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Experimental investigation on Peltier based hybrid PV/T active solar still for enhancing the overall performance

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ABSTRACT

The demand for water and electricity is gradually increasing throughout the years due to the modern lifestyle of humans to complete their daily activities. To make sustainable water and to produce electricity, the proposed experiment was done. In this, hybrid PV/T active solar still was designed and fabricated in which a solar PV powered Peltier system was incorporated. The Peltier used in this still helps in the enhancement of the distilled water production during both evaporation and condensation processes. Various investigations were made on the proposed active hybrid PV/T system to claim this as the best and it was succeeded. Finally, the proposed active hybrid solar PV/T still produces about 30% higher efficiency than the conventional passive still and also resulted in 38% improved efficiency than the actual solar PV system.

1. Introduction

The demand for water and electricity is gradually increasing throughout the years due to the modern lifestyle of humans to complete their daily activities [1]. Tremendous changes in the environment by the utilization of conventional energy sources, an increment in population and industries cause the pollution, scarcity of water and energy [2]. Shortage of water can be tackled by sustainable use of water like processing the wastewater with required techniques and getting fresh water [3]. By purifying the sea water only, fresh water quantity can be increased, since it is an inexhaustible source of water in the earth [4]. Desalination done by fossil fuel causes Green House Gas emission, a concern for environmental pollution which leads renewable energy as an alternate source for powering desalination units [5]. In order to accomplish all the problems in a sustainable manner this proposed work is done by using sea water and powered the still by solar photovoltaic (PV). Integration of solar PV with desalination system met improvement in sustainability and proved that it is efficient than other alternate sources.

Solar PV has a drawback of the decrease in efficiency due to increase in temperature. This drawback can be overcome by cooling it. The proposed system is an efficient active hybrid solar PV/T (Photo Voltaic/Thermal) desalination system in which, the efficiency of solar PV is increased by allowing the saline water to flow on the panel to cool it in discrete time manner with a valve control. Solar still is simple in construction, low in both initial cost and maintenance cost but has a drawback of low productivity [6]. Recently lot of research work has been done for constructing the various structures of stills (one slope [7], weir-type [8], two slope [9]) and for increasing efficiency lot of experiments were done by using fin [10,11], glass cover cooling [12] and rotation of air inside of solar stills [13,14]. Also, researchers analyzed the still performance by incorporating fin, wick, and sponge as storage material inside the still and reported an increase in productivity to 45.5%, 29%, and 15.3% respectively [15,16]. Kabeel [17] innovated a solar still which includes concave wick evaporation surface for performance improvement and reported it had an average efficiency of 30% and productivity of 4.1 L/m^2. Sadineni et al. [18] worked on the weir-type inclined solar still and reported as it has a daily productivity of 5.5 L/m^2 and has higher performance if the water depth is low. Phadatare et al. [19] also reported similar conclusion regarding the depth of water. Rahin et al. [20] divided two regions as condensing region and evaporating region and concluded the productivity of still

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Nomenclature

C_v	temperature coefficient,%/°C
$V_{mpp,rated}$	rated voltage at maximum power point, V
P_{max}	maximum power from solar PV, W
V_{mpp}	voltage at maximum power point, V
I_{mpp}	current at maximum power point, A
I_{sc}	short circuit current, A
V_{oc}	open circuit voltage, V
I_L	load current, A
V_L	load voltage, V
FF	fill factor
A_{pv}	area of solar PV module, m^2
A_s	area of solar still, m^2
A_c	area of collector, m^2
T_{apv}	temperature above solar PV surface, °C
T_{bpv}	temperature below solar PVsurface, °C
T_{bw}	basin water temperature, °C
T_b	basin temperature, °C
T_{gi}	glass inner surface temperature, °C
T_{go}	glass outer surface temperature, °C
T_a	ambient temperature, °C
V_a	airflow velocity, m/s
$\dot{m}_{ew}$	distillate water output (L/h)
P_m	maximum PV output power, W
G	solar irradiance, W/m^2
$G_s(t)$	solar irradiance on soalr still, W/m^2
$G_c(t)$	solar irradiance on collector, W/m^2
$G_{pv}(t)$	solar irradiance on solar PV, W/m^2
L	latent heat vapourization, J/kg
a	accuracy of instrument
u	standard uncertainty

Greek symbols

μ	module efficiency,%
h_{still}	thermal efficiency of proposed hybrid (PV/T) solar still,%
h_{pv}	electrical efficiency of PV module in proposed hybrid (PV/T) solar still,%
h_{tpv}	thermal efficiency of PV module in proposed hybrid (PV/T) solar still,%
h_{hybrid}	overall thermal efficiency of proposed hybrid (PV/T) solar still,%

was increased to 32%. Some researchers [21] modeled two glass collector still and proved that the productivity of still increases by increasing the water- glass temperature difference. The daily productivity can be enhanced by increasing the thickness of the rubber and size of the gravel in the still [22]. Generally still is classified as active and passive solar stills. If the basin water is not heated using any additional source for evaporation other than solar energy, then it is called as the passive solar still. Similarly, if it is evaporated by using any external source then it is called as the active solar still. In general, the amount of fresh water collected from an active solar still is more than the passive one. The yield of active solar still is enhanced by adding an extra device such as coolant [14], DC fan [23], solar tracking system [24] or collectors [25–27], for making more difference in temperature between evaporating and condensing area [55–58].

Lots of researchers were done and going on active solar stills. Solar collectors are used to enhancing the thermal processes (evaporation) in the solar still [28,29]. To improve still productivity, sun tracking system was implemented and 22% enhancement in still productivity was obtained by Abdallah et al. [24]. Voropoulos [30] doubled the productivity of solar still with solar collector and storage tank. Dwivedi et al.[31] proved that two slope active solar still thermal efficiency is less than the two slope passive solar still but the exergy is high in that still. Singh [32,33] made an active solar still containing flat plate collectors and parabolic concentrator. Lot of recent literature [34–38,49–54] were studied regarding the shape, size, materials used in the still and the properties of evaporation and condensation. Ninic et al. [39] discussed the concept of a solar distiller and an offshore wind power plant operating together. From the above literature, conventional solar distillation systems have low productivity due to the low evaporation rate in the basin and the low condensation rate at the glass cover. Efficiency can be improved by using nanofluids which are slightly a higher cost but effective [59–61]. N. Rahbar designed a new type portable thermoelectric solar still (PTSS) in which a thermoelectric module is used to improve the temperature difference between evaporating and condensing zones [50]. J. A. Esfahani fabricated a portable solar still with some techniques of using a solar collector, a wall covered with black wool, and water sprinkling system to increase evaporation rate and a thermoelectric cooling device to enhance water condensation [58]. M. B. Shafii designed and experimentally investigated a novel solar still equipped with thermoelectric modules to utilize the heat of vapor condensation [62]. S. Rashidi investigated the effects of partitioning in a solar still on performance recovery by experimentally and numerically [63]. Yu J, Wang B, done their research on thermoelectric materials having a figure of merit (ZT) higher values and passing from values of ZT around unity typical of the best commercial solution available to higher values (with maximum experimental ZT values of about 3 at 550 K reported in [64]. Harman TC reported on the development of nanostructured thermoelectric materials providing enhancement in cooling capacity for three stages having 35% improvement than single stage [65]. A number of investigations have been conducted to overcome these two problems. The solution of these two problems comes as the proposed work.

The concept of thermoelectric refrigeration [40] by Lenz was the keynote of the proposed work. Thermo Electric Module (TEM) or Peltier module is used in this proposed method which consists of P-type and N-type blocks of semiconductor materials. Peltier effect is the cooling and heating effect caused due to the passing of electrons between the semiconductors. So, TEM has no moving parts and this makes TEM to have a better life. Due to high temperature withstanding and being a solid material, it can be used in any place. The detailed specification of the Peltier used is given in Table 1. It can be operated with PV panel power directly since it voltage requirement is low [57,58]. Having the greater benefit in the process of cooling little-sized enclosure with low power capability, which is almost independent [40–42]. Peltier devices are simple, compact, and weightless, and they are easily controllable. These properties make Peltier as the suitable tool to propose this research work. Kumar, M et al. done their research and reported on parameter extraction technique to determine the best-suited model for

Table 1
Specifications of used solar PV module at STC.

Electrical Parameters	Specifications
Maximum power (P_{max})	50 W
Voltage at P_{max} (V_{mpp})	17.5 V
Current at P_{max} (I_{mpp})	2.90 A
Short circuit current (I_{sc})	3.20 A
Open circuit voltage (V_{oc})	21.8 V
Module efficiency (μ)	11.1%
Fill factor (FF)	0.72
Temperature coefficient of I_{sc}	0.105%/°C
Temperature coefficient of V_{oc}	−0.360%/°C
Temperature coefficient of P_{max}	−0.45%/°C