Techno-Economic Study of Linear Fresnel Solar Thermal Power Plant in Algeria

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Abstract— **The objective of the present work is to characterize a power plant with concentrator of Fresnel on various Algerian sites (Sahara). These sites were chosen for comparison by moving the power plant in the Algerian sites: Hassi-R'mel, Tamanrasset, Béni-Abbes, and El Oued. A technico-economic study was made to determine the various characteristics of the power plant. This study is carried out through a simulation in the hourly scale: it concerns the insolation, the system 'field', and the 'receiving' system. The results of the simulation are represented on annual average. Annual energy production and the cost per kWh are evaluated, the technico-economic results are also estimated for the same sites, and the results are compared for the purpose of site classification.**

Keywords— *solar energy; solar concentrator mirrors; thermoelectric plants, Fresnel solar thermal power plants; Techno-economic performance.*

I. INTRODUCTION

Energy consumption worldwide is increasing rapidly due to increasing global population and industrialization processes in many countries [1]. Consequently, considerable efforts are being made to effect a gradual transition from systems based on fossil fuels to those based on renewable energies. In Algeria, it has been announced in the renewable energy and energy efficiency program a new motivated CSP projects. In this ambitious program, CSP plants represent about 70 % of the total power projects to be installed [2, 3]. Moreover CSP can be a competitive source of bulk power in peak and inter mediate loads in the sunniest regions by 2020, and of base load power by 2025-2030 [4].

Renewable energies are at the heart of the 2011-2030 energy development program adopted by the Government in 2015. The program includes development of photovoltaic and wind energy, the use of waste biomass, cogeneration, and geothermal. It also postpones solar thermal (CSP) to 2021. To meet national market need over the 2015-2030 period 22000 MW is required, of which 2000MWis to come from solar thermal and it is to be expanded to be more than 4500 MW by 2030.

Concentrated solar power (CSP) is unique among solar energy technologies because it has been operating commercially at utility-scale since 1985, and it generates electricity with a thermal power cycle similar to that used in conventional fossil fuel-fired power plants **[5].**To extract electricity from solar radiation, the power plants use the technology of solar concentration. CSP technologies now constitute feasible commercial options for large scale power plants aswell as for smaller electricity and heat generating devices.

The main objective in this present work is to perform a theoretical modeling of a solar power plant equipped with concentrator of Fresnel, in such a way of being able to simulate it in various Algerian sites and to adapt it to the weather conditions of Algeria. This simulation will let the reader compare the annual deliverability of a 5 MWe power plant in different chosen sites and to evaluate the price of kWh product (L.E.C) for each situation: HassiR'mel for the Center, Béni-Abbes in the West, El Oued for the East and Tamanrasset for the South.

II. METHODS

SAM (solar advisor model) The System Advisor Model (SAM) is a performance and financial model designed to facilitate decision making for people involved in the renewable energy industry [6]. SAM makes performance predictions and cost of energy estimates for grid-connected power projects based on installation and operating costs and system design parameters that you specify as inputs to the model, it is developed by NREL

and it uses TRNSYS as a transient simulation code [6]. This work methodology is divided in this way:

• Collecting data: economical and meteorological data.

• Simulation: using SAM with entering all collected data and try to use all avail-able information.

• Discussing the results: to know and to decide the validity of the project.

The simulation is divided into two major parts, the technical and the economic one.

The solar power plant chosen for this study is a 5 MWe Fresnel concentrator plant which is technically similar to the German Novatec solar plant set up in Calasparra site in Spain [7].

All the characteristics of the said power plant are depicted in the following table [7].

TABLE I. Power plant characteristics

| Mirror field		Receiver		Power block	
Area of the solar field	21 571 m^2	Tube diameter	0.07 m	Efficiency of the plant	35 %
Length of the solar field	80.6 m	Receiver diameter	0.6 m	Inlet temperature	140 ^{0}C
Net opening area	18 489 m^2	Distance between the reflector and absorber	7 m	Outlet temperature	270 ^{0}C
Width of the field	16.56 m^2			Power output of the generator	5 MWe
Reflector surface	513.6 m^2				
Module length	44.8 m				
Length of the reflector	0.75 m				

III. RESULTS AND DISCUSSION

Figure 1 shows the hourly variations of the different techno-economical parameters for the different locations and based on the results obtained with the Software SAM. The different techno-economical parameters are mainly the annual direct irradiation IRDA, the annual energy produced, the Levelized Electricity Cost (LEC), the turnover (DA), and the number of years to recover the investment.
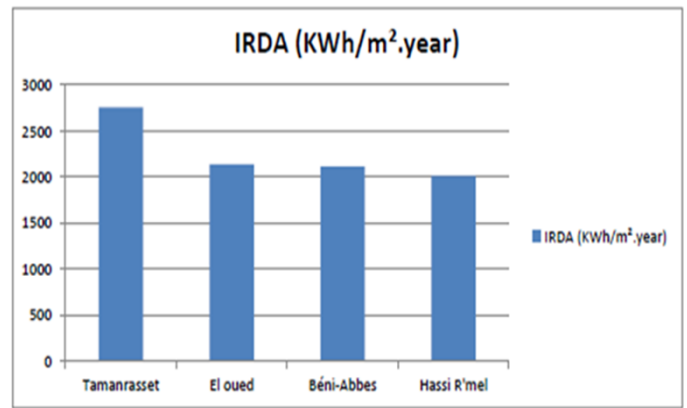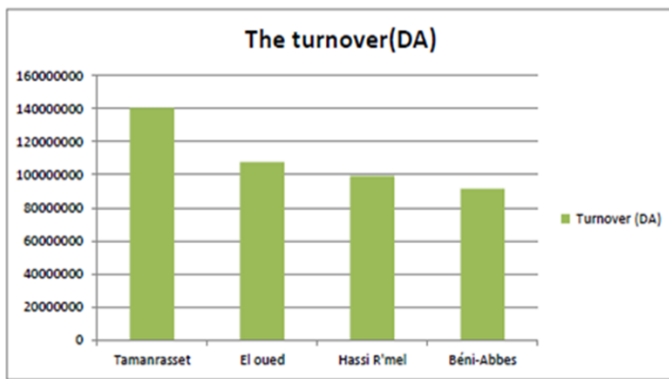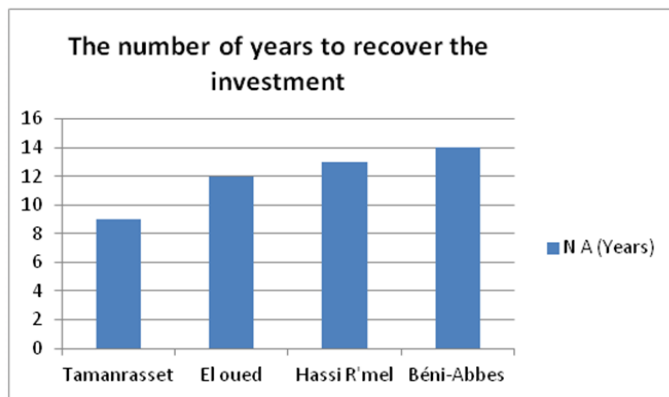
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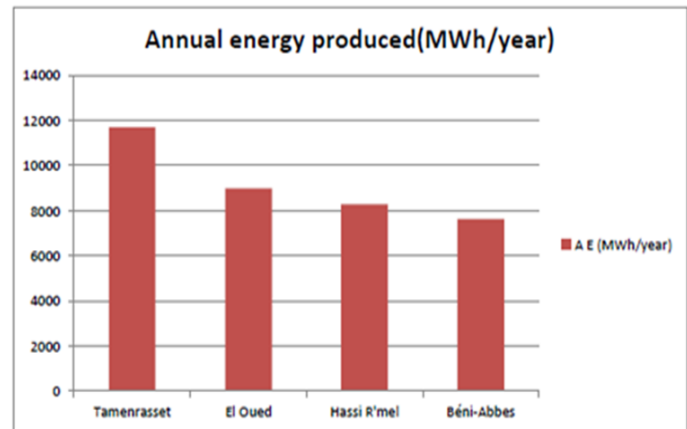
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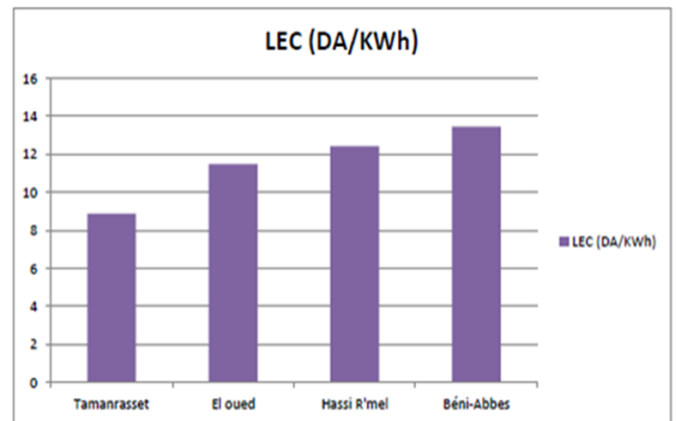
(c)

(d)

(e)

Fig. 1. Variation of the techno-economical performance for the 4 sites.

The annual direct irradiations of the sites of Tamanrasset, El Oued, Béni-Abbess, and Hassi R' mel are respectively 2759.4 kWh / m ² a year, 2137 kWh / m ² a year, 2114 kWh / m ² a year and 2008.4 kWh / m ² a year. Therefore, Tamanrasset has the most mattering solar field with an annual direct irradiation which exceeds 2500 kW / m ² a year, which returns this site the most favorable to this type of technology of solar concentration.

For the annual produced energy, one can notice that Tamanrasset appears at first also. It has a more important energy than the other sites; it is followed by El Oued, of Béni-Abbes then HassiRmel. These sites offer an annual energy respectively equal to 11 704.152 MWh, 8981.695MWh, 8280.325MWh and 7631.6 MWh.

Concerning the LEC (Levelized electricity cost), which indicates the cost updated by the electricity; the most profitable site is the one which has a weak LEC. Thus according to the Figure 1-c, the site which has a weak LEC is Tamanrasset, followed by El Oued, HassiR'mel, then Béni-Abbes, for values respectively of 8.86 DA / kWh, 11.47 DA / kWh, 12.42 DA / kWh, et13.45 DA / kWh.

The figure of affair (business) calculated for the four considered sites are obtained by multiplying the annual energy produced by the cost updated by the kWh (4DA). This gives the values of 46.816.608 DA for the site of Tamanrasset, 35.926.780 DA for the site of El Oued, 33.121.300 DA for HassiR'mel site, and 30.526.400 DA for the site of Béni-Abbes estimated at the rate of 4 DA the kWh (cost practised by Sonelgaz). If one take into account the law of help suggested by the government in the power production by solar means (that is3 times the above values) [8] It returns us to recalculate the figure of affair for 12 DA the kWh and the results are the following ones: 140.449.824 DA for the site of Tamanrasset, 107.780.340 DA for the site of El Oued, 99.363.900 DA for Hassi R' mel's site, and 91.579.200 DA for the site of Béni-Abbes.

Finally so that the power plant gets back its investment, the number of years of functioning which it is necessary to get back the capital cost of the power plant should be calculated. This parameter is obtained by dividing the total cost of the power plant which is 1.287.295.660 DA by the obtained figure of affair or for 4 DA the kWh or for 12 DA, if one takes into account incentive measures. The obtained results follow those of the produced energy, as well as the figure of affair. The most profitable site is the one of Tamanrasset, followed by that of El Oued, then HassiRmel, and Béni-Abbes, with respectively durations of 27 years, 35years, 38 years, 42 years,
at the rate of 4 DA the kWh. If the calculation is done for 12DA the kWh the results are 9 years, 12years, 13years, and 14years. Here, one can clearly see the importance of the application of the decree " feed in tariff " of the ministry of the energy which allows to sell to a triple price (prize) the kWh, by taking Tamanrasset for example, from 10th year the income of the power plant is 100% earnings (gains).

Selected locations	HassiR'mel	Tamanrasset	Béni-Abbés	El Oued
Annual radiation (kWh/m².year)	2008.4	2759.4	2114	2137
Net annual energy (MWh)	8280	11 704	7631	8981
LEC (DA/kWh)	12.42	8.86	13.45	11.47
Turnover for the kWh 4 DA	33 121 300	46 816 608	30 526 400	35 926 780
Turnover for the kWh 12 DA	99 363 900	140 449 824	91 579 200	107 780 340
Gain for the kWh 4 DA	2 594 900	16 290 208	0	5 400 380
Gain for the kWh 12 DA	7 784 700	48 870 624	0	16 201 140
Percentage of gain (%)	7.83	34.7	0	15
Number of years of profitability (4DA)	38 years	27 years	42 years	35 years
Number of years of profitability (12DA)	13 years	9 years	14 years	12 years

IV. Conclusion

This work concerned a comparative study of the techno-economical performance of a Fresnel concentrator based solar power plant for different locations in Algeria: HassiR'mel, Tamanrasset, Béni-Abbés, and El Oued. The different techno-economical parameters investigated are mainly the annual direct irradiation, the annual energy produced, the Levelized Electricity Cost, the turnover, and the number of years to recover the investment. Software SAM was used to perform the calculations supported by weather conditions related to the Algerian sites.It is shown that the most promising site for application of the power plant is the site of Tamanrasset with a net annual energy of 11 704 MWh, a levelized electricity cost of 8.86 DA/kWh, a turnover at 4 DA kWh of 46 816 608, a gain percentage of 34.7 %, and a number of years of profitability of 27 years.

Acknowledgements

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