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Optimization analysis of solar thermal water pump

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A R T I C L E I N F O

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A B S T R A C T

This paper investigates the performance of solar thermal system for powering irrigation pump. It also summarizes the recent developments of solar thermal power systems. Furthermore, it updates the literature about the recent findings of thermal solar power system and presents different methodologies of enhancing the solar energy conversion system. The solar thermal irrigation pump uses steam Rankine cycles SRC integrated with parabolic trough collector PTC. The selected site is located in the northern part of Jordan. Simulation models are built to assess the performance of solar thermal irrigation system. The simulation models are built by means of mass and energy balances applied to every component of the system. The model simulates the hourly thermal behavior of all system components. The effect of key operating variables on the system performance is examined. Simulation results show that there is an optimum values for mass flow rate where maximum power out can be obtained. The average daily overall efficiency ranges between 10 to 13% during summer time. The optimal daily average overall efficiency reaches 18%. Results show that the concentration ratio has negligible effect on the overall system performance. It is found that using PTC of area of 526 m^2 with SRC is reliable system producing above 30 kW during summer time. Economic analysis reveals that the solar energy cost is $0.075/kWh. Furthermore, this paper presents design optimization so that STWP can achieve higher reliable continuous operation with system components.

Contents

1. Introduction

It is now widely accepted that the nonrenewable sources in the world are finite and it is only a matter of time before reserves will essentially be consumed [1–4]. Up to date, 80% of electricity is generated by fossil fuels [1]. Irrigating the world's farmland takes a significant amount of energy. Irrigation operations in Jordan use about 25% of all the energy used by farms for direct production

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Nomenclature

A	Exchanger heat transfer area [m^2]
A_{ap}	Aperture area of the collector [m^2]
C	Concentration ratio
$C_{p,oil}$	Specific heat of oil [kJ/kg. K]
CSP	Concentration Solar Power
$C_{p,w}$	Specific heat of water [kJ/kg. K]
C_{omr}	Operation, maintenance and repair cost [$]
$D_{r,int}$	Receiver pipe inner diameter [m]
$D_{r,ext}$	Receiver pipe outer diameter [m]
D_{co}	Glass cover outer diameter [m]
D_{co}	Glass cover outer diameter [m]
Fr	Heat removal efficiency factor
F	Efficiency factor
k_r	Thermal conductivity for tube material [W/m.k]
HTF	Heat Transfer Fluid
$h_{c,i}$	Conv. heat transfer coef. between absorber and the fluid [W/m^2.K]
h_w	Conv. heat transfer coef. between receiver and ambient air [W/m^2.K]
$h_{r,r\text{-}a}$	Rad. heat transfer coef. between absorber tube and ambient [W/m^2.K]
I	Investment [$]
I_b	Solar beam radiation [W]
I_t	Beam flux incident normally on aperture plane [W]
i	Inflation rate
m_o	Mass flow rate of oil [kg/s]
m_w	Mass flow rate of water [kg/s]
Nu	Nusselt number
ORC	Organic Rankine Cycle
P	Pressure [Pa]
PTCs	Parabolic trough collectors
PVC	Present Value of costs
Pr	Prandtl number
Qu	Useful energy [W]
q_{loss}	Rate of heat losses [W]
RSC	Rankine Steam Cycle
r	Interest rate
r_b	Tilt factor
Re	Reynolds number
S	Scrap value [$]
STWP	Solar Thermal Water Pump
t	Lifetime of the system [years]
T_o	Temp. of the fluid comes out from the collector, [°C]
T_f	Temp. of fluid enter the collector (out of the stem cycle) [°C]
T_{pm}	Mean temperature of absorber tube [°C]
T_c	Mean temperature of the glass cover [°C]
T_a	Ambient temperature [°C]
T	Temperature [°C]
T_r	Temperature of the absorber surface [°C]
U	Overall heat transfer coefficient [W/m^2 K]
U_l	Thermal loss coefficient [W/m^2 K]
V	Average velocity of the fluid [m/s]
W	Collector width, [m]
W_{net}	Output work from turbine [W]

Greek letter

μ	Dynamic viscosity [N m^2/s]
η_{all}	Overall Efficiency [%]
ρ	Reflectivity for glass mirrors
ν	Kinematic viscosity [m^2/s]

Subscripts

a	Ambient
i	Inlet
o	Output
th	thermal

operations. Demands on irrigation have witnessed significant increase recently. The number of irrigated acres worldwide rose from 1 million in 1900 to about 561 million in 1976, and is expected to continue rising [5]. Conserving this use of energy and replacing fossil fuels used for irrigation with renewable sources of energy can have worldwide benefits by improving trade balances, by reducing inflationary pressures, and, especially, by lowering the costs of producing farm crops.

The energy required for irrigation pumping depends on the number of acres irrigated, the amount of water applied per acre, the height the water is lifted, and the method used to distribute or apply the water [6]. In addition to surface (gravity flow or flood) application, which currently represents the largest area irrigated with pumped water, various types of pressurized (sprinkler and drip) irrigation systems are in use. The use of sprinkler systems is increasing rapidly because surface application is not practical on certain types of soil, terrain, or crops, and requires large amounts of labor, which is costly and in short supply [6].

Solar energy is considered the main source of renewable energy. Solar energy is a permanent, none polluting and low running cost source of energy. Solar Thermal Power Plants (STPPs) are one of the most favorable systems and their installation is spreading widely. Solar thermal (Thermodynamic methods) and photovoltaic (solar cell) systems with concentrating and non-concentrating collectors are the two basic systems of using direct solar energy for irrigation pumping. In thermodynamic method, solar collector concentrators are employed to produce fluid at high temperature and pressure. This fluid at high pressure may be either utilized directly in the form of Rankine\Brayton or Stirling cycle to produce the mechanical energy needed to operate a conventional or an unconventional pump. The basic differences in heat engine devices are the type of working fluid used (organic, water, or gas) and the temperature at which they operate. Theoretically, the higher the operating temperature, the higher the thermodynamic efficiency of heat engines. However, in selecting a heat engine, consideration must be given to the overall efficiency and cost of producing energy. These systems are found technically feasible especially in remote areas where high level of solar radiation is available.

Researchers have been focusing on improving solar systems to provide energy for powering of irrigation pumps. The earliest experiments of using direct solar energy to lift water for irrigation purposes was described by the French engineer, Solomon de Caux, in 1615 [7]. In 1885 solar thermal energy was built to power an apparatus at Auteuil, France, which lifted over 300 gallons of water per hour from a depth of 19.8 m using 33.2 m^2 of solar collecting area [8]. In 1913, near Cairo, Egypt, Shuman and Boys built a large solar-powered system of over 50 horsepower that powered a heat engine and pumped irrigation water from the Nile River [9]. Tabor and Bronicki built a 3.68 kW solar system for pumping water [10].