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Techno-economic analysis of a thermodynamic solar power plant based on molten salts in different sites in Algeria

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Abstract

The use of renewable energies is one of the solutions to reduce CO_2 in the atmosphere and to satisfy our energy needs. Because, the exploitation of fossil energies such as carbon, gas and oil are responsible for the disruption of the climate system and the considerable increase of the temperature during the year and especially during the summer season as well as the atmospheric pollution.Algeria is one of the countries that is committed to this strategy and policy. This study presents a numerical simulation of a concentrated solar power plant with Fresnel mirror solar concentrator and thermal storage system. This study is carried out in the regions of Tamanrasset, Laghouat and Mascara. The SAM (System Advisor Model) software was used to calculate the DNI (Direct Normal Irradiation) of each region, the wind speed, the nominal and real LCOE (Levelized Cost Of Electricity) and the annual water consumption of the plant. The results of this simulation show that the Tamanrasset site is better selected with the annual capacity factor (CF) was 47.2%, the annual amount of water consumed is about 38709 m^3. The nominal and real (LCOE) are 14.57 ¢/kWh and 11.56 ¢/kWh, respectively.

Keywords: LCOE, Efficiency, SAM.

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1. Introduction

Fossil energies such as oil, gas, nuclear and coal have been considered as engines for the development of societies, especially for producing electricity and heating. Unfortunately, the exploitation of these energies without conscience by man has caused drawbacks and problems that threaten our planet, Because, man exploits all these energies as if they were inexhaustible and sustainable, among its consequences; greenhouse gas emissions, global warming, pollution, etc. At present, there is no other choice but to find sources that can replace these fossil resources and face climate problems. Renewable energies are one of the solutions that can deal with the above-mentioned problems and can replace fossil energies. Renewable energies use natural resources such as (the sun, wind, waterfalls, tides, plants earth, etc.) to convert them into other energy sources such as electricity and heat. The electrical and heating energy produced by renewable energies are classified as follows; marine energy (0.01%), solar energy (0.6%), geothermal energy (1.7%), biomass (6.3%), and wind energy (7%) [1-2-3]. Algeria is one of the countries that have thought about the dynamics of green energy and the development of renewable energy, among its objectives is to engage in a new energy strategy based on renewable and sustainable energy [4]. Algeria is considered among the countries that receive a really important potential in solar energy, due to its great Sahara whose annual average irradiation in this region is very favorable as shown in Figure 1.

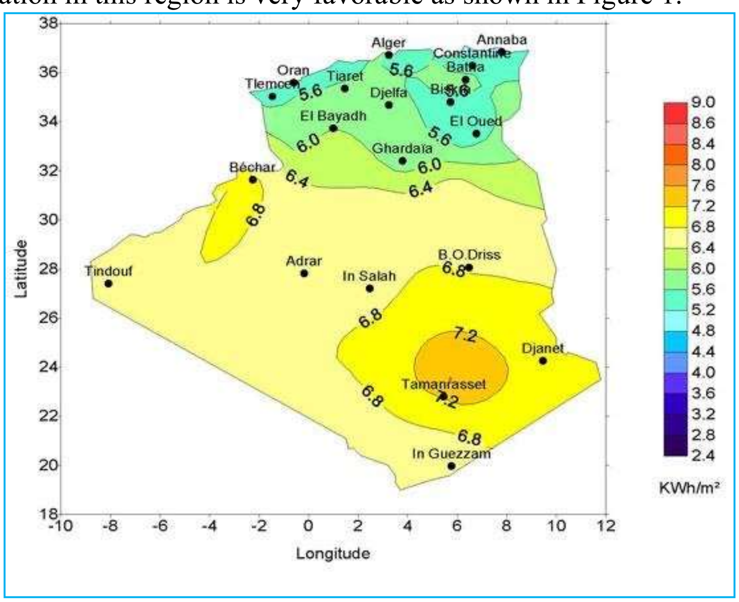

Figure 1. Global solar radiation in Algeria [5]

2. Method

The plant studied is a concentrating solar power plant with Fresnel mirror, with a power of 100 MWe, its characteristics are detailed in the table below and in Figure 2.

Table 1. Characteristics of the solar power plant studied.

Style name	**Brief description**
Sites	Mascara,Laghouat,Mas-cara
Single loop aperture	8217.6 m^2
Actual number of loops	53
Field inlet temperature	230°C
Field outlet temperature	440°C
Fossil fill fraction	0
Condenser type	Air-cooled
Storage HTF	*Hitec Solar Salt*
Thermal Storage	4h

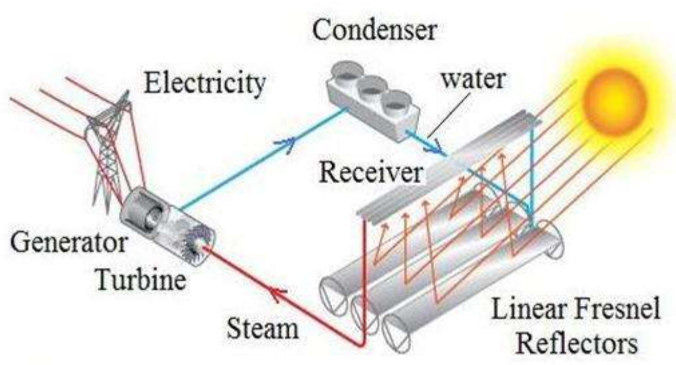

Figure 2. Solar power plant with Fresnel collector**.**

2.1 Mathematical models

Most models are based on the energy balance of the solar concentrator which includes thermal losses, optical losses and direct solar radiation, this balance allows us to calculate the useful power delivered by the receiver which is given by the following formula :

$$Q_u = Q_{ab} - Q_l \tag{1}$$

The power lost is given by the following expression:

$$Q_l = U_l S_{ab}\left(T_f - T_a\right) \tag{2}$$

The absorbed solar power is as follows [6]:

$$Q_{abs} = S_c I_d IAM \eta_{opt} K_{ex} K_o \tag{3}$$

With : I_d direct radiation given by the following formula [7]:

$$I_d = DNI * cos(\Phi) \tag{4}$$

The final power produced is given by the following formula:

$$P_f = Q_u \eta_{th} \tag{5}$$

η_{th} : the thermal efficiency given by the following relation [8]:

$$\eta_{th} = Q_f / Q_a \tag{6}$$

With; Q_f, Q_a useful power delivered by the heat transfer fluid, power absorbed by the receiver.
The factor capacity is given by the following formula:

$$CF = \frac{P_e}{P_n} \tag{8}$$

3. Results and discussion

Using SAM (System Advisor Model) software, we simulated and determined the different characteristics of the Fresnel collector solar power plant, the meteorological data of all sites are sorted from the NREL (National Renewable Energy Laboratory) database. The Figure 3 shows the annual average wind speed at three sites (Tamanrasset, Laghouat and Mascara). It can be seen that the wind speed is not really violent on the different sites during the whole year, the maximum value is 5.45 $m.s^{-1}$ in Laghouat.

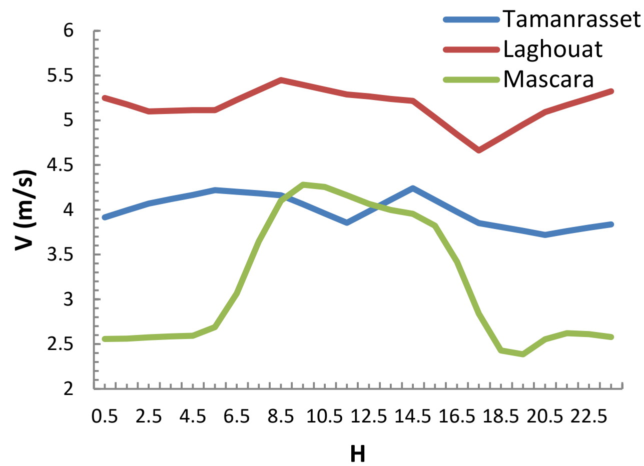

Figure 3. Annual average wind speed (m.s^{-1}).

The Figure 4 illustrates an analysis of the normal direct sunshine (DNI), we see that the curve is in the shape of a well-symmetrical bell, the region of Tamanrasset receives the maximum annual average value of direct sunshine reaches 803.9 W.m^{-2}.

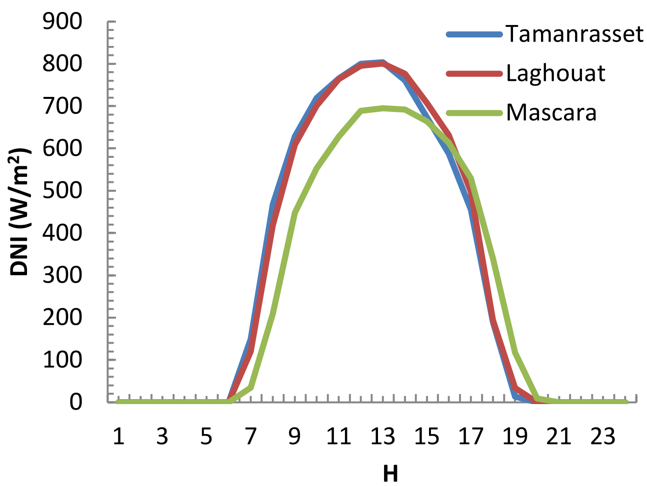

Figure 4. Average annual DNI (W.m-^{2}).

The Figure 5 shows the evolution of the yield of the solar power plant as a function of the solar multiple (SM) in the site of Tamanrasset, we see that the increase of the SM leads to the increase of the CF, we also see that when SM = 4 the yield of the plant is equal to 47.7 % beyond this value the yield increases slightly almost stable. The Figure 6 shows the annual energy delivered on an hourly scale, it is clear that the maximum annual energy delivered from the plant is about $3{,}38*10^8$ KWh obtained in the site of Tamanrasset, $3{,}32*10^8$ KWh in Laghouat and $2{,}83*10^8$ KWh in Mascara.

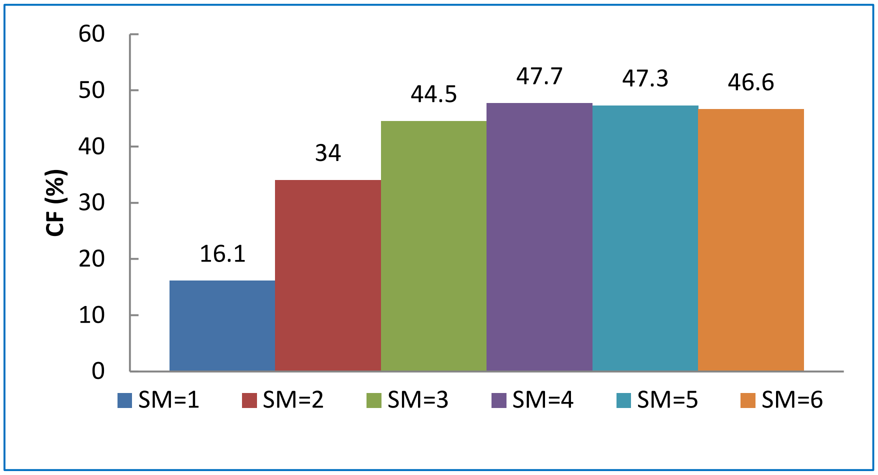

Figure 5. Capacity factor as a function of Solar Multiple.

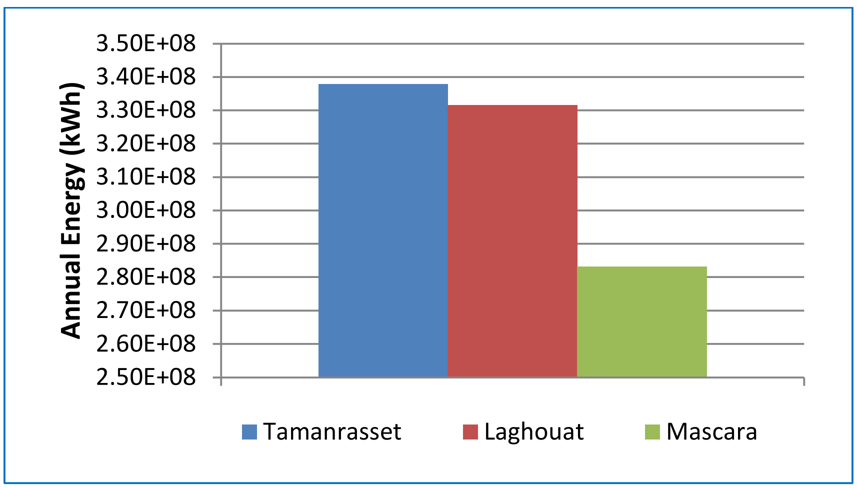

Figure 6. Annual energy delivered in (KWh).

The table below represents the tenico-econimic characteristics of the central soil in the regions of Tamanrasset, Laghouat and Mascara.

we have taken into consideration the following parameters; Levelized COE (nominal), Levelized COE (real),Net savings with system (year 1) and Net capital cost. This study allowed us to make a better decision to install this type of Fresnel mirror solar power plants. The results clearly show that the site of Tamanrasset provides a good efficiency and a less LECO.

Table 2. Technical and economic data sheet of the solar power plant in the regions of Tamanrasset, Laghouat and Mascara.

Metric	Tamanrasset	Laghouat	Mascara
Annual energy (year 1)	413 MWh	331 MWh	283 MWh
Capacity factor (year 1)	47.2%	37.8%	32.3%
Annual Water Usage	38,709 m^3	30,245 m^3	26,189 m^3
Levelized COE (nominal)	14.57 ¢/kWh	13.42 ¢/kWh	15.65 ¢/kWh
Levelized COE (real)	11.56 ¢/kWh	10.65 ¢/kWh	12.43 ¢/kWh
Electricity bill without system (year 1)	$104,412	$104,412	$104,412
Net savings with system (year 1)	$11,306,717	$-8,929,897	$7,626,305
Simple payback period	NaN	NaN	NaN
Net capital cost ($)	773,143,488	546,813,184	546,813,184
Equity ($)	386,571,744	273,406,592	273,406,592

4. Conclusion

In this study, we examined the effect of wind speed, solar radiation, efficiency and annual energy delivered in different sites in Algeria was presented, The simulation was carried out using the SAM software, we took the weather conditions of Tamanrasset, Laghouat and Mascara. The results obtained in this work have allowed to make the following conclusions:

- ✓ The site of Tamanrasset is the most favorable site with optimal delivered annual energy is 413 MWh.
- ✓ The Direct Normal Irradiation (DNI) for all regions is very encouraging for the installation of Fresnel collector solar plants, the optimal value obtained is 803.9 $W.m^{-2}$.
- ✓ The efficiency of the solar power plant increases proportionally with Multiple Solar.

- ✓ It is also concluded that the site of Tamanrasset is more optimal and favorable compared to the other sites examined, the values of Levelized COE (nominal) and Levelized COE (real) are 14.57 ¢$/kWh and 10.46 ¢$/kWh, respectively.
- ✓ Wind speed is not a disadvantage at all sites and does not pose a risk for Fresnel mirror solar plants.

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