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The application of Linear Fresnel and Parabolic Trough solar fields as thermal source to produce electricity and fresh water

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ABSTRACT

In the present paper, the integration of the Multi Effect Desalination (MED) system with the Solar Rankine Cycle (SRC) was considered in order to produce electricity and water. Parabolic Trough Collector (PTC) and Linear Fresnel (LF) solar fields were investigated as the thermal source of the SRC and a Natural Gas Boiler (NGB) was considered to supply part of the SRC required thermal energy during the non-availability of the solar thermal energy. A simple optimization approach was used in order to obtain the SRC plants with minimum electricity and water generation costs. A Thermal Storage System (TES) was also considered in the calculations of the present paper. For both PTC/SRC and LF/SRC plants, the required Solar Multiple (SM), electricity generation cost and water production cost were determined for different percentages of the solar share. A comparison between the PTC and LF solar fields was conducted in order to determine the required solar field and land area for producing the specific electricity and fresh water rates. Finally, a sensitivity analysis was performed to determine the importance of each cost parameters on the final electricity and water unit of costs for both PTC and LF base SRC plants.

1. Introduction

The desalination technologies such as Reverse Osmosis (RO), Multi Stage Flash (MSF) and Multi Effect Desalination (MED) are energy intensive. Among the mentioned desalination technologies, RO is a mature technology with the major disadvantage of high electricity consumption. The application of the power cycles with once through cooling system in the locations with high ambient temperature would result in lower thermal efficiency and consequently higher electricity and water production costs of the integrated RO unit; especially for the regions with high salinity of the sea water. MED technology with electricity consumption of 1.55–2 $/m^3 and high purity of the produced fresh water has been of interest over the recent years. However, MED is still an energy intensive process and the most suitable technology to reduce this drawback is to integrate MED unit with a power generation system [1]. Dual Purpose power plants have been reported to deliver substantial cost savings during their entire life-cycle [2]. The using of the waste heat from the power plants is one of the promising alternatives to reduce the thermal energy costs of the desalination processes [3,4]. The utilization of the solar thermal power as the thermal source of the steam or Organic Rankine Cycle (ORC) has been vastly investigated by the researchers. The off-design model of an organic Rankine cycle driven by compound parabolic solar collectors has been considered by J. Wang et al. [5]. In that research, the variation of the environment temperature also change in the thermal oil mass flow rates have been considered to investigate the off design condition of the solar Rankine cycle. The results of that research have demonstrated that the off-design performance of the organic Rankine cycle would be improved by both decreasing in ambient temperature and increasing in thermal oil mass flow rate.

A techno-economic analysis of the solar Rankine cycle with different Heat Transfer Fluid (HTF) has been carried out by M. Z. Yilmazoglu [6]. Four different condenser types have been considered in that work. The net electrical efficiency of the solar Rankine cycle has been shown to be equal as a value between 13% and 24% for different HTFs. Also, the Carbon tax/credit has been considered in the calculations of the electricity cost of the plant. A comparison has been made between the proposed solar Rankine cycle and the gas turbine, combined cycle plants. The results of that study have shown that solar thermal power plant with heat storage can be competitive when compared to gas turbines.

The performance of a solar Parabolic Trough Collector (PTC) integrated with a storage unit has been experimentally investigated by G. Kumaresan et al. [7]. The amount of energy stored in the storage,

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Nomenclature

A_{field}	solar field aperture area (m^2)
$C_{CAPEX}(D)$	capital annualized direct costs, $
$C_{CAPEX}(ID)$	capital annualized indirect costs, $
C_{el}	electricity costs, $
C_f	fuel costs, $
C_{Ins}	insurance costs, $
C_L	labor costs, $
CRF	capital recovery factor
C_{SP}	spare parts replacement costs, $
CSP	concentrating solar power plant
DNI	direct normal irradiation, W/m^2
DSG	direct steam generation
GOR	Gain Output Ratio
HTF	Heat Transfer Fluid
i	interest rate (%)
LCOE	levelized cost of electricity, $/kWh
LCOW	levelized cost of water, $\$/m^3$
LF	Linear Fresnel solar field
LF1	Linear Fresnel solar field of number 1
LF2	Linear Fresnel solar field of number 2
$\dot{m}$	mass flow rate, kg/s
$\dot{m}_{oil}$	therminol VP1 mass flow rate, kg/s
N	number of project life time
NGB	natural gas boiler
NSM	None Solar Field Land Area Multiplier
$Q_{absorbed}$	absorbed solar energy, W/m^2
Q_{hl_HTF}	Heat Transfer Fluid heat loss, W/m^2
$Q_{hl_{piping}}$	heat lost from solar field pipes, W/m^2
Q_{LFR}	solar field useful thermal output, W/m^2
Ra	entertainment ratio
T_{amb}	ambient temperature, °C
TAWP	total annual water production, m^3/yr
TAEG	total annual electricity generation, kWh/yr
TES	thermal energy storage
T_{in}	temperature of the heat transfer fluid at the inlet, °C

Greek symbols

η_{opt}	optical efficiency
$\eta_{endloss}$	end loss efficiency

the charging efficiency, the collector's instantaneous efficiency and overall system efficiency have been evaluated in that work.

The performance of a medium size Linear Fresnel (LF)/ORC plant has been studied for two different thermal storage methods by D. Cocco and F. Serra [8]. Different values of solar multiple and thermal energy storage capacity have been considered to make a comparison between two selected thermal storage systems. The results of that research demonstrated that two-tank energy storage system has slightly higher performance than thermocline storage system. The electricity generation rate of 1 MWh has been considered for the solar Rankine cycle and the electricity generation cost has been found to be a value between 0.42 €/kWh and 0.52 €/kWh for different storage capacities and solar multiples.

The large variety of systems, used to convert seawater into fresh water (with and without renewable energy sources) has been reviewed by S. A. Kalogirou [9]. The author has proposed some general guidelines for selection of desalination and renewable energy systems and the parameters that need to be considered.

The basic principle of desalination technologies has been reviewed by J.H. Lienhardt et al. [10]. In that work, various technologies that couple thermal or electrical solar energy to membrane or thermal based desalination systems have been reviewed and discussed.

A brief review on solar desalination technologies has been performed by A. Pugsley et al. [11]. The economic and environmental feasibility of the solar desalination technologies have been examined from a global perspective. The water scarcity and stress, saline water resources, and insolation levels have been ranked for various locations around the world based on a correlating method. A variety of solar energy technologies, and also various technologies for desalination systems including advanced techniques for energy-recovery have been reviewed by J. H. Reif and W. Alhalabi [12].

Several research works have been conducted regarding the applicability of the concentrating solar power for different locations with high solar radiation levels such as Chile [13], Egypt [14] and Tunisia [15]. L. Qoaider and A. Liqreina [16] have investigated the effectiveness of the dry cooled concentrating solar power plants in the some arid regions of Middle East and North Africa (MENA). The authors have performed an optimization analysis to improve the design configurations of the dry cooled solar power plants. The results of that work demonstrated that dry cooled concentrating power plants in sunny arid regions are a competitive option and can produce power at competitive costs. Also, it has been shown that the plant with Solar Multiple (SM) of 2 and large thermal storage capacities (7 to 9 h) performs better and can generate power at lower costs than smaller plants. N. B. Desai and S. Bandyopadhyay have performed an optimization analysis on the performance of the SORC/PTC plant [17]. The effects of turbine inlet temperature, inlet pressure, plant size, and design radiation on overall efficiency and Levelized Cost of Energy (LCOE) of the plant have been investigated. A detailed research review on the on current thermal and electrical energy storage options for different renewable energy base desalination processes has been performed by V.G. Gude [18]. According to the finding of that research work, the application of the energy storage systems has been found not to be ideal or economical in all cases since its feasibility depends on the location, type and size of the desalination application and the available renewable energy sources.

Two different seawater technologies of RO and MED have been considered to be coupled with the Solar Thermal Power Plant (STPP) based on parabolic trough mirrors and Direct Steam Generation (DSG), with the operation pressure of 60 bar, for the Almería located in southeast of Spain [19]. Four coupling arrangements have been considered in that work; replacing the condenser of the Power Block (PB) by the MED unit, the steam extracted from the PB steam turbine is used as the thermal source of the MED, the RO required electricity is supplied by the electricity generated from the PB and the RO connected to the electricity grid. The results of that work have shown that the coupling of the RO unit to the electricity grid has the minimum Levelized Water Cost (LWC) among the other arrangements.

Several studies have been reported concerning the integration of the MED with SRC and SROC plants. P. Palenzuela et al. [20] have investigated the integration of the RO and MED desalination units with the SRC (PTC) plant. The effect of the desalination system specific electric consumption and exhaust steam temperature on the efficiency of the both plants has been considered. The results of that work have shown that the integration of a MED unit with the PTC/SRC plant is more efficient than the other plant with RO desalination unit. The comparisons have been made based on a specific solar radiation level for 1 h of a typical year. Kh. M. Bataineh [21] has studied the performance of a thermo compressor MED/TVC unit integrated with the solar steam generation plant when it is located in Aqaba, Jordan. The water production capacity of the described plant has been considered as 50,000 m^3/day. The required solar field area, the Thermal Storage System (TES) system and thermal efficiency of the solar field have been determined for different contribution of the solar thermal energy in required thermal power of the desalination plant. The