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A solar hybrid system for power generation and water distillation

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ABSTRACT

A solar still of a single basin-slope coupled with a finned condensing chamber and photovoltaic cells immersed in the water basin and thermoelectric generators installed in the base of the basin has been presented in this paper. A mathematical model under steady-state conditions has been introduced and improved to investigate the system performance. An increase of solar radiation and ambient temperature or a decrease in wind velocity affect positively the distillation rate, still efficiency, system efficiency, and output power. Integrating fins through the wall of condenser increase the distillation rate of the proposed system. When the ambient temperature increases from 10 to 35 °C, the water distillation, still efficiency, and system efficiency will be increased up to 27%, 21%, and 28% respectively, but the power output will be decreased up to 16.6% at solar radiation of 1000 W/m^2. Moreover, when the ambient temperature increases from 10 to 35 °C, the water distillation, still efficiency, system efficiency, and power output will be decreased up to 37%, 32%, 34%, and 17%, respectively, at a wind speed of 10 m/s. Also, the water distillation, still efficiency, and system efficiency of the solar still with a condensing chamber will be higher than the conventional solar still up to 7%, 8%, and 7% respectively, but the power output will be decreased up to 3% at solar radiation of 1000 W/m^2. While in the third design, solar still with a finned condensing chamber, the water distillation, still efficiency, and system efficiency will be higher than the conventional solar still up to 14%, 12.5%, and 11% respectively, but the power output will be decreased up to 6% at solar radiation of 1000 W/m^2. The results of the simulation have been verified by comparing them with published theoretical and experimental results and the comparison shows very good agreement.

1. Introduction

Since we were children, our subjects at all grade levels dealt with the importance of saving water and energy in everyday uses, which we did not consider it as an important thing. Ignorance, unjust use and failure to take into account the importance of water and energy to us, to others and to those who will inhabit the earth in the future have established problems of limited or non-availability of these resources in some regions of the world. The process of producing energy requires water and the process of providing water for human use that needs energy. The process of water and energy dependence on each other has created a new and growing global challenge (Union of Concerned Scientists, 2017).

Most of the electricity generation sectors currently rely on water mainly. If we take into account, the power plants that use fuel in all forms in the generation of thermal energy to heat the water and convert it from liquid to steam to run steam turbines and many other applications. In order to solve this dilemma, the world is currently turning to a number of options that are easy to implement, such as applying the cost-effective principle, which is based on the working mechanism of appliances, tools, buildings, heavy machinery and transportation which has been applied in many major industrial countries. The process of using renewable energy, such as solar energy, wind energy, and many others, will reduce the use of water in the process of generating power, which does not need in both cases.

In the last decade, the renewable energy sector has developed, its efficiency and diversity of technology fields and the world's attention has increased because of its important impact in protecting the environment from pollution and its effects on the threat of life on earth. The solar energy is the most exploited in the renewable energy sector recently and the last decade has seen a lot of development in the field of tools and devices used in the generation of energy such as photovoltaic cells, the thermoelectric generators and solar concentrators (Nrel.gov, 2017). Photovoltaic systems have become used in many fields, whether industrial, commercial, domestic, and agricultural. Another application is the thermoelectric generator, a device that converts heat energy (temperature difference) to electrical energy directly through a phenomenon called the Seebeck effect. This device is new or not conventional compared to the photovoltaic cells and of these reasons it has a low efficiency, which may reach at the best conditions.

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Nomenclature

$A_{b,f}$ area of the base of the fins array (m^2)
A_b surface area of basin base (m^2)
A_c surface area of all constructed fins (m^2)
A_g area of the glass cover (m^2)
$A_{g.e}$ effective area of glass cover (m^2)
A_w free surface area of saline water (m^2)
A_{cf} surface area of all constructed fins array on TEMs (m^2)
A_p cross-sectional area of the positive doped leg of each thermoelectric unit (m^2)
A_N cross-sectional area of the negative doped leg of each thermoelectric unit (m^2)
$\dot{E}_{in.1}$, $\dot{E}_{in.2}$, $\dot{E}_{in.3}$, $\dot{E}_{in.4}$, $\dot{E}_{in.5}$ energy rate entering in system 1, 2, 3, 4, and 5 respectively (W)
$\dot{E}_{gen,1}$ the rate of energy generation by the PV module (W)
$\dot{E}_{out.2}$, $\dot{E}_{out.3}$, $\dot{E}_{out.4}$, $\dot{E}_{out.5}$ energy rate existing system 1, 2, 3, 4, and 5 respectively (W)
G solar radiation (W/m^2)
$h_{c.ga}$ convective heat transfer coefficient from transparent glass cover to ambient ($W/m^2\,°C$)
$h_{r.ga}$ radiative heat transfer coefficient from transparent glass cover to ambient ($W/m^2\,°C$)
$h_{c.wg}$ convective heat transfer coefficient from water to transparent glass cover ($W/m^2\,°C$)
$h_{ev.wg}$ evaporative heat transfer coefficient from water to transparent glass cover ($W/m^2\,°C$)
$h_{r.wg}$ radiative heat transfer coefficient from water to glass cover ($W/m^2\,°C$)
$h_{c,bw}$ convective heat transfer coefficient from basin to water ($W/m^2\,°C$)
$h_{k,bh}$ conductive heat transfer coefficient from basin to TEMs hot surface ($W/m^2\,°C$)
$h_{tt,ca}$ overall heat transfer coefficient ($W/m^2\,°C$)
$h_{t,ca}$ sum of convective and radiative heat transfer coefficients from TEMs cold surface to ambient ($W/m^2\,°C$)
$i_{fg.w}$ latent heat of vaporization for water (J/kg)
I generated electrical direct current (A)
K total thermal conductance for n pairs of thermoelectric legs (W/m °C)
K_b thermal conductivity of basin (W/m °C)
L_b thickness of water basin (m)
L_p length of the positive doped leg in each thermoelectric unit (m)
L_N length of the negative doped leg in each thermoelectric unit (m)
$\dot{m}$ mass flow rate (kg/s)
m matched load
n number of thermoelectric pairs in each module
P_L generated electrical power (W)
$P_{g.e}$ effective saturated vapor pressure of water at $T_{g.e}$(N/m^2)
P_w saturated vapor pressure of water at Tw (N/m^2)
$Q_{c.ga}$ rate of convective heat transfer from glass cover to ambient (W)
$Q_{r.ga}$ rate of radiative heat transfer from glass cover to ambient (W)
$Q_{c.wg}$ rate of convective heat transfer from water to glass cover (W)
$Q_{ev.wg}$ rate of evaporative heat transfer from water to glass cover (W)
$Q_{r.wg}$ rate of radiative heat transfer from water to glass cover (W)
$Q_{s.w}$ rate of energy absorbed by saline water (W)
$Q_{s,b}$ rate of energy absorbed by basin (W)
$Q_{S,pv}$ rate of energy absorbed by PV module (W)
$Q_{c,bw}$ rate of convective heat transfer from water basin to water (W)
$Q_{k,bh}$ rate of conductive heat transfer between basin to TEMs surface (W)
$Q_{t,ca}$ overall heat loss from the fins of cold-side TEMs to the ambient (W)
Q_h rate of heat transfer absorbed by the hot-side of the TEMs (W)
Q_c rate of heat transfer rejected by the cold-side of the TEMs (W)
R total electrical resistance of the thermoelectric modules (Ω)
R_L external load resistance connected to the TEMs (Ω)
T_a ambient temperature (°C)
T_g glass cover temperature (°C)
$T_{g,e}$ effective glass cover temperature (°C)
T_{sky} temperature of sky (°C)
T_w water temperature (°C)
T_b basin temperature (°C)
T_h TEMs hot surface temperature (°C)
T_c TEMs cold surface temperature (°C)
V wind velocity (m/s)
z the figure of merit
$\bar{\alpha}$ seebeck coefficient of tow junctions (average value)
α_g,α_w,α_b absorptivity of glass cover, water, and basin respectively
ε_g,ε_w emissivity of glass cover and water respectively
ε_{eff} effective emittance between water to glass cover
η_{pv} the efficiency of the PV modules (%)
η_{still} solar still efficiency (%)
η_{TEMs} the efficiency of the thermoelectric modules
λ_p thermal conductivity of the positive leg of the thermoelectric junction
λ_N thermal conductivity of the negative leg of the thermoelectric junction
σ Stefan–Boltzmann constant ($5.67 \times 10^{-8}\,W/m^2\,K^4$)
σ_N electrical conductivity of the negative leg of the thermoelectric junction $(\Omega\,m)^{-1}$
σ_p electrical conductivity of the positive leg of the thermoelectric junction $(\Omega\,m)^{-1}$
τ_g, τ_w transmissivity of glass cover and water respectively

Many researchers have recently gone on to create hybrid systems consisting of two or three systems that exploit as much as possible energy to improve system performance. These systems are diverse and exist in many applications whether they are based on fuel or renewable energy. A hybrid system consisting of four systems (photovoltaic cell system, wind energy conversion system, fuel cells and battery storage system) was built. This system produced electricity by two renewable energy sources (solar radiation and wind energy) and used fuel cells and batteries to keep the system working if any sources (solar radiation or wind energy) were interrupted. This system has the ability to operate independently and in different climatic conditions such as cloudy weather and makes it a destination for the use of people in remote areas (Fathabadi, 2017). Another hybrid system consisting of a conventional distillation system (conventional still) and a photovoltaic cell system has been studied. The system has been modified by adding a condenser, which improves the efficiency of the system. The results of the research have been compared and supported by other similar theoretical and experimental research. Some factors have been studied their effects on the system performance in terms of efficiency and productivity. Some of these factors are based on system design such as the installation of fins

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