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Design and Development of Solar Umbrella Based on Peltier Effect

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Abstract—The manuscript proposes socio-commercial heat pumping system from interior to exterior and vice-versa based on the principle of Peltier effect. In this manuscript, an improved topology is proposed to power the thermoelectric devices using solar cells to produce a cooling effect to the user. The same is prototyped in the form of an umbrella that could provide ventilation as well as cooling to the end-user. The solar power is actively tracked using a maximum power point tracking circuit and Peltier plates are employed as the heat exchanging devices. Depending on the direction of the current flow in the thermoelectric circuit, the umbrella can pump heat from the interior to the exterior or vice-versa. The developed design also provides and tests a suitable method to maximize the cooling power while effectively discharging the generated heat, without any use of chemical batteries.

Keywords—solar, thermoelectric, photo-voltaic, Peltier plate, Peltier effect, maximum power point tracking circuit

I. INTRODUCTION

As common person's aspirations and awareness grow, freedom from constraint and ease are bound to play key roles in day-day to life. With the innovations and increase in use of new technologies in particular body sensor networks, medical devices, and other wearable sensors are more pervasive in the near future. Replacing or recharging batteries for these devices can be inconvenient or costly. Therefore, substituting for the chemical batteries, in the present manuscript, the authors have focused on energy harvesting from ambient sources to provide a promising solution. One of the alternatives to these problems may be a call for renewable energy resources. This gives an opportunity to harness the abundant solar, wind and other alternative green technologies in extracting the power.

The solar and other renewable sources of energy can be used to solve many of the practical problems. One such type of problem is patrolling at remote border areas during scorching sunny days of summer. Despite the advancements in technology that have led to solutions such as air conditioners, room heaters etc. to aid the thermal comfort of people, they pose a problem of mobility. Creating a comfortable thermal environment for the user within an enclosed space of small proximity while providing comfort, practicality and mobility is the main objective.

The technological advancements in the refrigeration has provided the solutions to keep the people thermally comfortable such as air conditioning and heating units. They have come a long way and have been successful in helping

people obtain comfort in their dwellings (e.g. home or car), but are not personal mobility solutions. What if one has to be out in the weather? The addition or subtraction of layers with coats and jackets, are popular solutions to such problems, but do not always yield utmost satisfaction, the layers become cold over time and sunburn is a serious problem [1]. This provides the authors to look into the problem and yield the solution, which can dissipate cooled air when the weather is hot or sunny and vice-versa. In the current market, many products like coats [2] and gloves that provide the cooling from the exterior weather are available but they are not feasible and cost effective. To provide a socio-commercial solution authors of the manuscript have taken a step to look into a viable solution that can be commonly used during rainy and sunny seasons.

In the present manuscript, authors have attempted to prototype a heating/cooling umbrella, which can be a very beneficial product for the masses. Such an umbrella allows the user to control as well as monitor the internal temperature of the umbrella from high temperatures to low temperatures, depending on the season. The manuscript also presents the discussion with respect to an umbrella that would be effective in regulating the temperature around the user's body. With an ambient temperature of about 27°C and the user's body temperature of about 37°C, this umbrella is expected to cool down the ambient temperature to about 23.5°C within 10 minutes in addition to providing ventilation and shade to the user. The range of potential applications for these kind of product in difficult condition includes the steel/chemical industries, fire brigades, armed forces, mining, forestry emergency services as well as for private sector use in sports and fitness pursuits.

The proposed umbrella actively cools the ambience of the user whereas other products of a similar kind in the market just furnish the user with airflow without any cooling impact. This umbrella would be especially helpful for people in tropical countries like India with high variations in temperature and abundant sunlight cover.

Featuring quiet operation, the ultrathin thermoelectric cooler module which is used in the proposed umbrella is more affordable and provides needful solutions to the people making the system less complex, with very less power consumption, small in size, and weight. The authors have prototyped the system using commercially available Peltier plates. The measured experimental results indicate that the system can produce air at 15.16°C in an ambient of 27°C.

The manuscript is arranged as follows. Section II describes the methodology using a block diagram. Section III describes the proposed design and its implementation. Section IV discusses the experimental results obtained from the designed prototype. Section V concludes the manuscript.

II. METHODOLOGY

As the primary objective of the work is to design and implement a solar-powered temperature-regulating umbrella, which has the capacity to derive electrical energy from the solar irradiation falling on the canopy, using an array of flexible photovoltaic cells placed on top. It is important to ensure that no energy storage elements like batteries are incorporated in the design, since that may have added to the bulk and mass of the prototype. The harnessed solar energy from the PV cells will be processed through a Maximum Power Point Tracking [3] system based DC-DC converter, followed by a voltage conditioning circuit, which acts as the source for the thermoelectric devices.

The block diagram of the topology is shown in Fig.1 consists of majorly three blocks: Solar Photovoltaic cell module, Power conditioning circuit, and the thermoelectric plate. Each of these blocks is described in the subsequent sections of the manuscript. Photovoltaic cells are the basic unit of the system where photovoltaic effect is used to produce electricity from light energy. Here, they are employed to power up the internal circuitry of the umbrella and is an input source of energy to the battery [4].

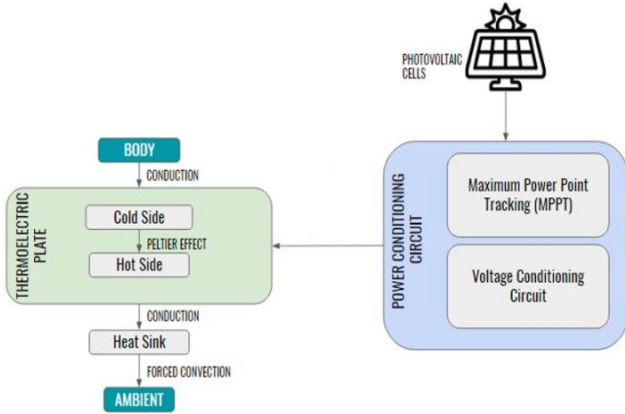


Fig.1. Block Diagram

A. Power Conditioning Circuit

Power conditioning circuit is an interface between the solar PV module and thermoelectric plates. It consists of two parts one is the DC-DC Converter with maximum power point tracking (MPPT) control and other is Voltage Conditioning Unit (VCU) control. The fluctuating DC power from the solar module is passed through the DC-DC converter to provide a constant DC voltage without any ripples. The required PWM pulse to drive the converter is provided from the microcontroller unit followed by a gate driving circuitry. The PWM pulse to switch is generated from the microcontroller is by tracking the maximum current and voltage i.e., maximum power from the PV modules using a maximum power tracking control topology based on perturb and observe (P&O) [3]. This is implemented to adjust the impedance seen by the solar array to keep the PV system operating at or close to, the peak power point of the PV Panel

under varying conditions. The block diagram for the same is presented in Fig.2, which shows the flow of current from the solar plates to the load and the voltage conditioning circuit provides or adjusts the power required to the Peltier or thermoelectric plates based on the external and internal temperature and needs to be adjusted by the user.

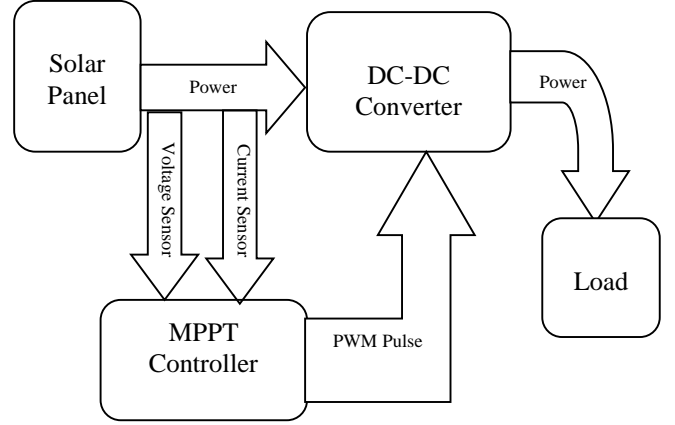


Fig 2. MPPT based DC-DC converter block diagram

B. Thermoelectric Plate

A typical thermoelectric module consists of a P and N type semiconductor material. Where the electrons move from P-type to N-type material through an electrical connector. These electrons jump to a higher energy state by absorbing thermal energy i.e., N-type to P-type. Hence, dropping to a lower energy state or releasing energy as heat to the heat sink simultaneously decreases the temperature on the other side [5]. This is based on the Peltier effect. It can be analysed as given below.

The volumetric flow rate (V) of the fan was obtained from the manufacturers specifications. The time contact of the air with the thermoelectric surface is then given by:

$$t = (L \times A) \div V \quad (1)$$

Where,

L = Length of the Thermoelectric Zone, and

A = area of cross-section of the plate

The Peltier effect can be calculated as:

$$Q = P \times I \times t \quad (2)$$

Where,

Q = Amount of heat absorbed by the Peltier Plates (in Joules)

P = Peltier Coefficient

I = Current (A), and

t = Time of contact

Finally, the change in temperature can be found using the heat expression,

$$dT = Q \div (m \times C_p) \quad (3)$$

Where,

m = Mass flow rate (kg/s), and

C_p = Specific heat of air in constant pressure (Joules/kg.K)

III. PROPOSED DESIGN SOLUTION AND ITS IMPLEMENTATION

The proposed design of the umbrella 3-D model is as shown in Fig.3. The basic structure of the design comprises of two metallic ducts, with a rectangular cross-section placed along the central spine of the umbrella, with the Peltier plates sandwiched between these two ducts. One of these ducts will be acting as the exhaust (placed on the hot side of the Peltier plates) is designed in such a way that it can release the air in the surroundings above the umbrella. While the other duct (placed on the cold side; which would function as the cooling vent) has an outlet that curves back to be able to direct the air back onto the user. Both these ducts have fans placed at their upper ends to ensure consistent flow of air in the area.

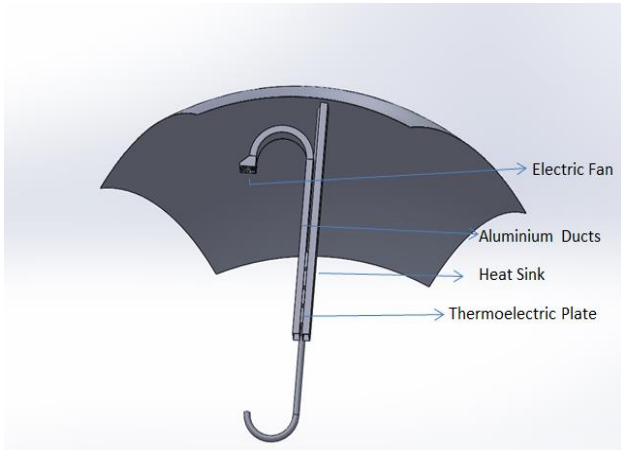


Fig. 3. Proposed Design.

The experimental prototype of the proposed model is shown in Fig.4. Based on the chosen design suitable thermoelectric plates of TC1-12706 are selected for the prototype. The design comprises of two thermoelectric plates. Each thermoelectric module can absorb approximately 6 Watts of power. So, the number of thermoelectric plates can be used depending upon the severity of the activity. The thermoelectric plates can be connected electrically in parallel to enhance the cooling activity. Finally, these are connected at the output of the voltage conditioning circuit consisting of power drivers via a control switch. The control switch regulates the flow of current through the thermo electric modules (Peltier plates) in the circuit.

When the current passes through the Peltier plate the electrons carry heat from the cold face to the hot face as discussed in above. The heat is rejected at the hot face of the thermoelectric plate. The heat extracted will be dissipated with the help of heat sink. To alleviate this, fans have been employed to aid to the forced convection via aluminium ducts. Heat sinks are added to allow better dissipation of heat on the exhaust side. To facilitate the temperature control and display the mode using a digital display to the user the control is implemented using Texas Instruments Microcontroller MSP430 [5].

IV. EXPERIMENTAL RESULTS

A. Results and Discussions

The proposed design shown in Fig.4 is tested experimentally and the results are explained in the subsequent paragraphs. Before testing the prototype with Peltier plates first the authors have analysed the performance of the same with an ambient temperature at different voltages. Table.1

shows the results at an ambient temperature of 30°C and the final cooling temperatures with each voltage is tabulated with current consumed. These individual plates are tested without heat-sink, so voltage to the Peltier plates is limited to low. The tabulated results show that the Peltier plates is able to deliver a cooling temperature of 15.9°C in static condition, these results are obtained in a period of 20 minutes of time.

Table 1
Temperatures of Peltier plates 1 and 2 with their corresponding voltage and current values.

Voltage (V)	Current (A)	Power (W)	Temperature on plate 1 (°C)	Temperature on plate 2 (°C)	Average Temperature (°C)
1	0.28	0.28	21.5	20.5	21
1.5	0.67	1.005	18.4	18.7	18.55
2	1	2	16.5	17.1	16.8
2.3	1.35	3.105	15.9	15.9	15.9



Fig 4. Working Model of the Umbrella or Prototype

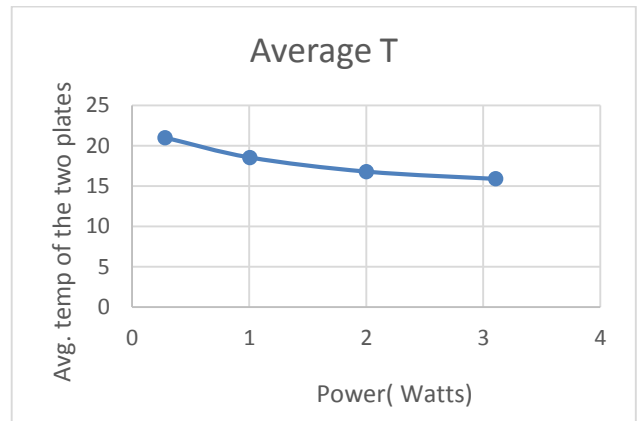


Fig 5. Average Temperature (°C) vs Power (W) graph for peltier plates.

Later the same plates are utilized for the prototype design as shown in Fig.4 and respective results with actual heat sink and ducts are given in Table.2. A 12 volts cooling fan with a CFM of 32.1 is used to facilitate the airflow over Peltier plates and the cooling air temperature is obtained for various ambient temperatures. The results in table 2 show that on an average the solar umbrella is able to deliver a cooling air temperature of 15.16 °C to the user at 30°C ambient temperature.

Table 2
Cooling air temperatures provided to the user.

Voltage (V)	Current (A)	Power (W)	Ambient Temperature (°C)	Cooling Air Temperature (°C)
3.8	3.9	15.006	25	13.8

4.2	4.5	19.161	28	14
4.49	5	22.450	30.7	14.5
5.52	5.05	27.826	31.5	16
5.75	5.1	29.205	33	17.5

V. CONCLUSIONS

The manuscript presents a temperature-controlled umbrella that can monitor the extreme temperatures, controls and provides tolerable temperature to the user by thermoelectric cooler module (Peltier plates). The heat dissipated in this system is controlled at a maximum rate using a heat sink and a portable fan. Thus, the system eliminates the conventional methods of handling heat dissipation. As the ultrathin thermoelectric cooler module is more affordable and provides useful solutions to the people with the minimum complexity at low power consumption, small in size, and as well as weight. This kind of product is very useful in real time applications like soldiers or the people who works even in extreme weather conditions. It is

highly durable as well as deploys solar energy and is ideally suited for mobile or movable applications too.

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