International Journal of Research in Engineering, Science and Management
Volume-2, Issue-8, August-2019
www.ijresm.com | ISSN (Online): 2581-5792

Design and Performance Investigation of Hybrid Solar Photovoltaic Thermoelectric System

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***Abstract*: The performance of the solar cell is strongly depends on it's operating temperature. The high operating temperature of the solar cell causes the thermal agitation and in turns the loss of free carriers in the crystalline PV modules. The electrical conversion efficiency and the power output of the solar cell decreases with an increase in the working temperature. Exhaustive work based on the performance improvement of PV modules using various cooling methods is reported in many literatures so far. In the present work, an experimental work to harvest the heat from solar PV module and to use it in the thermo-electric converter is described. In the designed system, the series connected solar cells are mounted on an aluminum base and Bi-Te thermoelectric modules are attached to the dark side of the base. The aluminum base creates the hot junction for the thermo-electric (TE) modules and the cold junction is achieved by circulating water. The temperature of PV cell reduces as the heat is transferred from the PV module to the circulating water via TE modules. This also creates the temperature difference across the junctions of the thermo-electric modules to generate additional electrical output. In this study, the performance of solar photovoltaic cells, PV – TE hybrid system is studied. The net efficiency of the system was found to be around 23%. The constructional details and the performance analysis are presented in this article.**

***Keywords*: Peltier Plate, Power output, Solar Energy, TEG Unit**

1. 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). Additionally, the harnessing of solar energy, taking Libya as an example of an oil depending country, is briefly discussed. 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.

A. Statistics and benefits of solar energy

Since ancient times through to the industrial revolution and the space age, solar energy has been exploited as a source of useful energy (Walker, 2012). For millennia humans have harnessed solar energy by capturing light and heat from the sun's rays. The ability to do so was first discovered when people used magnifying glasses, around the 7th century BC, to make fire and burn ants (US Department of Energy, 2013). Later, in the 3rd century BC, the Greeks and Romans used mirrors to concentrate the sun's rays and create light torches (Ngô & Natowitz, 2009). It was rumoured that during the Romans' siege of Syracuse in 211 B.C., Archimedes set fire to the Roman's wooden ships by focusing sunlight on them, using shields made of bronze as mirrors (Ngô & Natowitz, 2009). This achievement may only be a myth, but there are various reports of solar energy being used to heat homes, bath houses, and public buildings (US Department of Energy, 2013). In the 1830s, the world's first solar collector was built by a Swiss scientist for cooking food (Boinpally, 2010). Into the latter half of the 19th century and the 20th century, more ways of harnessing solar energy were discovered, devolved and implemented (see US Department of Energy, 2013, for further details). The amount of solar radiation impinging on the earth is measured at 1.368 kW/m² (Al-Karaghouli, 2007), which indicates that the total solar energy reaching the surface of the earth is 173,000 terawatt (TW) (Goldenberg & Johansson, 2004; Abbasi & Abbasi, 2010). Furthermore, solar thermal energy is also reported to be the most abundant source of all the renewable sources of energy. It is available in both direct and indirect forms, and the energy emitted by the sun is about 3.8x1023 kW while the energy received by the earth is around 1.08x1014 kW (Thirugnanasambandam et. al., 2010). This seemingly unlimited energy from sunlight, in the form of heat and light, can be harnessed by using various different technologies. Examples include solar for water heating and for electrical power production, or as a combination of both technologies. However, despite the enormous amount of solar energy the earth receives, it's still a fairly unexplored subject. This is because the power generated by traditional sources, such as coal, oil and natural gas, is easily accessible. These common methods represent approximately 80% of the world's current energy consumption (Kumara et al., 2010). Cost challenges are also a factor.

2. Literature Review

Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World, Swapnil Dubey, Jatin Narotam, Sarvaiya Bharath Seshadri, Solar cell performance decreases with increasing temperature, fundamentally owing to increased internal carrier recombination rates, caused by increased carrier concentrations. The operating temperature plays a key role in the photovoltaic conversion process. Both the electrical efficiency and the power output of a photovoltaic (PV) module depend linearly on the operating temperature. The various correlations proposed in the literature represent simplified working equations which can be apply to PV modules or PV arrays mounted on free-standing frames, PV-Thermal collectors, and building integrated photovoltaic arrays, respectively. The electrical performance is primarily influenced by the material of PV used. Numerous correlations for cell temperature which have appeared in the literature involve basic environmental variables and numerical parameters which are material or system dependent. In this paper, a brief discussion is presented regarding the operating temperature of one-sun commercial grade silicon- based solar cells/modules and its effect upon the electrical performance of photovoltaic installations. Generally, the performance ratio decreases with latitude because of temperature. However, regions with high altitude have higher performance ratios due to low temperature, like, southern Andes, Himalaya region, and Antarctica. PV modules with less sensitivity to temperature are preferable for the high temperature regions and more responsive to temperature will be more effective in the low temperature regions [1]. The geographical distribution of photovoltaic energy potential considering the effect of irradiation and ambient temperature on PV system performance is considered.

On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations E. Skoplaki, J. A. Palyvos, A brief discussion is presented regarding the operating temperature of one-sun commercial grade silicon-based solar cells/modules and its effect upon the electrical performance of photovoltaic installations. Suitable tabulations are given for most of the known algebraic forms which express the temperature dependence of solar electrical efficiency and, equivalently, solar power. Finally, the thermal aspects of the major power/energy rating methods are briefly discussed [2].

Performance analyses of combined heating and photovoltaic power systems for residences, Martin Wolf, The performance of a combined solar photovoltaic and heating system for a single family residence has been analyzed over a full year, using hourly U.S. Weather Bureau data for insolation and environmental temperature for Boston, 1963. The collector analyzed is a flat plate thermal collector with heat transfer to the load via a liquid loop. The collector contains in lieu of the usual absorber surface a silicon solar array. The analysis has been carried out by use of existing detailed programs for hourly computation of the building heat load, of solar heating system performance, and of solar photovoltaic system performance. The optical properties of the photovoltaic array were used for the absorber plate in the thermal collector performance evaluation, and the available energy input to the absorber was reduced by 10% to account for the electrical energy taken out, as a first order approximation. The thus obtained hourly absorber temperatures were used in the computation of photovoltaic array performance. The hourly electrical load has been synthesized. The analysis has shown the combination system to be a viable approach. It will require a means for temperature control while heat energy is available in excess of load and is being dumped into the environment. Several system design parameters were varied for a sensitivity analysis.

On heat rejection from terrestrial solar cell arrays with sunlight concentration, Florschuetz L. W., Simple model for preliminary assessment of cooling system requirements for heat rejection from solar cells subjected to concentrated solar irradiation levels is presented, based on an effective thermal conductance concept. Several basic passive and active cooling schemes are analyzed, and representative effective thermal conductance values determined. Results show that passive cooling to ambient air with extended surfaces can accommodate irradiation levels achievable with practical linear or trough type concentrators, but performance will depend on adequate local wind characteristics [3]. Once through forced cooling with ambient air is not a viable alternative. For irradiation levels typical of paraboloid concentrators, appropriate types of water cooling should be adequate.

Combined photovoltaic and thermal hybrid collector systems, Kern E. C., Russell M. C., A program for the development of hybrid solar energy collectors which convert solar radiation into a balance of low-grade thermal energy and direct-current electricity, is discussed. The program entails development and performance testing of hybrid collectors, performance modelling, a retrofit experiment with separate thermal and photovoltaic collectors, and economic analysis. The performance of five hybrid heating and cooling systems has been modelled for office building and residential applications in Phoenix, Arizona, Miami, Florida, Boston, Massachusetts, and Fort Worth, Texas. The systems considered include a baseline solar heating system, a parallel heat pump system, a series heat pump system, an absorption-cycle chiller, and a high-performance series advanced heat pump. A cost analysis has also been carried out to identify systems with optimum economics [4]. Results show that greatest potential energy savings in all four geographical regions are offered by an advanced heat pump system. Various researcher’s engine [4].

3. Problem definition and solution

A. *Problem Definition*

The electrical conversion efficiency and the power output of the solar cell decreases with an increase in the working temperature. Exhaustive work based on the performance improvement of PV modules using various cooling methods is reported in many literatures so far.

B. Objectives

1. Design and construct a basic measurement through which to investigate the heat absorbed by the system. (This would determine the absorber's efficiency, through application of heat to the absorber alone).
2. Study & analyze combine effect of hybrid PV & TEG module.
3. To design & investigate an effective hybrid solar photovoltaic thermoelectric system .

We have decided to complete the project in simple waterfall model

Communication Phase

Communication phase includes:

- Discussion of topic with guide
- Actual farm visit and understanding various method
- Literature survey
- Problem identification
- Analysis of problem
- Concept development
- Discussing various certainties and uncertainties

Planning Phase

Planning phase includes:

- Process planning
- Raw material planning
- Force analysis
- Process scheduling

Construction and Testing

Construction phase includes:

- Selection of proper manufacturing methods
- Working as per process scheduling and plan
- Testing of equipment on field
- Error analysis
- Repair if any

Deployment

- Comparing the project with the designed output
- Preparation of testing results
- Preparation of project report
- Final submission of project

4. Proposed Setup and experimental procedure

The principal objective was to check the performance of PV system using attached TE modules. Series connected thirty poly C-Si solar cells of size 52mm × 30 mm × 400µm were used as PV module. All the solar cells were mounted on the Aluminum plate. Eight thermoelectric modules of Bismuth Telluride of size 40mm × 40mm were thermally connected to the bottom of the aluminum plate. To extract more heat from the cold junction of the thermoelectric modules, specially designed aluminum heat sinks are attached. The top side of the PV cells was covered with the glass material. The cold junctions of the TE modules were achieved by immersing the attached heat sinks in a water flowing channel. The block diagram of the whole assembly is shown in fig.

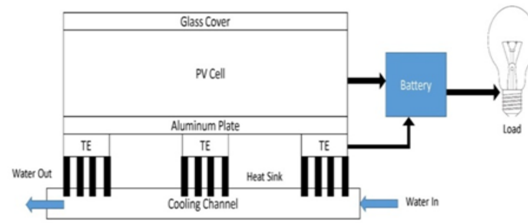

Fig. 1. Working Principle of PV TE Model

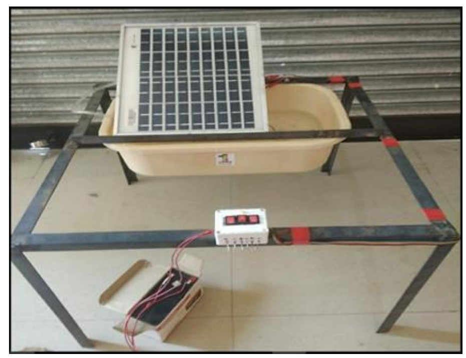

Fig. 2. Experimental set up for combine PV TEG setup

A 10W, solar panel and a 4cm×4cm bismuth telluride based thermoelectric generator is analyzed separately with solar radiation. The solar panel is combined with 4cm×4cm thermoelectric generator and analyzed experimentally. The hot and cold junction temperatures were measured with temperature gun and the corresponding voltage and current were measured with a multi meter with a load resistance of 3.3 Ω and the power is calculated. A 10W, 12V, 0.83A, solar panel is analyzed with solar radiation with a load of 3.3Ω. The corresponding voltage and current were measured in Solar panel with a multi meter and the power is calculated.

A. Experimental analysis of TEG

Bismuth Telluride based thermoelectric generator of area 4 X 4 cm^2 with 127 thermocouples connected in series along with heat dissipater at the cold side is fixed on a stand. The terminals of the cold side are connected to multi meter and 3.3Ω load. The hot and cold junction temperatures were measured with temperature gun and the corresponding voltage and current were measured with a multi meter and the power is calculated.

B. Experimental analysis of solar panel with TEG

A 10W, solar panel and a 4cm×4cm bismuth telluride based thermoelectric generator is analyzed with solar heat. The hot and cold junction temperatures were measured with temperature gun and the corresponding voltage and current were measured with a multi meter and the power is calculated.

Optimization of thermo leg length is done for maximizing the

International Journal of Research in Engineering, Science and Management
Volume-2, Issue-8, August-2019
www.ijresm.com | ISSN (Online): 2581-5792

power output. As the temperature gradient increases, the voltage and current also increases thus increasing the power output. The power output from the combination of PV panel and TEG is more compared to that of PV panel alone. The performance of a 4cm×4cm bismuth telluride based thermoelectric generator is analyzed with solar heat and an average power of 0.0552 W is obtained. A 10W, solar panel is analyzed with solar heat and the average power output is 8w. When the solar panel is combined with 4cm×4cm thermoelectric generator experimentally the average power obtained is 17 W. Performance is improved by cooling the cold side of 4cm×4cm thermoelectric generator with pump cooing system and an average power of 7W is obtained experimentally. When the entire area of the solar panel is combined with thermoelectric generator, the estimated power of 18 W can be obtained. Similarly, when the entire area of the solar panel is combined with cooled thermoelectric generator and estimated power output of 10.772 W can be obtained. The heat dissipated at the cold side of the TEG can be harvested by placing phase change material (PCM) at the cold side of TEG.

C. Observation Table

Table 1
Overall output gained from PV TEG module

		PV Cell		TEG Module		
Sr no.	Time	Voltage	Power Output (Watts)	Voltage	Power Output (Watts)	Total Output
1	09:00 – 10:00	11.7	9.711	9.1	7.553	17.264
2	10:00 – 11:00	11.7	9.711	9	7.47	17.181
3	11:00 – 12:00	11.9	8.877	9.1	7.553	16.43
4	12:00 – 13:00	12.2	10.126	9	7.47	17.596
5	13:00 – 14:00	12	9.96	9.2	7.636	17.596
6	14:00 – 15:00	12.3	10.209	9.2	7.636	17.845
7	15:00 – 16:00	12	9.96	9	7.47	17.43
8	16:00 – 17:00	11.8	9.794	9	7.47	17.264
9	17:00 – 18:00	11.8	9.794	8.8	7.304	17.098

Observations:

Our Required o/p to run an application is 15-17 Watts, for that given system is designed from which, 60-70 % of Input is collected from Photovoltaic system and remaining is utilized from TEG system to avoid heat losses and to bring an effective system.

Required output is fulfilled from combine PV TEG system as per observed data analysis.

D. Experimental results

The experimental results are shown in the following graph.

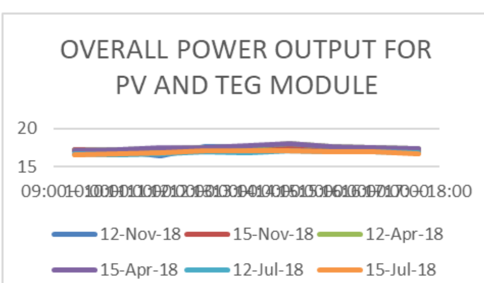

Fig. 3. Overall power output for PV & TEG Module

Above graph shows overall power generated by combine PV-TEG module which directly compares the effectiveness of combine PV-TEG modules.

E. Discussion

The combined performance of a solar photovoltaic (PV) and thermoelectric generator (TEG) system have been examined for different weather conditions & time as represented by graphs.

The degradation of PV performance with temperature was shown to be much faster than the increase in power produced by the TEG, due to the low efficiency of the TEG.

The net efficiency of the system may found to be around 23% based on year round readings.

After certain studies, we may conclude that thermal efficiency of the system will increase (for combined system) by utilizing heat losses caused due to PV system alone.

5. Conclusion

The main objective of the work embodied in the thesis was to design, construct and investigate the feasibility and performance of a PV/TEG hybrid system. This objective has been achieved through systematic experimental investigation on the temperature coefficients of all available solar cells, development of theoretical model (and experimental validation) for design and optimization of TEG geometry, and creation of a unique PV/TEG hybrid system The major achievements are summarized as follows:

A 10W, solar panel is analyzed with solar heat and the average power output is 8W. When the solar panel is combined with 4cm×4cm thermoelectric generator experimentally the average power obtained is 17 W. Performance is improved by cooling the cold side of 4cm×4cm thermoelectric generator with pump cooing system and an average power of 7W is obtained experimentally. When the entire area of the solar panel is combined with thermoelectric generator, the estimated power of 18 W can be obtained. Similarly, when the entire area of the solar panel is combined with cooled thermoelectric generator and estimated power output of 10.772 W can be obtained. The heat dissipated at the cold side of the TEG can be harvested by placing phase change material (PCM) at the cold side of TEG.

1. The combined performance of a solar photovoltaic (PV) and thermoelectric generator (TEG) system have been examined for different weather conditions & time as represented by graphs.
2. The degradation of PV performance with temperature was shown to be much faster than the increase in power produced by the TEG, due to the low efficiency of the TEG.
3. The net efficiency of the system may found to be around 23% based on year round readings.
4. After certain studies, we may conclude that thermal efficiency of the system will increase (for combined system) by utilizing heat losses caused due to PV system alone.

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