Development of a Hybrid Solar and Waste Heat Thermal Energy Harvesting System

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Received: 14 December 2022 | Revised: 10 January 2023 | Accepted: 15 January 2023

 DOI: https://doi.org/10.48084/etasr.5561

ABSTRACT

This research aims to develop a Hybrid Solar and Waste Heat Thermal Energy Harvesting System that integrates Thermoelectric Generator (TEG) with a solar PV system. The main focus is given to the development of the hybrid solar and waste heat released from the solar panel by using the TEG system. This hybrid system consists of photovoltaic (PV) cells to absorb the solar energy and the TEG attached to the back of the panel to absorb heat waste and convert it into usable electricity. The PV cell and the TEG are integrated with each other in order to obtain maximum energy and increased system efficiency. The experimental results show that the maximum output voltage produced from the solar PV is 20.37V and the maximum output current generated is 203.72mA. The maximum output voltage obtained from the TEG is 18.92V and the maximum current produced is 189.265mA. This experimental result shows that the maximum voltage and current produced from solar and waste thermal heat from PV panels can be used to charge and to power up portable electronic devices. More efficiency is accomplished by combining the TEG to absorb waste heat loss from the PV cell, thus improving the performance of the PV panel system.

Keywords-solar and waste heat thermal energy harvesting system; thermoelectric generator (TEG); photovoltaic (PV) cell; solar, thermal

I. INTRODUCTION

Energy harvesting is the process by which the energy produced from other sources is derived, collected, and sometimes stored in banks or batteries for future use. Solar energy nowadays is very popular for its promising power production. However, even though its capability in producing a large amount of power is undeniable, the temperature of the panel gradually increases from time to time due to continuous hit by the solar irradiation [1]. While the solar panel is harvesting energy, the high temperature on the surface of the panel leads in performance de-escalation. Many recent research projects have been conducted in renewable energy focused on increasing the chances to harvest, store, and distribute the solar energy [2]. There are several ways and types of new implementations of solar power that continue to increase as the price of harvesting solar power is reduced. The heat produced during the operation of the electrical equipment will usually be wasted and released to the environment [3]. By an energy harvesting system, a certain amount of heat can be utilized and recycled to convert the energy from the waste heat into electrical energy [4]. The thermoelectric generator (TEG) has been proposed to be intergraded with photovoltaic cell (PV) in a hybrid system [5]. The purpose of this system is to analyze the output and develop a suitable design that improves energy harvesting. TEG devices are widely used in studies of thermal energy development [6]. TEG was designed by applying the concept of Seebeck effect which was described back in 1820

[7]. Thomas Seebeck, who came with the theory, stated that thermal energy could be harvested into direct electrical energy achieved across the thermal difference between two dissimilar metals [8]. TEG is a temperature-dependent device, where bigger thermal gradients possess higher capability to generate electricity [9]. To achieve the desired electrical output, the temperature gradient between the hot and cold sides of the TEG are maintained by heat from PV cells and the cooling part from the flowing coolant in the heat sink [10]. This system is a hybrid system between photovoltaic (PV) and thermoelectric generator (PV/TEG) [11]. When the solar panel is exposed to the sun, it will convert heat into electricity while thermal losses are produced [12]. As the temperature is getting higher, solar efficiency drops by 0.5% per degree. The purpose of applying TEGs is to absorb the excess heat from the panel in conjunction with generating direct electricity [13]. The PV panel gets a source of energy from the solar radiation and the TEG from the backside of the PV panel which is very hot due to heat loss [14]. The heat delivered from the bottom part of the PV module to the hot side of the TEG module can be utilized in the TEG module to produce electricity directly [15]. The Seebeck effect concept defines that, when there is a difference in temperature from each side of the module, electrical energy can be produced. The basic TEG unit consists of p-type and n-type semiconductor elements which are connected electrically in series and thermally in parallel [16].

II. RESEARCH METHODOLOGY

There are several methods for harvesting solar energy such as PV cells, solar thermal, combined systems, thermoelectric devices, and the recent integrated hybrid systems of PV cells and TEG. This research considers developing and designing a Hybrid Solar and Waste Heat Thermal Energy Harvesting System that integrates TEG with PV cells. PV sells convert sunlight directly into electricity. When sunlight hits a cell, the energy knocks electrons free of their atoms, allowing them to flow through the material. The block diagram of the Hybrid Solar and Waste Heat Thermal Energy Harvesting System shown in Figure 1 is the basic model that defines the structure and operation of the system.

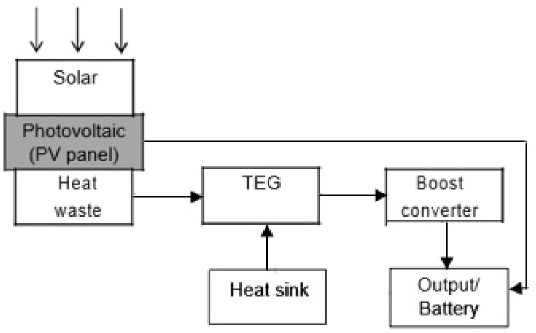

Fig. 1. Block diagram of the Hybrid Solar and Waste Heat Thermal Energy Harvesting System that integrates TEG with solar PV cells.

A. System Architecture

The system architecture flow consists of the main system components and the system development and implementation as shown in Figure 2. The system begins with the PV panel that generates electric power by converting the incident light rays from the sun into a flow of electrons [17]. In this system, the direct current electricity produced by solar cells will be used to supply current in an electrical appliance or to recharge a battery [18]. The hot side of the TEG will be placed directly under the PV panel and the cold parts will be directly placed on the heat sink [19]. The bottom part of the TEG is attached with the liquid cooler radiator to create temperature gradient between the hot and cold sides of the TEG [20]. The TEG is connected to the boost converter to increase the output voltage to its optimum value [21]. It is then connected to a USB port charging by a direct current DC USB connector. The PV cell is connected to solar charge control and directly charges the 12V battery. The output can be delivered using a socket that is installed in the control panel. The hybrid PV/TEG system can be used to charge and to power up a notebook, laptop, or any other portable electronic device [22].

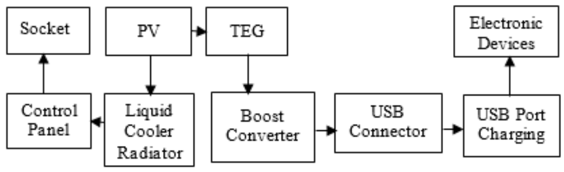

Fig. 2. Detailed architecture flow of the Hybrid Solar and Waste Heat Thermal Energy Harvesting System.

B. Design and Development

The design concept in this research involved a PV panel, a cooling system, and a solar control panel. The framework is designed to place the solar panel on top with an angle of 15°. The framework has 90cm height and the top and base dimensions are 60cm×40cm. The solar panel is placed on top of the framework and the TEG is placed under the solar panel along with the cooling system to provide temperature difference between the hot and the cold sides. The size of the TEG used is 4cm×4cm. There are 3 TEGs used in this research with the same specifications. The control panel is designed to place the circuit breaker, socket outlet, inverter, terminal block, USB port charging, solar charge controller, and 12V battery. A rechargeable 12V lead-acid battery is used as a power supply which is also recharged by the PV panel. The circuit breaker is used to protect the electrical circuit from any damage caused by excess current from an overload or short circuit. The terminal block is used to connect all the wires. There are 10 terminal blocks used in this study. The solar charge controller is used to supply voltage from the PV panel to the rechargeable lead-acid battery and prevent from overcharges.

Figure 3 shows the block diagram of the Hybrid Solar and Waste Heat Thermal Energy Harvesting System. The PV cells' output is directly connected to the solar charge controller to recharge the battery. It will directly be connected to the inverter to convert the direct current to alternating current so that it can be used at the socket outlet to supply power for any electrical appliance. The resulting DC (direct current) electricity is then sent to a power inverter for conversion to AC (alternating current). Figure 4 shows the hardware implementation of the

Hybrid Solar and Waste Heat Thermal Energy Harvesting System. Three TEGs connected in series are attached under the PV cells to get the thermal heat and to generate electricity. That heat would be otherwise dissipated [23]. The TEGs are attached by using thermal grease to avoid the presence of any air gaps and to obtain maximum heat transfer [24]. A copper plate is also attached with TEG to increase the heat transfer from the liquid cooler pump. The output from TEG is directly connected to the boost converter to step up the output voltage and is finally connected to the USB charging port. The type of boost converter used is XL6009 (Figures 5-6).

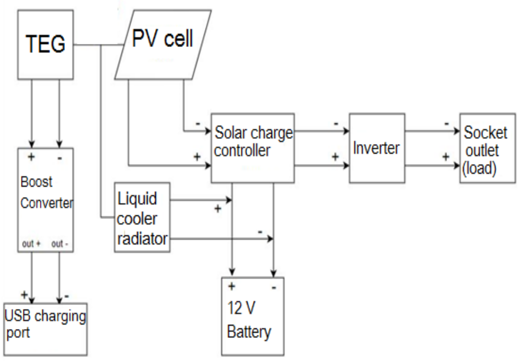

Fig. 3. The overall Hybrid Solar and Waste Heat Thermal Energy Harvesting System.

Fig. 4. Hardware implementation of the system.

The Hybrid Solar and Waste Heat Thermal Energy Harvesting System is designed to achieve the minimum input voltage from 5V to an optimum output voltage up to 25V which is suitable for the application of small electrical appliances. The liquid cooler radiator which is placed under the solar panel is used to reduce the temperature of the cold side of the TEG and increase the gradient temperature between the hot and cold sides to maximize the output [22]. The design of the liquid cooler radiator consists of a pump, two pipes, and a radiator. Table I shows all the parts and pieces of equipment used in this research.

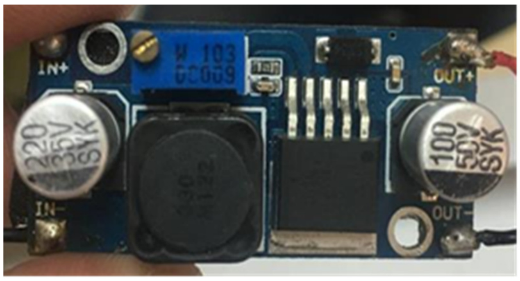

Fig. 5. XL6009 boost converter.

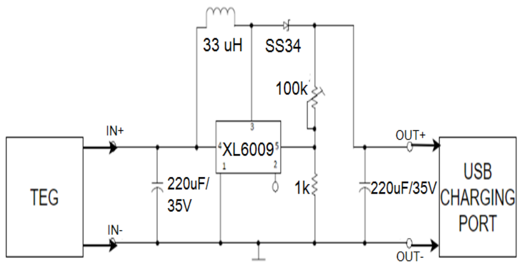

Fig. 6. XL6009 module circuit diagram.

TABLE I. SYSTEM COMPONENTS

No.	Component
1	Photovoltaic cells (50W)
2	Thermoelectric generator (TEG)
3	Liquid cooler radiator
4	Boost converter
5	Cooler fan
6	Copper plate
7	Control panel
8	Battery 12V
9	Inverter
10	Terminal block
11	Solar charge controller
12	Circuit breaker
13	Socket outlet
14	USB charging port

III. RESULTS AND DISCUSSION

Figure 7 shows the data collection during experimentation. It shows that the solar panel is capable of generating higher output voltage compared to the TEGs [26]. The output voltage from the TEGs only depends on the temperature of the solar panel to generate electricity. As the solar panel gained higher temperature at 12.05 pm, the voltage of the TEGs increased drastically. At 12.55 pm, the graph shows a decrease in solar voltage but the TEGs were still generating high voltage. This event occurred as the temperature of the solar panel had exceeded the limits and performance degradation took place. The constant line for both TEG and solar panel Voltages in Figure 7 is due to the integration of voltage during this time interval as the TEG voltage is integrated with the solar panel voltage. The full line on the graph shows that this system was able to increase the TEG's voltage generation by using 3 TEGs connected in series, a voltage booster, and a cooling pump for higher thermal gradient across the TEGs.

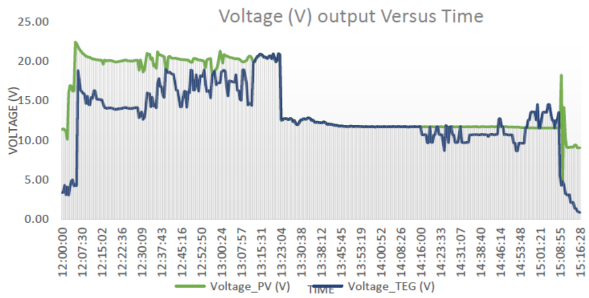

Fig. 7. The output voltage of TEGs and PV panel.

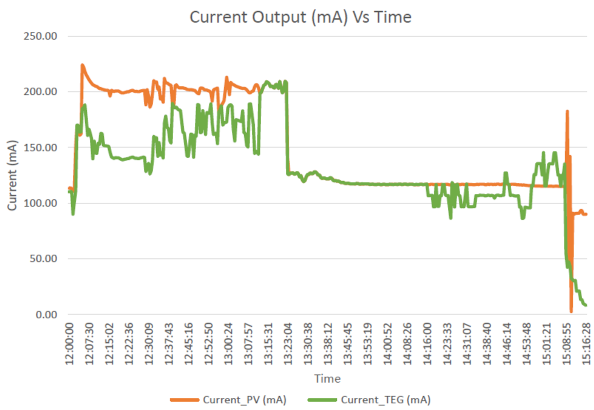

Fig. 8. The output current of TEGs and PV panel.

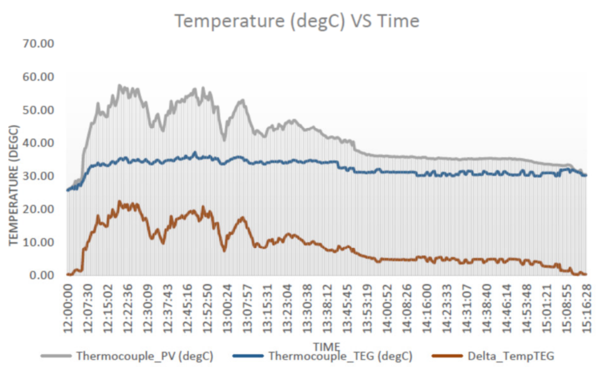

Fig. 9. Temperature of TEGs and solar panel.

Figure 8 shows a similar pattern with Figure 7 as the current increased when the output voltage increased. As expected, the panels generate higher output than TEGs. The constant line shows TEG and panel having similar output current. This happened as the surface temperature of the solar panel increased contributing to the TEGs' efficiency. The highest achieved voltage from the PV cells was 20.37V with current 203.72mA. The highest temperature recorded was 56.43°C as shown in Figure 9 and the power generated is 4.15W. From these data, it can be concluded that the expected output voltage from PV cells of 20V is achieved.

Figures 7-8 show that the highest voltage from 3 TEGs in series is 18.92V and the current is 189.27mA. The highest optimum temperature is 37.29°C and the output power generated is 3.58W. The highest gradient temperature between the cold and hot side of TEGs is 20.87°C. From these data, it can be concluded that the voltage from TEGs is expected to get 12V and the project target output voltage is finally achieved. The gradient temperature between the cold and the hot side of the TEGs shows a very good result, increasing voltage and current output.

IV. CONCLUSION

A Hybrid Solar and Waste Heat Thermal Energy Harvesting System is produced in this study by integrating the thermoelectric devices into PV systems. The overall performance of the hybrid energy harvesting system and the efficiency of the thermal management in the PV solar panel have been improved. The integration of TEGs with the PV panel, utilizing the waste heat, generated greater output voltage from the harvesting system [27, 28]. The thermoelectric cooler is used to remove the waste heat from the PV and increase the temperature difference between the hot and the cold side of the TEGs [29]. The main objective of this research has been achieved and the expected output voltage was produced. The highest recorded voltage from the PV cells is 20.37V and the highest voltage produced from 3 TEGs in series is 18.92V. The contribution of this research is the creation of another renewable energy harvesting system while maintaining the quality and performance of the output voltage and power at low cost.

ACKNOWLEDGMENT

This research was conducted at the Universiti Kuala Lumpur – Malaysia France Institute (UniKL-MFI) laboratory. The authors acknowledge the financial support from UniKL-MFI and the provision of the laboratory and the required equipment.

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