PV module. These technologies can be more energy efficient overall than solar photovoltaic (PV) or solar thermal alone, like wise many problems can be identified in electricity generation via solar energy. Some of the major drawbacks are as follows:

1. The Solar Panel when used for electricity generation degrades its lifespan due to excess temperature which cannot be controlled

2. The excess heat which is dissipated by the solar panel cannot be utilized thus it is wasted.

3. The Solar Panels are exposed to excess amount of temperature due to which it starts degrading its lifespan.

Following points were observed while studying the system which can be considered as scope of work.

1. We can utilize excess amount of waste heat released by the solar panel to generate electrical energy using thermo electric generator.

2. The efficiency of Thermo electric generator can be increased by placing substance which is responsible for creating large amount of temperature difference.

3. Also the efficiency of thermo electric generator cane be tested under different conditions by using different mediums such as still water, flowing water,etc.

Hybrid solar energy with thermoelectric generator has following outcomes:

1. Excess heat liberated by solar panel can be efficiently used.

2. Lifespan of the solar panel increases

3. The system is able to harness both light as well as thermal energy.

SYSTEM DESCRIPTION AND METHODOLOGY

The work projected in this paper is the combination of two commercially available products, i.e. a traditional flat plate solar collector and thermoelectric generators (TEG) into a single unit capable of generating both hot water and electrical power.

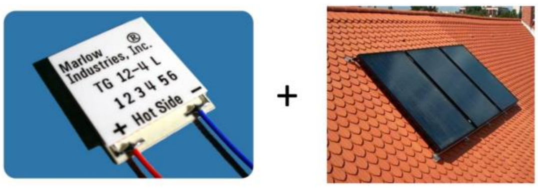

Figure 1 Thermo electric generator and solar panel

The combination of thermoelectric generators and a solar collector into a so-called hybrid solar panel. The device to the left is a thermoelectric generator and to the right, flat plate solar collectors are shown. The original objective of the project was to design, build and test a hybrid solar panel system capable of generating electrical power with releasing heat as bi-product. Using that excess heat inducing in the solar panel has to be utilized to generate electricity using Thermo Electric generator which can beneficial to save solar panel degradation due to high temperature at mid day time.

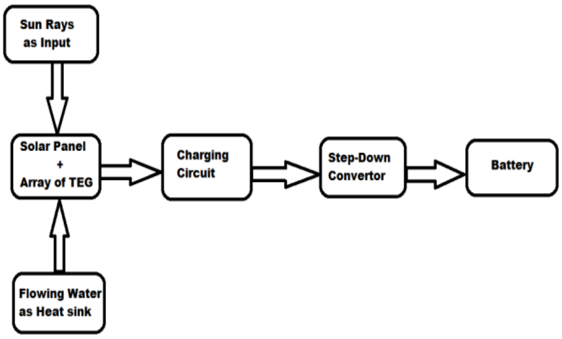

Fig.2. Block diagram of hybrid solar energy with thermo electric generators

A. Solar Panel:- The solar panel generates electrical output by converting the incident light rays from solar energy by the phenomenon of photovoltaic energy generation. It acts as one of the major power source for the hybrid energy harvesting system.

B. Thermoelectric Generators (TEG's):- These modules are placed at the rear side of the solar panel harnessing the wasted thermal energy and converting the heat energy in useful electrical output by maintaining a proper temperature gradient across its surfaces. The continuous flowing water or the still water is employed as a heat sink for sustaining the temperature difference as required for generation of electrical output.

C. Charging Circuit-: The charging circuit consists of a voltage regulator, which helps in maintaining suitable electrical charge. The potentiometer employed helps to prevent the back flow of the current from battery to solar panel and array of TEG's.

D. Voltage Regulator: - The voltage regulator is employed in the circuit in order to maintain a constant +12 volt supply to the battery.

E. Battery:- The +12 volt lead acid rechargeable battery is used for storing the electric charge as it has low current discharge capability, which is further used to drive the load.

A solar TEG system is to be designed and constructed as shown in Figure 2. The system consists of a light source and a plate (as solar absorber). The TEG is positioned between the heat absorber and the heat exchanger, which were immersed in a water container. In order to ensure high absorption rate of light, the top surface of a solar absorber was painted with black high temperature paint (pnm type). A channel was made on the reverse of the absorber used to measure the temperature of the absorber, which is also the hot side temperature (Th) of the TEG.

The TEG's cold side temperature (Tc). The heat exchanger was submerged in a water container to improve the heat transfer between heat exchanger and water and to ensure the temperature of the water is uniform in the container. Although a solar simulator can be used which provides the best match to solar spectrum, it has very limited irradiation area and limited operation period.

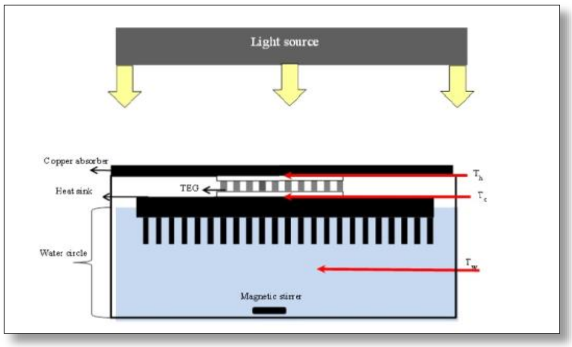

Fig.3. Schematic diagram of experiment setup

DESCRIPTION OF EXPERIMENTS

The solar radiations are made to fall on the solar panel which generates electrical output by process of photovoltaic generation. The array of TEG's is employed at the rear side of the solar panel to absorb the wasted thermal energy and also preventing in the rise of the temperature of the solar panel, which results in its fall in the efficiency. The still water or the continuous flowing running water has been employed as a suitable heat sink for maintaining temperature gradient across its surfaces. The harnessed voltage from the proposed hybrid energy system is fed to the charging circuit which is used along with the voltage regulator has been used for the constant supply of +12 volts to the battery.

In this proposed work, the EH system is simultaneously harvesting both solar energy as well as thermal energy, making it suitable to be termed as a hybrid system. The solar radiations from the sun are made to be incident on the solar panel, harnessing these light radiations and converting them into electrical output by the phenomenon of photovoltaic energy generation. But in this whole process, the panel gets heated up with these radiations and results in the reduction in its efficiency. The thermoelectric generators employed absorb the heat generated at the back side of the solar panel and is able to generate electrical output if suitable temperature gradient is maintained across the surfaces. These thermal radiations which acts as a heat source, falls on the hot surface of the thermo-electric module so as to raise the temperature of hot surface, whereas the another surface of the thermo-electric module, which is placed on the polyurethane foam, gets cooled down by the continuously flowing water as well as by the convective flow of air through the pores.

This results in the generation of an electrical output due to the phenomenon of Seebeck effect. The side view of a single thermo-electric module is shown in the fig.

CONCLUSION

The hybrid energy harvesting system employing thermoelectric generators integrated with solar panel. The designed system is able to utilize both light as well as thermal energy. The thermoelectric generators are employed at the rear side of the solar panel so as to protect the solar panel from getting heated up and at the same time gracefully utilizing the wasted thermal energy. The proposed system can be designed, implemented and experimentally tested for the results. The hybrid energy harvesting system can be employed in dams for keeping check on water levels and generation of electricity for faraway areas. The proposed energy harvesting system is able to harness an electrical output which is effective enough to charge a 12 Volt rechargeable battery.

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