Chapter 3
Feasibility Study of Linear Fresnel Solar Thermal Power Plant in Algeria

Hani Beltagy, Sofiane Mihoub, Djaffar Semmar and Noureddine Said

Abstract Clean renewable electric power technologies are important in human life, a great number of thermal solar power plants with different configurations are being considered for deployment all over the world. In this work, we propose a feasibility study of concentrated solar power plant to be set up in different sites of Algeria. It is essential that the plant design will be optimized to each specific location. Among the CSP technologies, we will emphasize on the Fresnel solar power plants at different areas of Algerian Sahara. These areas have been chosen for comparison by shifting the plant to different locations; namely Hassi R'mel, Tamanrasset, Beni-Abbes, and El Oued. Direct Normal Irradiance (DNI), solar field surface, block number, the block surface, block panels' number, absorber surface, and finally thermal power losses in the absorber are the key parameters for optimization and performance evaluation. The calculation results have been depicted for each site. Indeed, the calculation of performance varies from one site to another with DNI mean values of 788.4, 698.7, 671.7, and 636 W/m^2, respectively for Tamanrasset, Beni-Abbes, El Oued and Hassi R'mel sites. The surface of solar field, block number, absorber surface and power loss have been also evaluated for the same sites.

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3.1 Introduction

It is universally acknowledged that two of the key technological and economic challenges of the 21st century are energy and environment [1]. Consequently, considerable efforts are being made to effect a gradual transition from systems based on fossil fuels to those based on renewable energy (RE). Electricity generation from solar energy is currently one of the main research areas in the field of renewable energy. In the case of Algeria; the newly adopted version of the National Renewable Energy Program offers the country the possibility to integrate 27% of renewable energy in the national energy mix. Preservation of fossil re-sources; diversification of electricity production and contribution to sustainable development are among challenges that face the country nowadays [2]. It is recognized that solar-thermal energy can play a useful role in generating electrical power despite concerns regarding cost as the thermal source is accessible and ubiquitous [3]. The use of linear Fresnel solar power plant for electricity production, or heat supply is one of the most attractive solutions for developing countries with high sunshine because of the accessible level of technology involved [4].

In this study, our main purpose is to describe Fresnel concentrator solar plant characteristics, through defining its different performances, so that influence of changing location and climatic conditions can be seen on plant cost-effectiveness and productivity for each location i.e. Hassi R'mel, Beni-Abbes, El Oued, and Tamanrasset for Central, West, East and South of Algeria respectively.

3.2 Plant Description

The solar power plant chosen for this study is a 5 MW electric Fresnel concentrator plant which is technically similar to the German Novatec solar plant set up in Calasparra site in Spain (same make and model) (Fig. 3.1).

The design parameters of the power plant are shown in Table 3.1 (Novatec solar) [5].

3.3 Specification

In this section, we have drawn up a specification in which plant characteristics, namely Direct Normal Irradiance (DNI), solar field surface, block number, have been defined (it should be noted that a block contains reflecting mirrors, absorber

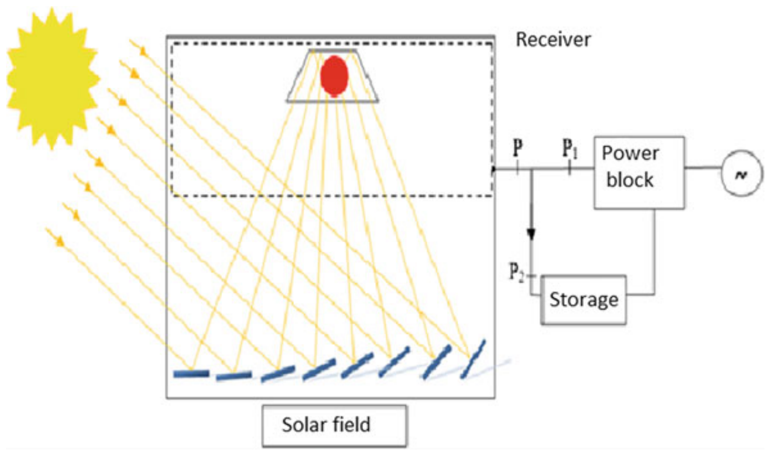

Fig. 3.1 Power plant layout

Table 3.1 Power plant characteristics

Mirror field	Solar field size Solar field length Net opening surface Field width Reflector surface Panel length Reflector length	21,571 m^2 806 m 18,489 m^2 16.56 m^2 513.6 m^2 44.8 m^2 0.75 m
Receiver	Tube diameter Receiver diameter Length reflector-absorber	0.07 m 0.6 m 7 m
Power block	Block efficiency Inlet temperature Outlet temperature Power at the generator output	35% 140 °C 270 °C 5 MW electric

tube, and steam separator). We have also defined the block surface, block panels' number, absorber surface, and finally thermal power losses in the absorber.

A. Sizing calculation

The generator output power is equal to: P_g = **5 MW$_{\mathbf{electric}}$**.

In order to supply a small city of 5000 inhabitants, whose daily consumption is **5 kWh** per family of electricity, each family is composed of **5 persons**.

B. Distribution of powers per activity

Polyclinic = **0.2 MW**, factory = **1 MW**, Administration = **0.5 MW**, other = **0.3** MW. The sum is **2 MW**, so it remains **3 MW** for inhabitants: this is the peak power needed by these places.

Therefore, inhabitants number = **1000 houses**, or: x = 1000 * 5 = **5000 people** So, the consumption of the city is **5 MWe,** it is distributed as follows:

- Polyclinic = 0.2 MW
- Factory = 1 MW
- Administration = 0.5 MW
- Inhabitants = 3 MW
- Others = 0.3 MW

The solar multiple is taken as equal to **1.6** which corresponds to **1.5 h** of storage. The selected locations are:

- West → Beni-Abbes
- Center → Hassi R'Mel
- East → El Oued
- South → Tamanrasset

Table 3.2 represents site meteorological data.

C. Calculation of plant characteristics

- DNI_{avg} calculation (direct normal irradiance)

$$DNI_{avg} = \frac{DNI_{annual}}{\text{Insolation period}} = \frac{2236}{3200} = 0.698\ \text{kW/m}^2 \times 10^3$$

= **698.7** W/m^2 for Beni-Abbes and the same calculation is done for the other locations.

- Calculation of power

$$\left.\begin{aligned} \text{Generator efficiency} &= 9.5\% \\ \text{Turbine efficience} &= 38\% \\ \text{Parasitics efficiency} &= 98\% \end{aligned}\right\} \text{we will obtain}$$

$$\eta_{bloc} = 0.95 * 0.38 * 0.98 = 0.35 = 35\%$$

Table 3.2 Site meteorological data [6]

Site selected	Beni-Abbess	Hassi R'mel	El Oued	Tamanrasset
DNI_{annual} (kWh/m^2 year)	2236	2035.5	2149.5	2759.4
$T_{amb,\ avg}$ (°C)	22	22.4	21.4	22.7
Insolation duration (h/year)	3200	3200	3200	3600
DNI_{avg} (W/m^2)	698.7	636	671.7	788.4

$$p_1 = \frac{p_g}{\eta_{bloc}} = \frac{5}{0.35} = 14.28\ \text{MW}_{thermal}$$

$P = P_1 + P_2 = SM * P_1$, with SM is the solar multiple = 1.6
$P = 1.6 * 14.28 =$ **22.84 $\mathbf{MW_{thermal}}$**
So: $P_2 = 22.84 - 14.28 =$ **8.56 $\mathbf{MW_{thermal}}$**
All efficiencies and powers are shown in Table 3.3.

- Calculation of field surface for each location

If receiver efficiency = **85%** we will obtain: Optical efficiency = **45%**
So, global efficiency is obtained:

$$\eta_{global} = 0.85 * 0.45 = 0.38 = \mathbf{38}\%$$

$\eta_{global} = \frac{p}{A*\text{DNI}} \Rightarrow A = \frac{P}{n_g*\text{DNI}} = \frac{22.84\times10^3}{0.38*0.698} = 86,000\ \text{m}^2$
For Beni-Abbes, and the same calculation is done for the other locations.
"A" represents field surface.

- Calculation of block number and surface of each block

The size of (Novatec) plant solar field is S = **21,571 m²**
This plant contains **2** blocks, each block has a power of **0.7 MW** electric

$\frac{A}{S} = \frac{86,000}{21,571} = 3.98$ is the number of block for a power of **0.7 MW** electric

$3.98 * 2 = 8$ blocks is the number of block for a power of **1.4 MW** electric
"A" is the block surface.
The surface of a block is given by:

$A = \frac{86,000}{8} = 10,750\ \text{m}^2$ for Beni-Abbes and the same calculation is done for the other locations.

Table 3.3 Efficiencies and power [5]

Generator output	5 MW (%)	Global efficiency	38%
Generator efficiency	95	Solar multiple	1.6
Turbine efficiency	38	Number of storage hours	1.5 h
Accessory efficiency	98	Input temperature	140 °C
Power block efficiency	35	Output temperature	270 °C
Optical efficiency	45	Power P_1	14.28 MW_{th}
Receiver efficiency	85	Power P_2	8.56 MW_{th}

Table 3.4 Plant characteristics in each site

Selected locations	BA	Hassi R'mel	El Oued	Tam
DNI_{avg} (W/m^2)	698.7	636	671.7	788.4
Solar field surface	86,000	94,000	89,000	76,000
Block number	8	8	8	7
Block surface (m^2)	10,750	10,804	10,853	10,857
Unit number of a block	21	21	21	21
Actual absorber surface (m^2)	564.48	564.48	564.48	564.22
Total surface of absorbers (m^2)	4515.8	4911	4628.7	3949.5
Lost power (W)	2.93×10^6	3.19×10^6	3×10^6	3.5×10^6

- Calculation of actual absorber surface

Absorber unit surface is: $L * D$
L represents unit length = **44.8 m**, D represents receiver diameter = **0.6 m**
$A_{abs;\ unit}$ = 44.8 * 0.6 = **26.88 m^2**
Each block contains a unit whose surface is 513.6 m^2

$$\text{Unit Number} = \frac{\text{Block surface}}{\text{Unit surface}}$$

$$\frac{10,750}{513.6} = 21\,\text{units}$$

So: $A_{abs\ actual}$ = Number of units multiplied by unit absorber surface.
= 21 * 26.88 = **564.48 m^2** is the absorber surface in a 0.7 MW block.

Total surface of absorbers is calculated by multiplying the result of block number by the actual absorber surface.

S_{Total} = 8 * 564.48 = **4515.8 m^2** for Beni-Abbes and the same calculation is done for the other locations.

- Calculation of lost power

$P_{loss} = U_L * A_{abs\ actual} * \Delta T$
We have: T_{in} = **140 °C**, T_{output} = **270 °C**, U_L = **5 W/m^2 °C**
P_{loss} = 5 * 4515.8 * 130 = **2.93 * 106 W** for Beni-Abbes and the same calculation is done for the other locations. Final results are shown in Table 3.4

Table 3.5 Comparative study

Selected sites	Hassi R'mel	Tamanrasset	Beni-Abbess	El Oued
DNI_{avg} (W/m^2) [M1]	636	788.4	698.7	671.7
Power (MW) [Ml]	5	5	5	5
Power (MW) [SAM]	4.74	5.01	5.14	45.43
Error (%)	5.12	0.37	2.7	7.9

3.4 Results Analysis

As a comparison, we want to check the results found in the first part, then validate them through drawing up specifications in which different plant performances are defined, while using a global calculation method. These performances have been calculated, through using a DNI calculated on the basis of annual normal irradiation ratio to sunshine hours. We propose to verify hereafter these results with those found by SAM simulation software [7]. Simulation of energy performance is carried out in another study using a SAM simulation software, as well as the techno-economic study [8]. A comparative study is made while taking a representative day of the year (21st June, the longest/hottest), we took the DNI values, and then recalculate the power output to adjust the results for each site.

The results are shown in Table 3.5.

M1 shown in the table depicts the first calculation method (the global method set forth in the specifications). According, this comparative study aiming at the verification of the results obtained in the global method with those calculated by SAM simulation software, we notice that the output power varies from 4.74 to 5.43 MW, so we can see that there is a slight difference between powers calculated by both methods, and according to the calculations show a difference of less than 8%. The results found by the global method used for the cases studied here are quite satisfactory.

3.5 Conclusion

The study we carried out on Linear Fresnel Concentrator Solar Power Plant allowed us to understand the operating system of this type of plant, as well as the parameters affecting its operation and performances. We have also noticed that the blocking and shadowing effects between mirrors and the cosine effect represent a great obstacle for the power plant cost-effectiveness and productivity. According to this study, we were able to notice the importance of a good choice of the power plant site, as each site is characterized by its direct radiation, ambient temperature, sunshine hours, wind speed, latitude, height above sea level, and other factors which play a key role in the power plant cost-effectiveness and productivity.

This is clearly shown in the results obtained according to which the plant different parameters and characteristics vary when it is shifted in different sites.

According to the results obtained for the plant different characteristics in the 4 sites, we can see that Algeria has great opportunities to choose this kind technology i.e. linear Fresnel concentrator solar power plant.

Finally, we can conclude that, among the above-mentioned sites, the most suitable on performance basis is Tamanrasset followed by Beni-Abbes, then El Oued, and finally Hassi R'mel.

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References

1. R.E. Smalley, Future global energy prosperity: the terawatt challenge. MRS Bull. **30**, 412–417 (2005)
2. S. Mihoub, A. Chermiti, H. Beltagy, Methodology of determining the optimum performances of future concentrating solar thermal power plants in Algeria. Energy Int. J. **122**, 801–810 (2017)
3. B. Srimanickam, M.M. Vijayalakshmi, E. Natarajan, Experimental performance assessment of single glazing flat plate solar photovoltaic thermal (PV/T) hybrid system. Prog. Ind. Ecol. Int. J. **9**(2), 111–120 (2015)
4. H. Beltagy, D. Semmar, L. Christophe, N. Said, Theoretical and experimental performance analysis of a Fresnel type solar concentrator. Renew. Energy Int. J. **101**, 782–793 (2017)
5. http://www.Novatecsolar.com
6. ONM/ Office National de la Météorologie, ministère des transports, Algeria
7. http://www.Nrel.Gov/Analysis/Sam
8. H. Beltagy, D. Semmar, N. Said, Performance of medium-power Fresnel Concentrator solar plant in Algerian sites. Energy Procedia **74**(2015), 942–995 (2015)