Peltier Module-Based Water Generation and Waste Heat Management System

Trisha Patra, Samik Basu and Soma Barman (Mandal)

Abstract Human civilization, from the very beginning of its existence, has relied on natural resources. With time, the resources are depleting and energy generation from such resources is reaching toward crisis period. In order to cope up with such situation, an alternative technology needs to be discovered that can utilize waste energy and generate energy in useable form. This paper is addressing such problems and presenting an alternate technology of Peltier effect as a solution to energy scarcity. In the proposed system the cold side of the Peltier module generates water from the moist air. Additionally, waste heat from the hot side of the module is utilized by our system to generate low-power regulated voltage using thermistor sensor. This regulated voltage is used to control the speed of 3 V motor to run a fan. The Peltier module directly converts waste heat energy into electrical energy without utilizing natural resources and without harming environment. Hence, this system is to be considered as a green system.

Keywords Peltier module · Peltier effect · Condensation · Waste heat energy · Thermistor · Voltage generation · Green system

1 Introduction

Day by day the human civilization is attaining new heights. With the growth in population, demand for resources is also growing. The main problem occurs when enough resources are not available to meet the needs of increasing demands. As a result, fuel price is increasing which leads to further discomfort for people. In recent

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years, green and renewable energies have found utmost importance in technological fields. Renewable resources are the need of the hour, resulting in pollution-free and cost-friendly alternatives. In countries like India, reusing the waste resources, like heat and water, can help to overcome the water shortage issues in dry areas and also solve the electricity problems. Peltier modules are very popular for green technologies [1] because of its small and lightweight structure and immovable parts. These modules are based on the principle of Peltier effect.

With the increase in demand for renewable sources of energy, Peltier modules are gaining importance. Many noticeable works have been done in the recent past utilizing the Peltier effect. Due to its cooling capacity, the modules are utilized in building eco-friendly refrigerator [2]. Allwin Jose et al. proposed an air conditioner based on Peltier module [3]. Utilizing both the hot and cold sides of the module, portable food warmer and cooler were proposed by Pavan Attavane et al. [4]. Since the module can perform Seebeck effect also, works on generating electricity from heat and maintaining a temperature difference has been done by Prisilla A. J. Stecanella et al. [5, 6]. Sagar Venkateshwar Nemani et al. proposed a system based on generating electrical energy from exhaust gases of automobiles [7]. The cold side has been used for experimental investigations on generating portable freshwater by Joshi et al. [8]. The figure of merit, thermal conductivity, and electrical conductivity of Bi_2Te_3 and $CoSb_3$ based modules has been compared as a function of temperature by Andreas Larsson et al. [9, 10]. Kumar G. B. Arjun et al. proposed a Peltier module-based refrigerator powered by solar panel [11, 12].

Since Peltier module shows its potentiality in renewable energy generation, the authors in this paper proposed a green system using Peltier module. The module functions in twofold. First, the cold side of the module is used for water generation from atmospheric moisture. Second, the waste heat from the hot side of the module is used for voltage generation. The water generated from the cold side can further be processed for household and laboratory purposes. The collected water can further be used to measure atmospheric pollutants. The hot face of the module generates regulated power supply of the range 3.2–6.25 V using thermistor sensor with some electronic circuit arrangement. The regulated voltage is tested to control the speed of a 3 V motor along with a fan. It can also be used to run low-power devices, for example, Arduino, MSP430, and electronics vehicles.

The paper consists of five sections. In Sect. 2, the system architecture of the system is briefly explained. The experimental setup and methodology is presented in Sect. 3. In Sect. 4, the discussion is presented based on the results obtained. Finally, in Sect. 5, the paper is concluded along with future scope.

2 System Architecture

The general block diagram of the proposed system is given in Fig. 1. The system is divided into two main units—water generation unit and power generation unit.

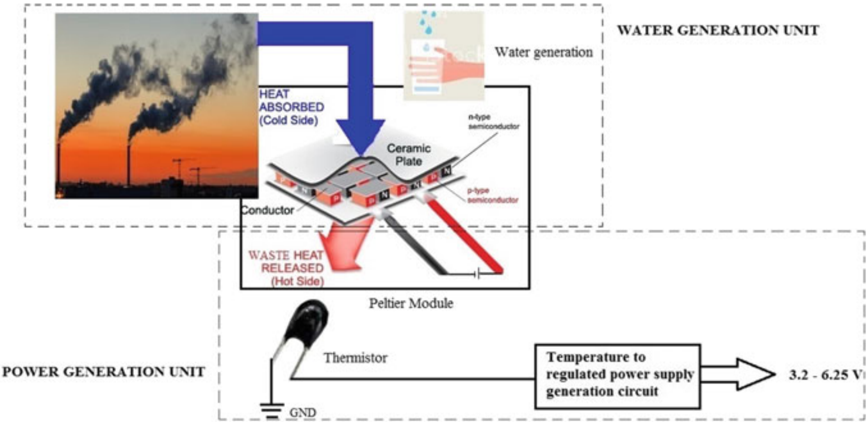

Fig. 1 General block diagram of the proposed system

2.1 Water Generation Unit

Peltier module. A Peltier module is a collection of array of Bismuth Telluride p- and n-type semiconductor cubes, sandwiched between two ceramic plates. The semiconductors are electrically connected in series and thermally connected in parallel. A pair of p- and n-type semiconductor cubes is called a couple. A thermocouple produces low voltage and high current. Thus, in order to obtain a significantly high voltage, a number of thermocouples are connected.

The module works on the basic principle of Peltier effect, which states that when current is made to flow at the junction of two dissimilar semiconductors, one junction gain heat (cold side), and the junction releases heat(hot side) [13]. The Peltier coefficient, π_{AB}, between two conductors, A and B, is equal to the ratio of the rate Q of heating or cooling at each junction to the electric current I, is represented in the following form:

$$\pi_{AB} = Q/I. \tag{1}$$

The basic reason being jumping of electron to higher energy state (when current flows from p- to n-side), it gain energy and makes the surface cold. In the next cycle (n- to p-side), the electron jumps to lower energy level and releases energy, hence, making the surface hot. Figure 2 shows the current and heat flow between the couples of a module. The hot and cold sides are interchangeable based on the polarities of supply voltage [14]. In this system, TEC1-12706 module has been used. It consists of 127 couples and provides maximum temperature difference of 66 °C at 25 °C [15]. The main advantages of using Peltier module, in addition to being eco-friendly, are no moving parts, no noise, no vibration, compact, and no Freon refrigerants.

Atmospheric air. When the atmospheric air comes in contact with the cold side of the Peltier module, due to condensation the moisture in the air settles down on the

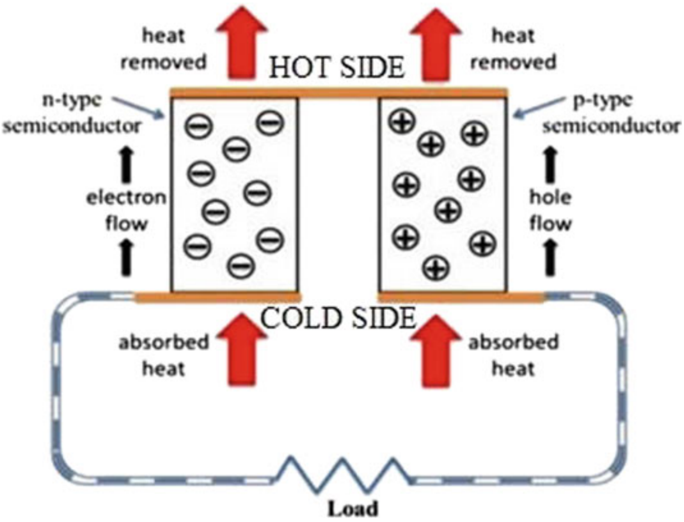

Fig. 2 Schematic of current and heat flow

cold surface. As a result, water droplets are formed. These water droplets are collected and can be utilized for various fields like laboratory purposes. The collected water can be a good source to quantify the atmospheric pollution level. The amount of water condensed on the module depends on the amount of moisture in the area. So, if the system is installed in coastal areas, the amount of water derived will be maximum.

2.2 Power Generation Unit

Thermistor sensor. The hot side of the Peltier module is kept in contact with an NTC thermistor sensor, which is thereby connected to a temperature to voltage converter circuit. The main function of the thermistor is to utilize the waste heat from the hot side of the module. It senses the heat and reduces the resistance to the circuit and a regulated voltage is obtained. After neglecting the self-heating of the thermistor, its resistance at temperature T K is related to its resistance at temperature T_0 K by the relation of the form

$$R_T = R_{T_0} e^{\mathrm{B}(1/T - 1/T_0)}, \tag{2}$$

where B is the material constant of thermistor.

3 Experimental Setup and Methodology

Experimental setup of our proposed system is shown in Fig. 3. The Peltier module is connected to a 9 V battery. As soon as the setup is connected, the module instantly shows the temperature difference, i.e., one face becomes hot and the opposite face becomes cold. The Peltier module is connected to an external heat sink with fan on the cold face. This increases the surface area for cooling operation and also increases the rate of condensation. As the moist air comes in contact with the cold side, the air starts cooling and its temperature reaches to the dew point and condensation begins. Due to gravity, the water droplets start flowing downward in the container.

For the second part of the system, the waste heat from hot face of the module is sensed by thermistor sensor and converted into voltage by temperature to voltage converter circuit shown in Fig. 4 [16]. The converter circuit consists of opamp and zener diode for maintaining regulated voltage at the output. The thermistor is basically a negative temperature coefficient (NTC) type thermistor of 10 KΩ rating. As the name suggests, it shows a negative slope in temperature versus resistance plot. With increasing temperature, the resistance of the thermistor decreases, as a result of which, the output voltage from the opamp increases [17]. However due to the opamp, the voltage is regulated after the temperature increases. The output voltage is measured across output pin of opamp and ground. It is measured using multimeter. The output-regulated voltage is used to regulate the speed of motor to run a fan.

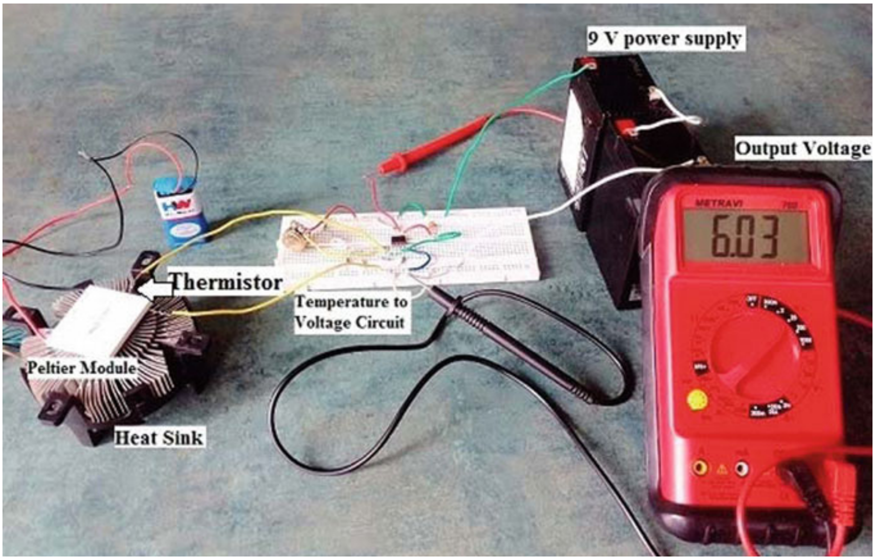

Fig. 3 Experimental setup of the proposed system

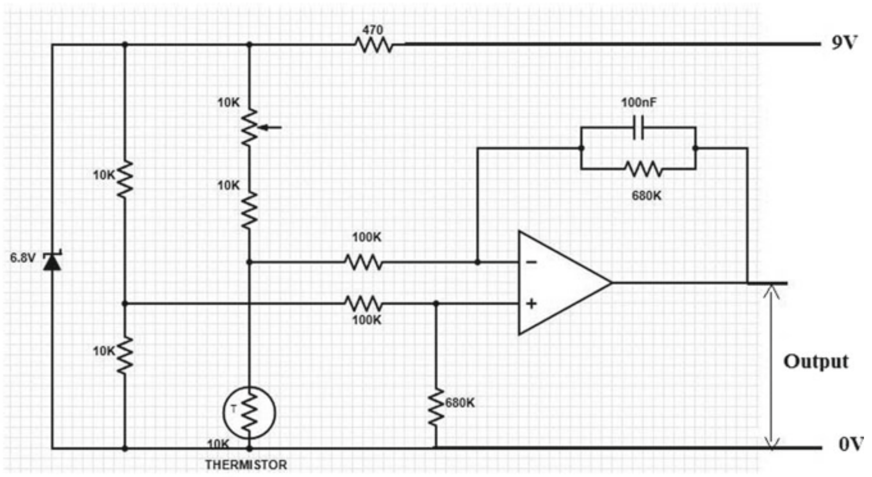

Fig. 4 Temperature to voltage converter circuit

4 Results and Discussion

After connecting Peltier module to a 6 V battery, the temperature difference on both faces of the module is instantly observed. The change in temperature values of both sides is very rapid and changes in few seconds. The cold side temperature goes as low as 21.1 °C and the hot side temperature goes up to 39.38 °C. The module's efficiency as a heating system is more prominent than as a cooling system. This leads to a slight increase in temperature on cold side. This happens because of the heat conduction from hot side through the modules. In Fig. 5, the graph shows the variation of temperature of two faces of the Peltier module with time.

The cold side of the module, when comes in contact with atmospheric moisture, undergoes condensation and water droplets are formed. The rate of condensation is directly proportional to the humidity in the air [5]. The experiment was performed in the month of November and the humidity was 50%. As a result, the rate of condensation is a bit low. Figure 6 shows graphical representation of collected water with time. The amount of water collected at the end of 143 min is 0.5 ml. The quantity increases with time.

The hot side of the module, when it comes in contact with the thermistor sensor connected in electronic circuitry, produces a regulated voltage [18, 19]. The thermistor is NTC type, which results in decrease in its resistance with increase in temperature. As a result, the output voltage through opamp increases. Figure 7 shows variation of resistance with temperature. It clearly shows the decrease in resistance and increase in temperature. The variation of voltage at the output of opamp with increase in temperature is shown in Fig. 8. With the decrease in resistance, voltage is increasing.

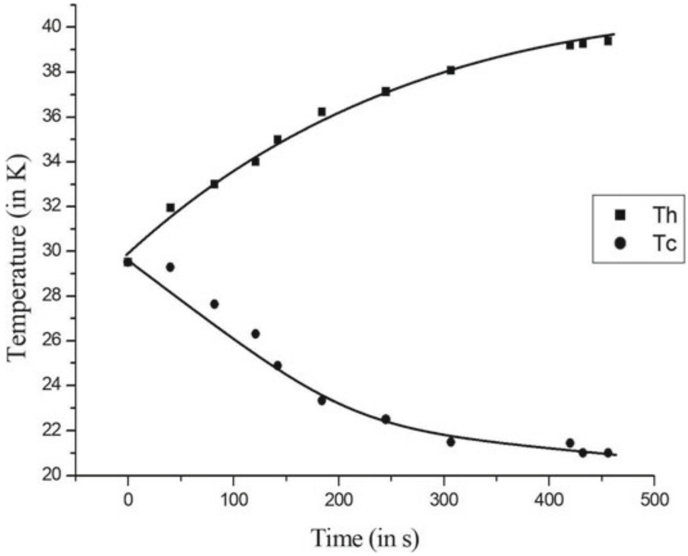

Fig. 5 Variation of the temperature of two sides of Peltier module with time, where *Th* and *Tc* are hot side temperature and cold side temperature, respectively

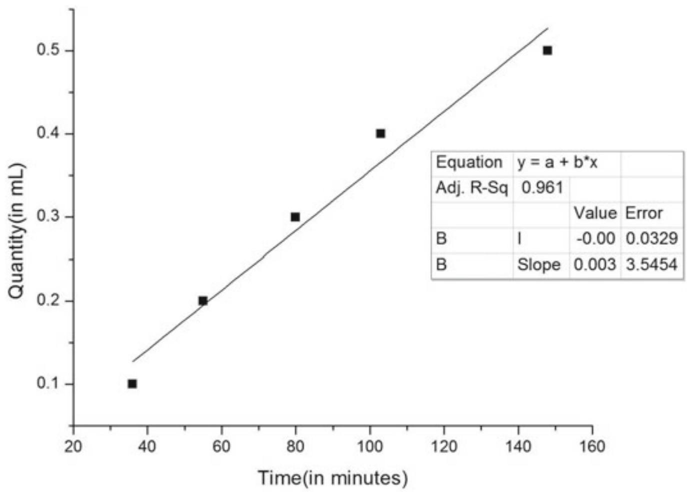

Fig. 6 Experimental result: amount of water collected versus time plot

This output voltage, is thereby, utilized to control speed of 3 V motor and a fan, as shown in Fig. 9. The fan runs for approximately 8 min and the speed of the motor is controlled using 10 KΩ potentiometer. This voltage can also be used to run other low-power devices, for example, Arduino and MSP430.

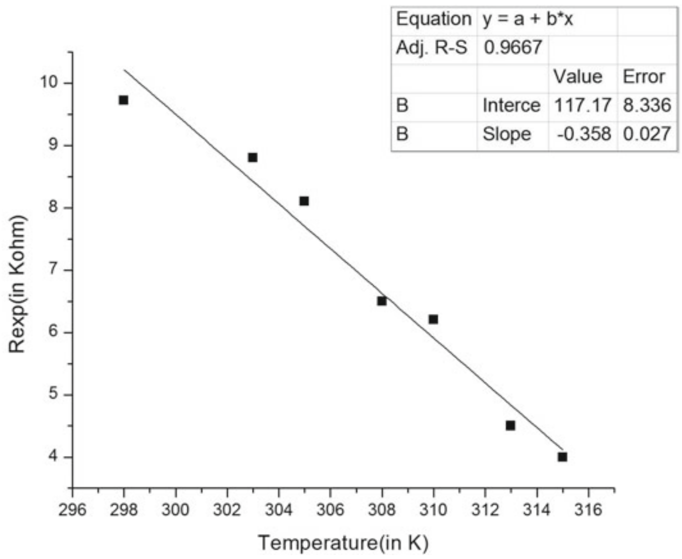

Fig. 7 Variation of resistance with temperature

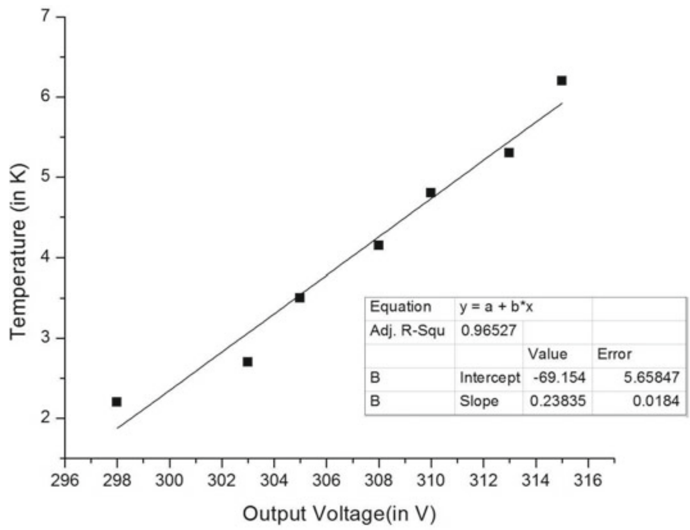

Fig. 8 Variation of output voltage with temperature

5 Conclusion and Future Work

The proposed system is an energy conservation system that generates water and also utilizes waste heat from hot side of the Peltier module for voltage generation [20].

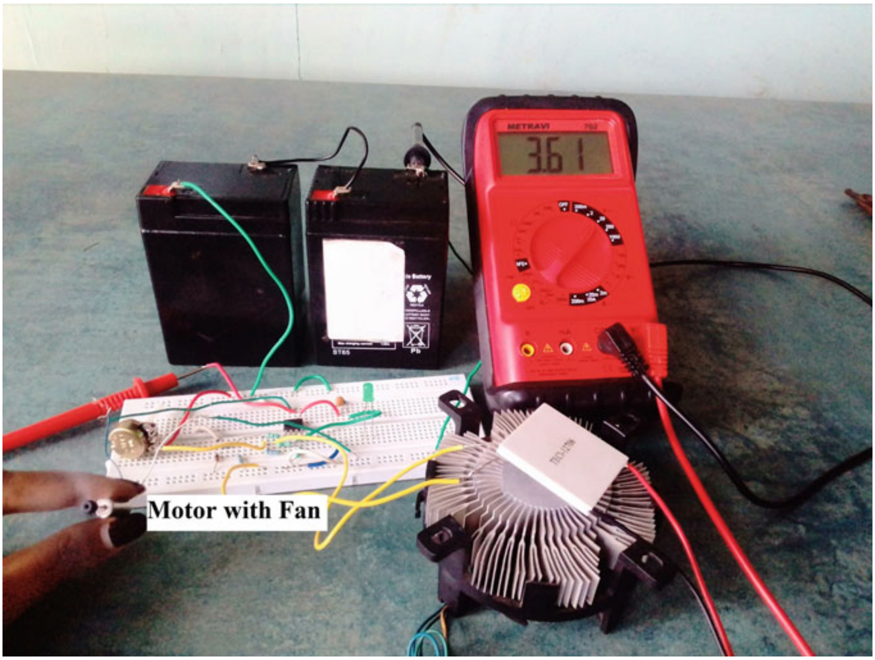

Fig. 9 The running motor with fan utilizing regulated output voltage

The temperature to voltage converter circuit is powered through two 6 V batteries collectively providing 9 V supply. The system will be potential for sufficient quantity of water generation if it is installed in high humidity areas like coastal regions. This water, on further processing, can be made consumable and for other commercial uses. The water droplets which are generated from moist air also be used to measure atmospheric pollution contents. The chemicals dissolved in the air can be tested using these water droplets.

The regulated voltage is tested here to run a motor and fan with variable speed. It can be used for operating low-power systems. This voltage can further be utilized to power the Peltier module itself. The system can also be powered using solar panels, making it a greener and more eco-friendly option.

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