Le 2ème Séminaire International sur les Energies Nouvelles et Renouvelables
The 2nd International Seminar on New and Renewable Energies
Unité de Recherche Appliquée en Energies Renouvelables,
Ghardaïa – Algérie 15, 16 et 17 Octobre 2012

Application of the Parabolic Trough Solar Collector Technology under the Algerian Climate

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Abstract— the present study deals with the design and performance assessment of parabolic Trough solar field. The solar field model is similar to that given by Lippek (1995) and is based on experimental measurement of the SEGS LS-2 trough collector performance. It uses a synthetic-oil heat transfer fluid (Therminol VP-1) in the collector loop to transfer thermal energy to Rankine cycle via heat exchangers train. The solar field of 113 040 m^2 surface area and of 60 MW$_{th}$ output thermal power designed for a future ISCCS or SEGS power plant, for two sites in Algeria, for the site of Tamanrasset and the second is in the region of Algiers. The studied performance parameters include the output HTF mass flow rate, the net output thermal power, the solar field thermal efficiency and the HTF pump power consumption. This is done for different direct normal irradiation (DNI) conditions and ambient temperature for the two chosen sites. The study includes also comparison of the above mentioned performance parameters and the technical aspect point of view for the two considered sites.

Keywords— Parabolic trough; Solar thermal power; Solar power plant; Concentrating solar power; Solar energy

I. INTRODUCTION

Algeria is located between latitudes 18° N and 36°N, with 2.381.741 km^2 of land area, over 70% of its area is consisted of deserts. According to study of the German Aerospace Centre (DLR), Algeria has 1.787.000km^2, the largest long term land potential for concentrating solar thermal power plants (CSP). According to the irradiation maps, the total annual direct normal irradiation ranges from 2 100 kWh/m^{2}Yr to over 2 700kW/m^{2}Yr, and it is accounted among the best insolated areas in the world, (as Algeria lies in the so-called Sun Belt) [1].

Algeria has rapid population growth, i.e. 3.8 per annum in the period from 1999 to 2003; Algeria's electricity demand is growing rapidly at 5%-7% annual rate, and will, according to Sonelgaz, require significant additional electricity [1].

Despite the fact that Algeria is among the mains producer and exporter of fossil power and has 160 trillion cubic feet of proven natural gas reserves, now it puts renewable energy in the heart of its energetic and economic politics.

Program of capacity of 22 000MW is planned for the horizon of 2030 in which 1 200MW will be for national consumption (40% from renewable energies: 37% from solar energy and 3% from wind power), and 10 000MW will be for exportation.

The program includes realisation from now till 2020 of about 60 photovoltaic and solar thermal power plants, wind farms, and hybrid power plants. This is in order to achieve global electrical capacity between 75 and 80 TWh, and between130 and 150 TWh in 2030.

In May 2011 the first Algeria's solar thermal power plant (STPP1) started in production, with overall capacity of 150MW in Hassi R'mal in which 25MW from solar.

The present study selects the plant based on parabolic trough because it has a simplest design and can be effectively integrated with conventional steam cycle plant, as well as with combined cycle plant for excellent performance and no emissions, besides parabolic trough collector is a proven technology since the eighteenth of the last century in USA and its Levelized Electricity Cost (LEC) is lower if it compared with the other options of concentration solar power.

Also the objective of the preset paper is to make simple framework for design and performance simulation of solar thermal power plant and to encourage both researchers and Algerian government and private sector to implement the STPP for future scheduled projects.

The favourable site selection include high direct radiation, flat topography, suitable water supply, access to electric transmission facilities and availability of auxiliary fuel supplies [2]. In designing and operating any SPP it is necessary to have reliable meteorological or satellite data. In the present study, two different solar radiation sites have been chosen as following:

1. The southern region (Tamanrasset: Latitude 22°.46`N, and longitude 5°.27`E) the yearly sum of direct irradiation exceeds 2200kWh/m^2 Yr [1].
2. The northern region (Algiers: latitude 36°.46`N, and 3°.03`E) the yearly sum of direct irradiation is 1489 kWh/m^2 Yr.

II. Design Criteria

The collectors are single-axes tracking and aligned on a north-south line, thus tracking the sun from east to west.

Heat transfer fluid (HTF) is pumped from the steam heat exchangers in the power cycle to east and west solar fields through the east and west supply header. The diameter of the cold header steps down as the distance from the power bloc increases to provide a roughly uniform fluid velocity in the header. Similarly, the diameter of the hot header increases as the distance to the power block decreases [3].

The parabolic collector technology is classified as medium temperature system in which the outlet heat transfer fluid is kept constant T_{out} =393°C and the pressure must kept greater than 16 bars to avoid the decomposition of the synthetic oil (Therminol VP-1) used in the collector loops.

In the present research, we have designed a solar field that consists of parallel rows (i.e.30 lops or 30 Collectors) of parabolic trough collectors with each row having 8 SCAs in series (i.e. the total is 480 Solar Collector Assembly). The number of parallel rows of the solar field will depend on the designed power output required. It has been decided to design a solar field having an output thermal power of 60MW$_{th}$ with 113 040 m^2 total area designed for a future ISCCS or for a SEGS systems.

(STPP Gross electrical power output) = (solar field output thermal power) (power block efficiency) (electrical generator efficiency).

The HTF undergoes significant volume changes over a day due to changing average temperature. To accommodate this effect, an expansion vessel is located between the solar field and the heat exchanger train.

For the designing and selection of solar power systems, the following data is considered.

- Detailed solar data for specific site;
- The consumer demand profile at the same site;
- The performance characteristics of the solar collectors.

TABLE I

Specification of Parabolic Trough Solar Collector Assembly [4]

Collector type	LS-2
Aperture width (m)	5
Length (m)	47.1
Optical efficiency (%)	73
Focal length, (m)	1.84

To investigate the effect of climatic conditions on the output power and the efficiency of the solar field, we have used both the ambient temperature and the direct normal irradiation for the two sites as the input for the performance assessment of the designed parabolic trough solar field.

III. Parabolic Trough Field Simulation

The parabolic trough solar field is similar to that of Lippek (1995), and is based on experimental measurements of the SEGS LS-2 trough collector performance (Dudley et al., 1994). The SEGS IV operators control manually the flow rate of the Therminol VP-1 synthetic-oil heat transfer fluid (HTF) through the field of parabolic collectors. Normally, the flow is adjusted to maintain roughly a constant inlet and outlet field temperature, T_{in}=293°C and T_{out}=393°C [5].

The required mass flow rate of HTF is calculated from a first-law energy balance on the field.

$$\dot{m} = \frac{\dot{Q}_{net}}{Cp(T_{out}-T_{in})} \qquad (1)$$

where,

$$\dot{Q}_{net} = \dot{Q}_{abs} - \dot{Q}_{pipe} \qquad (2)$$

the absorbed power [6], [7] is described by

$$\dot{Q}_{abs} = DNI_{incid} A_{ap} IAM(M)\, S\big(Opt_{eff} - 0.007276 * \Delta T\big)$$
$$-0.496 * \frac{\Delta T}{DNI_{incid}} - 0.0691 * \frac{\Delta T^2}{DNI_{incid}} \qquad (3)$$

where,

$$\Delta T = \frac{T_{out} + T_{in}}{2} - T_{amb} \qquad (4)$$

and the incident angle modifier [6] is given by

$$IAM = \cos(\theta_i) - 0.00035120\theta_i - 0.00003137 \qquad (5)$$

S, considers shading of parallel rows [8]

$$S = \frac{L_{Spacing}}{W} * \frac{Cos(\theta_z)}{Cos(\theta_i)} \qquad (6)$$

M, factor describes the end losses [6], [7] is given by

$$M = 1 - \frac{f \tan(\theta_i)}{L_{SCA}} \qquad (7)$$

DNI_{in} is the incident direct normal irradiation. Opt_{eff} is the optical efficiency of the absorber tube, Q_{pipe} accounts for losses in the piping, is the incident angle and L_{sca} is the length of the solar collector assembly and A_{ap} is the total aperture area of the solar field. The above experimental equations are for cermet coated stainless steel receiver tube and vacuum in annulus.

The pressure loss in the flow to the outermost loop defines the pressure loss in the flows through all of the loops. This can be calculated using the standard Darcy-Weisbach equation [9], this is done by dividing the length of one loop to six equal segments, and calculate the Reynolds number and all needed physical proprieties of the HTF at the average temperature for every segment.

To achieve the design and performance of the proposed solar field, a computer program was built from zero using Matlab.

TABLE II

BOUNDARY CONDITIONS FOR THE SIMULATION

Pressure at collector outlet	27 bar
Pressure drop across the collector loop at design point	26.67 bar
Pressure drop across the heat exchangers train, HTf side at design point	3.6 bar
Oil temperature at outlet	393°C
Oil temperature at inlet	293°C
HTF mass flow rate at design point	236.22 kg/s
Direct Normal Irradiation at design point	850 W/m^2
Inner diameter of the absorber	65.5 mm
Reference HTF pump efficiency	0.6
Reference HTF pump power	1.62 MW_e
Spacing between 2 rows	15 m

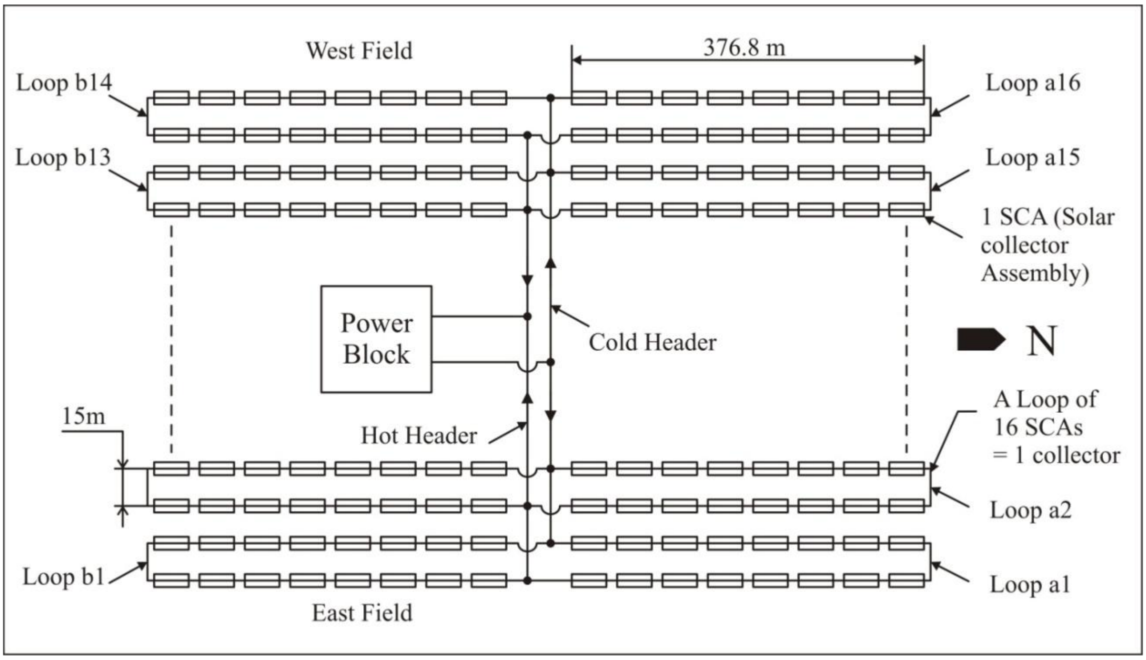

Fig.1 Layout of the designed solar field

IV. RESULT AND DISCUSSIONS

The performance of the suggested solar field design was analysed. It can be seen as in from fig. 2 when the solar radiation increases, the output thermal power and the heat transfer fluid mass flow rate increase. Approximately 10-15% of the energy absorbed by the receiver tube is not retained by the heat transfer fluid, due to thermal losses from the field to the surroundings.

It can be concluded as in fig. 3 that the efficiency increases sharply at low solar radiation and slowly from about 500W/m^2 till it reaches the peak (65%) at the designed maximum power output of 60MW_{th} it can be showing also from fig. 3 that the pressure drop across the solar field loops increases with solar radiation which causes that the HTF pump power increases to overcome this pressure losses.

An analysis of hourly thermal output, DNI and the efficiency for the two chosen sites has been carried out. Fig. 4 and 5 show the daily solar field output thermal power and efficiency on (23 June). Obviously, the output of the solar field is highest at higher solar radiation. The results have shown that Tamanrasset site is more suitable then Algiers. Finally it is known that the solar power plant works several hours in year above the design point.

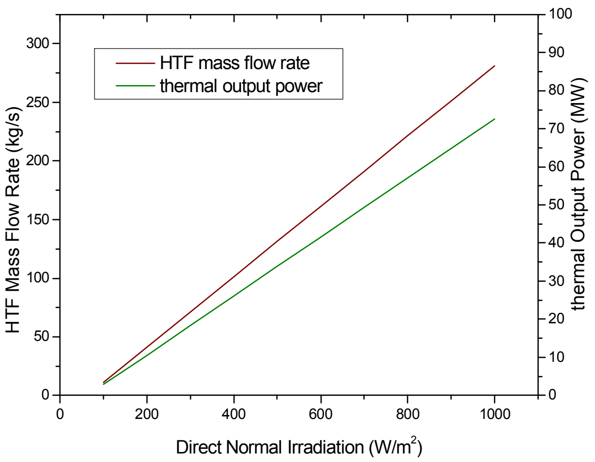

Fig. 2 The output thermal power and the HTF mass flow rate at difference normal direct irradiation and (T_{amb}=36°C)

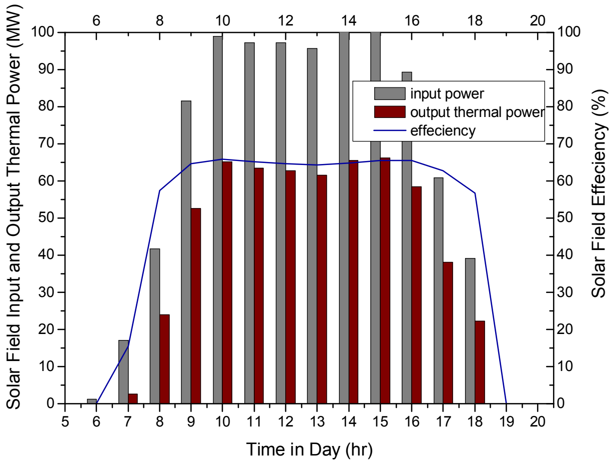

Fig. 4 The hourly thermal output, direct normal irradiation and efficiency for Tamanrasset site on 23 June

V. Conclusions

The aim of the present study is to encourage the government to achieve the scheduled program concerning the solar thermal power plant both for ISCCS and SEGS system, and to make simple framework to the Algerian researchers and designers in this field. The simulation of the designed solar field has been compared with the result of Patnode (2006) and proved to be good. It is clear that from the present study or from the precedent studies of the German Aerospace Centre (DLR) that the south of Algeria is among the best region for the STPP in the world [1], but the problem lies in the water shortage for such region for cooling, mirrors washing or reflectivity maintenance and for working water

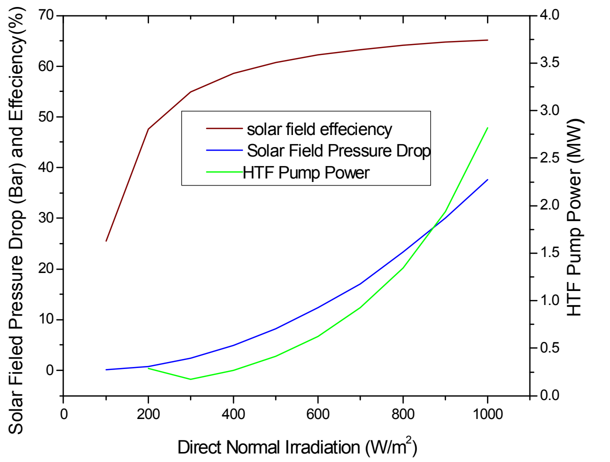

Fig. 3 The pressure drop, solar field efficiency and the HTF pump power for different solar radiation and (T_{amb}=36°C)

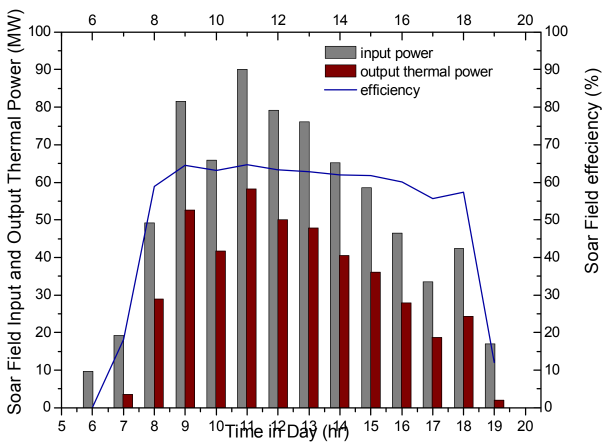

Fig.5 The hourly Thermal output, direct normal irradiation and efficiency for Algiers site on 23 June

make-up. Using cooling tower for recycling the cooling water needs about 2 kg/s of water make-up for such power plant to compensate the evaporation rate, which is between 1 and 1.5% of the circulating cooling water in one side [10]. And in other side the vapour from cooling tower suspended in air accumulates in the collector's mirrors especially with the seasonal sandy wind which causes more need of washing water and affects the reflectivity of the mirrors. The best solution is to use Air Cooled Condenser (ACC) despite that its condensing pressure is higher and as a result its efficiency is decreased if it is compared with that a using wet cooling.

ACKNOWLEDGMENT

The authors wish to thank Dr. Markus Eck and Michael Wittmann of the Institute of Technical Thermodynamic of the DLR in Stuttgart, Germany, for their help during realization of the present study.

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