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Multi criteria sizing approach for Photovoltaic Thermal collectors supplying desalination plant

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ABSTRACT

Reverse osmosis desalination plants require both thermal and electrical energies in order to produce water. As Photovoltaic Thermal panels are able to provide the two energies, they become suitable to supply reverse osmosis plants mainly while installed in remote areas. Autonomous based desalination plants must be optimally sized to meet the criteria related to the reverse osmosis operating temperature, the plant autonomy, the needed water, etc.

This paper presents a sizing approach for Photovoltaic Thermal collectors supplying reverse osmosis desalination plant to compute the optimal surface of Photovoltaic Thermal collectors and the tank volume with respect to the operating criteria. The approach is composed of three optimization consideration steps: the monthly average data, the fulfillment of the water need and a three day of autonomy for the water tank volume. The algorithm is tested for a case of study of 10 ha of tomato irrigation. The results converged to 700 m^2 of Photovoltaic Thermal collector's surface and 3000 m^3 of water tank volume.

1. Introduction

Reverse osmosis desalination process is considered as the suitable desalination process due to its high recovery ratio and low energy consumption [1]. Additionally, it offers a low production cost [2]. The increase of feed water temperature impacts the membrane permeability of the reverse osmosis unit [3]. In fact, the recovery ratio of reverse osmosis unit improves while the feed water temperature increases [4], which decreases the energy consumption per cubic meter [5]. Also, since the desalination plant is supplied by groundwater, a pumping system should be installed which involves the necessity of electric energy. Hence the desalination plant needs two energy forms: electrical and thermal: this can be ensured by a Photovoltaic Thermal panel. Photovoltaic Thermal collector is a hybrid system which combines the functions of solar thermal collector and Photovoltaic panel. While coolant fluid circulates into the Photovoltaic Thermal (PV/T) collector, it decreases the Photovoltaic (PV) cell temperature which improves the electric efficiency.

Several researchers focused on studying PV/T technology types in order to favor either the thermal or electric generation. Therefore, PV/T collectors are classified according to the type of coolant (air or liquid). This classification serves to identify the usefulness of each PV/T category [6]. Different PV/T configurations are conceived, studied, and compared. The comparison indicates that electrical and thermal efficiencies vary with the PV/T configuration [7]. Unglazed and glazed PV/T collectors present the two most compared configurations. It is deduced that unglazed configuration presents the best overall thermal energy gain [8]. Also, dynamic models are established for PV/T module [9]. These models are based on heat transfer phenomenon. They vary with the considered PV/T configuration. The models simulations show the impact of mass flow rate variation on thermal and electrical PV/T efficiency [10]. In addition to the heat production, results indicate that in low temperature operating systems, PV/T systems produce electrical energy more than PV systems. Besides, control laws are developed in order to optimize PV/T energy production [11]. As the work was developed considering a preinstalled plant, the present paper contributes with the sizing of the plant on the basis of some optimization criteria. The gathered algorithm offers an efficient tool that allows a plant sizing and control. The control consists of varying the mass flow rate inside PV/T module. The influence of the mass flow rate variation is shown experimentally [12]. Numerous studies were interested to PV/T based plants. In fact, PV/T technology is exploited and plants models are simulated for domestic uses [13] as for industrial applications [14]. The objective was to analyze the fluid temperatures inside the plant and the consequence on the heat and electrical generations. For higher load

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Nomenclature

A_b	boiler surface (m^2)
Ac	PV/T field surface (m^2)
$C_{p,w}$	water heat capacity (J/kg °C)
C_p	fluid heat capacity (J/kg °C)
E_{hw}	energy consumed by the auxiliary heater (W h)
Fr	collector heat removal factor
G	solar radiation intensity (W/m^2)
g	the gravitational constant ($m\ s^{-2}$)
h	the change in the water height (m)
$h_{conv,b}$	convective heat transfer coefficient in the back surface (W/m^2 K)
$h_{conv,t}$	convective heat transfer coefficient on the top surface of the PV/T panel (W/m^2 K)
h_f	fluid heat transfer coefficient (W/m^2 K)
h_{p1}	penalty factor due to the presence of solar cell material, glass and EVA
h_{p2}	penalty factor due to the presence of interface between tedlar and working fluid
h_{rad}	radiative heat transfer coefficient (W/m^2 K)
K_g	conductivity of glass cover (W/m K)
K_i	conductivity of back insulation (W/m K)
K_{si}	conductivity of silicon solar cell (W/m K)
K_T	conductivity of tedlar (W/m K)
L	length of the PV/T panel (m)
L_g	thickness of glass cover (m)
L_i	thickness of back insulation (m)
L_{si}	thickness of silicon solar cell (m)
L_T	thickness of tedlar (m)
m_s	the exiting water flow rate from the boiler (m^3/s)
$\dot{m}$	fluid mass flow rate (kg/s)
$\dot{m}_w$	mass flow rater of the pumped water (m^3/s)
P_b	exiting brine pressure (Pa)
P_{ER}	recovered power by the exiting brine (W)
P_f	reverse osmosis membrane feed pressure (Pa)
P_{HP}	required power by the high pressure pump (W)
P_p	permeate water pressure (Pa)
P_{RO}	required power by the reverse osmosis process (W)
Q_b	brine flow rate (m^3/s)
Q_f	feed water flow rate (m^3/s)
q_{ls}	extracted energy from the boiler (W)
$Q_{p,s}$	average product flow (m^3/h)
Q_p	permeate flow rate (m^3/s)
q_{stl}	storage heat loss (W)
$\dot{Q}$	transferred heart to the working fluid (W)
$\dot{Q}_s$	heat transfer over the exchanger to the pumped brackish water (W)
Rec	recovery ratio
S	PV/T field surface (m^2)
t	number of daylight hours (h)
T	temperature (°C)
T_b	water temperature in the boiler (°C)
TCF	temperature correction factor
U_b	overall back loss coefficient from flowing fluid to outside (W/m^2 K)
U_L	heat loss coefficient of the PV/T collector (W/m^2 K)
U_{st}	boiler overall heat loss coefficient (W/m^2 °C)
U_t	overall heat transfer coefficient from solar cell to ambient through the glass cover (W/m^2 K)
U_T	conductive heat transfer coefficient from solar cell to following air through tedlar (W/m^2 K)
U_{tf}	overall heat transfer coefficient from glass to air through solar cell and tedlar (W/m^2 K)
U_{Tt}	overall heat transfer coefficient from glass to tedlar through solar cell (W/m^2 K)
V_b	water volume in the boiler (m^3)
V_{cap}	daily production (m^3)
V_{hw}	heated water volume (m^3)
V_w	wind velocity (m/s)
W	width of the PV/T panel (m)

Greek symbols

$(\alpha\tau)_{eff}$	product of effective absorptivity and transmissivity
η	efficiency (%)
η_{FP}	efficiency of the feed water pump (%)
η_{HP}	high pressure pump efficiency (%)
α_c	absorptivity of solar cell
α_T	absorptivity of tedlar
β	cell efficiency temperature coefficient (K^{-1})
β_c	packing factor of solar cell
ε_{ex}	exchanger efficiency (%)
ε_g	glass emissivity
Θ	temperature (K)
ρ	water density (kg/m^3)
σ	Stefan Boltzmann's constant ($W/m^2\ K^4$)
τ_g	transmittivity of glass cover

Subscripts

a	ambient
b	boiler
bs	back surface
cell	PV/T cells
el	electric
FP	feed water pump
f	fluid
HP	high pressure pump
i	in/back insulation
in	inlet
max	*maximum*
min	*minimum*
o	out
op	*optimum*
out	outlet
PV/T	Photovoltaic Thermal collector
PV	Photovoltaic
ref	*ref*: reference
Si	silicon solar cell
sky	sky
T	tedlar
th	thermal
w	water

temperature applications, an economic analyze shows better cost/benefit ratio for PV/T system compared to PV [15]. PV/T applications are diversified to include desalination systems [16]. In reverse osmosis process, feed water in high temperature impacts positively the recovery ratio and decreases the energy consumption per cubic meter of desalinated water [17]. In addition, reverse osmosis plants powered by Photovoltaic show good performances [18]. Many others researchers were occupied by sizing solar powered systems. With classical solar thermal panel, sizing aims to determine panels' surface necessary to satisfy the requirement [19]. Minimizing the storage volume was an interest center in sizing strategy [20]. The methodology is based on analytical tech-