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Techno Economic Evaluation of Solar Dish Stirling System for Stand Alone Electricity Generation in Algeria

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Abstract: The Concentrated Solar Power (CSP) electricity production technology incorporates three essential and different designs: the parabolic trough, the power tower and Dish Stirling system. The Dish Stirling system consists of four components; the parabolic Dish, the thermal receiver, the Stirling engine and electrical generator. The modern Dish Stirling systems are recognized as the most efficient of the existing technologies for the solar to electricity conversion by converting nearly 31.25% of direct-normal incident solar radiation into electricity. On the other hand, these systems have reached in different countries around the world an important reliability degree and their cost has considerably decreased during the lasts years. Since 1970, several Dish Stirling systems ranging in size from 5-50 kWe were developed, installed and tested worldwide (USA, Spain, Germany, Italy, Australia…). This study presents, the results of an investigation concerning the application of two configurations of Dish Stirling system (prototype, mature) in order to use it as stand alone systems under the Algerian climate for three different sites (Algiers, Bechar and Tamanrasset). Furthermore, this study presents, the social and environmental impacts of using this technology. An analysis of the daily performances, monthly performances and annual performances for the three sites has been presented. In addition, an economic assessment of these systems has been performed. The results show that both Tamanrasset and Bechar are more suitable than Algiers site for the implementation of the Dish Stirling systems. Finally, we note from this study that the use of a Dish Stirling system for electricity production is competitive to both photovoltaic and conventional technology in the south of Algeria. Consequently, its application is suitable in the isolated rural areas.

Key words: Dish Stirling system, eurodish, global efficiency, levelised energy cost, paraboloidal concentrator, power output, solar energy, techno economic

INTRODUCTION

In Algeria, oil and gas are the most important natural resources, which provide energy, generate electricity and finance the development. It is obvious that resources are limited and lead to pollution.

Algeria's electricity demand is growing rapidly (average of 7% year^{-1}) due to industrial, commercial and residential sector growth, including the Sahara that represents 86% of the total surface of Algeria. In these isolated regions, the density of the population is very low, the solar radiation potential is very important and the habitats are dispersed.

The use of the conventional energy sources requires high costs and the extension of the electric networks finds enormous problems. According to some estimates, >5 million Algerians do not have access to grid electricity (Himri *et al*., 2009a). In these rural areas, diesel generators are used in most cases for power generation and feed separated network, although these devices have undesirable environmental effects and present a problem of fuel transportation. In this way, 175 MW is generated by using 183 diesel generators with individual rating between 0.35 and 8 MW.

Currently, Algeria envisages the substitution of the fossil energies by other sources. The market of renewable energies (especially, solar energy) is promising and their promotion constitutes one of the large axes of the energetic and environmental policy of Algeria. In this context, the government of Algeria has committed itself to

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develop solar energy as its largest renewable energy source; to cover 5% of the national electricity needs by 2010 with renewable energy (Abbas *et al*., 2009).

It is to note that the use of renewable energy is still at the beginning in spite of the financing of several prototypes by the state. The major problems are certainly identified but very difficult to solve: high costs, customs taxes and more particularly the low price of the fuel. The price of the diesel liter is one of the lowest prices in the world (Bouzidi *et al*., 2009). In spite of these barriers, many efforts are being realized in Algeria to satisfy the energy requirements and for various applications by the Photovoltaic systems and the Concentrating solar power technology.

In this context, Algeria has established a national program in 2000 for rural electrification of 20 village of 1000 habitation (Benatiallah *et al*., 2007) spread out among the four Wilayas in the south (Tindouf, Tamanrasset, Adrar and Illizi) using photovoltaic solar system installation in order to satisfy the domestic needs in electricity and pumping of water. The overall installed photovoltaic power is about 1.2 MW (Himri *et al*., 2009b). Concerning the thermal solar power and after the visit of the START (Solar Thermal Analysis, Review and Training) team of Algeria in 2003, NEAL's (New Energy Algeria, created in 2003) first initiative is to build the Algeria's first large solar thermal power plant (Geyer, 2003). It is a hybrid 140 MW Integrated Solar Combined Cycle System (ISCCS) with 30 MW of solar output. This project is the background of several hybrid (solar-gas) power plants that will be realized in the next future in order to take advantage of the ideal opportunities combining Algeria's richest natural gas with Algeria's most abundant solar energy source.

Hereinafter, the state of art of the techno economical studies applied to Dish Stirling systems will be described in order trying to highlight the actual commercial and economic situation of Dish Stirling system.

Theocharis *et al*. (2003) present an economic of the feasibility study for a solar power system based on the Stirling Dish as a parameter to alleviate the energy system of the Cretan system. The study find that only the massive production of solar Stirling systems could provide a long-term economical feasible solution. The technical and economic evaluation shows that the Stirling Dish technology offers a technical feasible and economic viable solution under some conditions such as: system purchase price 550 kW^{-1}; solar radiation 1700 kWh m^{-2}; annual generated electricity 69.711 MWh; electricity sale price 0.073 € kWh^{-1}.

Beerbaum and Weinrebe (2000) analyze the potential and the cost-effectiveness of centralized and decentralized Solar Thermal Electricity generation in India (Dish Stirling technology included). They used the comparison between the Levelized Electricity Costs (LEC) for the Solar Thermal Electricity, for three different insolation levels, with the corresponding LEC for the electricity generating options used in India. The calculations show that the LEC of Dish Stirling system range between 11.3-15.8 cents$ kWh^{-1} for centralized energy generation. Concerning the decentralized energy generation option the LEC range from 16.9-23.9 cents$ kWh^{-1} with storage and from 11.7-16.5 cents$ kWh^{-1} without storage.

Pitz-Paal *et al*. (2005) have realized the ECOSTAR study. They have shown which of the various innovations aspects is the most appropriate to achieve a significant cost reduction in seven CSP systems investigated (Dish Stirling technology included). The approach used is to analyze the impact on cost of different innovations applied to a reference system (50 MWe in Spain) in order to identify those with the highest impacts. Cost and performance information of the reference systems are currently at a different level of maturity. The calculations blended LEC at the given fuel price of 15 € MWh^{-1}, result in hybrid electricity costs of 28.11 cents€ kWh^{-1} 4.6 cents€ kWh^{-1} of this amount is attributed to fuel costs. When cost of solar and fossil operation are artificially separated to split the generation cost to the solar and fossil part, the solar LEC would be 38.4 cents€ kWh^{-1} and the fossil LEC 19.7 cents€ kWh^{-1}.

The ECOSTAR study estimates that the production of nearly 3000 dish/engine units, required for a 50 MWe facility, would reduce the system cost by over 40%, to <4700 € kWe^{-1}. It is further estimated that the system availability would improve and the O and M cost would be reduced during this commercialization phase. Innovative developments leading to a larger dish concentrator size would further reduce system cost and LEC The combined LEC cost reduction due to this innovation and the number of produced systems for a 50 MWe plant would be about 50%, leading to LEC value of under 0.12 € kWh^{-1} for the entire dish/engine system.

Nepveu (2009) present an economic feasibility study of three degree of maturity of Dish Stirling system used for both electricity generation and cogeneration for two different sites in France. The results indicate that the mature system used in cogeneration has the lower LEC in the two sites chosen; it's about 0.241 € kWh^{-1} in Odeillo and 0.296 € kWh^{-1} in Vignola. This is due to the recuperation of the heat rejections from the Stirling engine.

The present study selected the implementation of a Dish Stirling system due to its high efficiency and modularity. The system can be installed to satisfy the electricity demand for the people living in the isolated and desert area of Algeria. Therefore, the object of this study is to estimate and choose the appropriate site for the implementation of the Dish Stirling system.

Also, the objective of this study is to encourage and push the Algerian government to implement these systems for future expansion of electricity supply and diversified energy sources and environmental protection.

In the present research, we have simulated two scenarios of development of the system; a prototype and a mature Dish Stirling unit of 10 kWe (Eurodish system) for decentralized electricity generation in three different sites in Algeria (Algiers, Bechar and Tamanrasset). An analysis of the daily, monthly and the annual performances of the suggested system for selected days has been presented.

In this study, the economic feasibility of these systems has been studied because the economic analysis is a way to justify the installation of a CSP plants and evaluate its profitability.

In this study, we have selected the analysis of the Eurodish Stirling system because it is one of the two systems that have already demonstrated the high conversion efficiency and maturity.

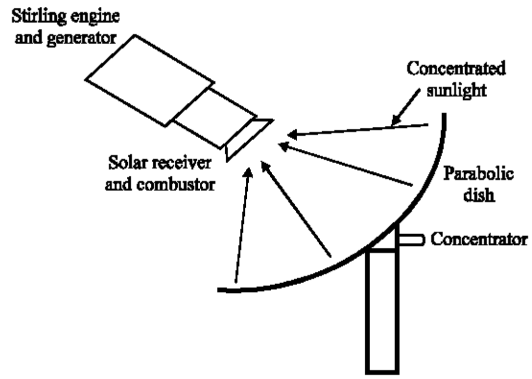

Fig. 1: The Dish Stirling system

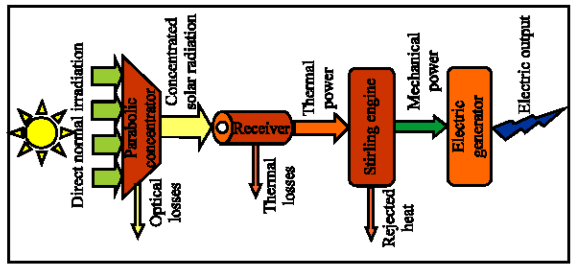

Fig. 2: The energetic chain of Dish Stirling system

Description of the Dish Stirling system: The Dish Stirling system shown in Fig. 1 consists of four components; the parabolic dish, the thermal receiver and the Stirling engine coupled with an electrical generator. The sunlight are reflected and concentrated by the dish parabolic into the receiver placed in the focal point of the dish. The receiver is designed to transfer the absorbed solar energy to the working fluid (air, helium or hydrogen) in Stirling engine. The Stirling engine then converts the absorbed thermal energy to a mechanical power by compressing the working fluid when it is cool and expanding it when it is hot. The linear motion is converted to a rotary motion to turn a generator to produce electricity, as shown in Fig. 2. In order to increases the efficiency of these systems; they must be equipped with a dual tracking solar mechanism that keeps the dish aperture always normal to the incoming solar radiation. This mechanism assures azimuth-elevation tracking or polar tracking. Larger Stirling dishes have used azimuth elevation tracking and smaller Stirling dish systems have used polar tracking (Fraser, 2008). Dish-Stirling systems have demonstrated the highest efficiency of any solar power generation system by converting nearly 31.25% of direct-normal incident solar radiation into electricity after accounting for parasitic power losses. On the other hand, these systems have reached an important reliability degree and their cost has considerably decreased during the lasts years.

The Dish Stirling system is characterized by the instantaneous power output that due to its low thermal inertia. Thus, on cloudless days the very first hours of sunshine can be exploited and daily operation time is almost as long as the daylight hours. Even on days with variable weather conditions these systems demonstrate good efficiency due to the fast system response and the efficiency of the Stirling engine under partial load. (Schlaich, 1999).

One the few disadvantages of the Dish Stirling system is its cost. However, its cost is less than the cost of a photovoltaic unit, for the decentralized electricity generation and comparable to the cost of parabolic trough systems, for the centralized electricity generation. Furthermore, the combination of technical improvements and mass production could reduce this cost by over 50%. In this context, recent cost reduction studies have already pointed out that approximately half of the cost reduction potential for CSP can be attributed to scale-up to larger plant sizes and volume production effects, whereas the other half is attributed to technology R and D efforts (Pitz-Paal *et al*., 2005).

Because the Dish Stirling systems are modular; each system is a self-contained power generator, they can be assembled into plants ranging in size from a kilowatts to ten megawatts (Mancini *et al*., 2003). They can be used for grid connected power in developing countries and in the isolated regions. They are well suited for centralized and decentralized power production. Thus, both stand-alone operation in remote areas and supply for villages or small communities is possible.

Stirling engine: A stirling cycle machine is a device, which operates on a closed regenerative thermodynamic cycle, with cyclic compression and expansion of the working fluid at different temperature levels (Thombare and Verma, 2008). It can be described as an ensemble of pistons and heat exchangers. A typical arrangement has two pistons and three heat exchangers. The pistons, a displacer and a power piston, affect the fluid motion inside the machine and the heat exchangers affect the heat transfer from the heat addition and heat rejection devices and heat flows internal to the engine. In order to obtain net positive work from the power piston, the displacer and power pistons are not in phase with each other. This phase difference is manifested in the two major categories of Stirling engines: the kinematic and the free-piston.

Kinematic design: The phase difference is controlled by a mechanical linkage, such as a crankshaft or a swash-plate, between the displacer and the power piston.

Free piston design: There is no direct mechanical linkage between the two pistons; the necessary phase difference is determined by the varying pressures in the cycle and the dynamic response of the components. The free-piston design can result in a hermetic containment with no fluid inventory losses, but the lack of a mechanical linkage between the displacer and the power piston may result in non-optimum performance. These designs promise long lifetimes with minimal maintenance requirements.

Concentrator: The size of the solar collector for Dish Stirling systems is determined by the power output desired at maximum insolation levels (1000 W m^{-2}) and the collector and power conversion efficiencies. With current technologies, a 5 kWe Dish Stirling system requires a dish of 5.5 m, in diameter. 10 kWe requires a dish of 7.5 m in diameter and a 25 kWe system requires a dish of 10 m in diameter. Because of the parabolic shape, the dishes have concentrations ratios ranging from 600-2000 and they can achieve temperatures in excess of 1500°C (Theocharis *et al*., 2003). Concentrating reflectors can be divided in 3 categories as follows (Stine and Diver, 1994):

Glass-faceted concentrators: Use spherically curved individually alignable glass mirror facets, mounted on an approximate parabolic-shaped structure. These designs generally have high concentration ratios and they also tend to be heavy and expensive and require accurate alignment of a large number of mirrors.

Full-surface parabolic concentrators: The entire surface forms an approximately parabolic shape.

Stretched-membrane concentrators: It can be a single-facet or multifaceted. The design incorporating thin membranes stretched over both sides of a metal ring. The membranes may be thin plastic sheeting or thin metal sheeting with a reflective coating applied to one of the membranes. This technology revealed problems of behavior of materials. Nowadays, it is reserved for parabolas of smaller diameter.

Concerning the reflective surface, three types are used in concentrator designs:

- Reflective surface of aluminum or silver deposited on glass or plastic; it's the most durable reflective surfaces with a reflectance value in the range of 95%. This concept is used in many current concentrator designs (Suncatcher systems, EURODISH, WGA, big dish)
- Reflective polymer films; they have the low cost but their optical and mechanical properties get damaged after long exposure to ultraviolet rays. They are characterized by low cost, flexibility and high reflectance (96%)
- Reflected polished aluminum sheet; they have a low cost. Their major disadvantages are that they have only a moderate specular reflectance (85%) and a poor weatherability

Receiver: Receivers for dish Stirling systems are cavity receivers with a small aperture through which concentrated sunlight enters. The receiver aperture is optimized to be just large enough to admit most of the concentrated sunlight but small enough to limit radiation and convection loss. Two different heat transfer methods are commonly used in the parabolic dish receivers.

Direct-Illumination Receivers (DIR): Adapt the heater tubes of the Stirling engine to absorb the concentrated solar flux. It's capable to absorb high levels of solar flux. This type of receiver is uses in several Dish Stirling systems like EURODISH, Suncatcher and Sundish.

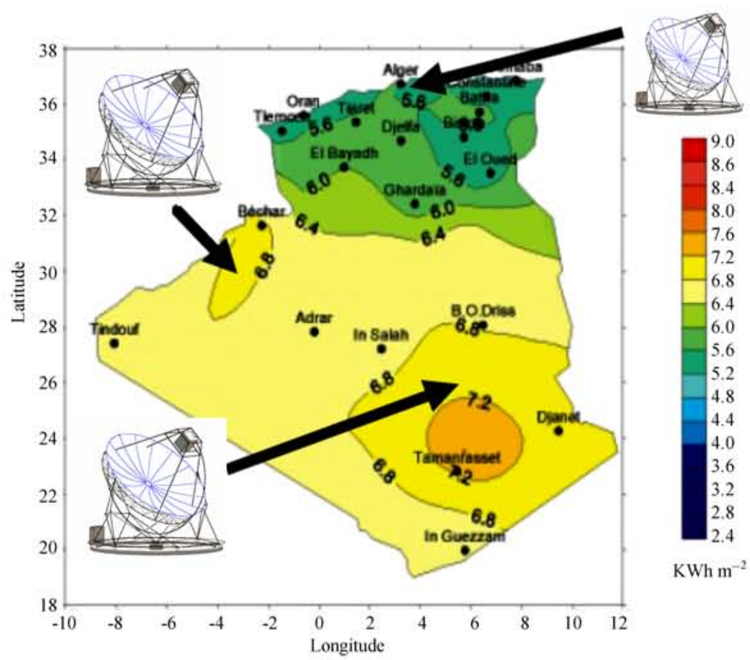

Fig. 3: Solar map of Algeria with average daily of direct normal irradiation for July month and sites chosen for implementation of Dish Stirling systems

Indirect receiver (liquid-metal, heat-pipe solar receivers): Uses a liquid-metal intermediate heal-transfer fluid, the liquid sodium metal is vaporized on the absorber surface of the receiver and condensed on the Stirling engine's heater tubes, that's assures a uniform temperature on the heater tubes.

The solar potential of Algeria: To determine the potential use of solar Dish Stirling technology for electricity generation in Algeria, one has to look first at the geographical and climatic conditions. The geographic location of Algeria has several advantages for the extensive use of the solar energy. Algeria is situated in the centre of North Africa between the 38-35° of latitude North and 8-128° longitude East, it has an area of 2, 381,741 km^2. The Sahara represents the 86% of the area of the country. The climate is transitional between maritime (North) and semi-arid to arid (middle and South).

According to a study of the German Aerospace Agency (DLR), Algeria has with 1,787,000 km^2 the largest long term land potential for concentrating solar thermal power plants. Solar radiation fall between 5.6 and 7.2 kWh m^{-2}, this corresponds to 1700 kWh/m^2/year in the north and 2650 kWh/m^2/year in the South, as shown in Table 1, it is considered as being one of the best insolated areas in the world. The average solar duration over the quasi-totality of the national territory exceeds 2000 h annually and may reach 3900 h in the Sahara.

Likewise, these results are previously corroborated by the first solar radiation Atlas for Arab world realized by ALESCO from experimental data for nearly 280 stations from 19 Arab states (Alnaser *et al.*, 2004). The solar map of Algeria has been elaborated and witnesses to the high solar potential of the country as shown in Fig. 3.

Table 1: Solar potential in Algeria: table of statistics of the sunshine hours per zone (Harouadi *et al.*, 2007)

Region	Coaster regions	High plateaus	Sahara desert
Area (%)	4	10	86
Average Solar duration (hours/year)	2650	3000	3500
Annual direct normal irradiation (kWh/m^2/year)	1700	1900	2650

It is worth mentioning that the satellites show that solar thermal installation does not appear to be economical on sites with a direct normal irradiance below 1800 kWh/m^2/year. It means that the majority of Algeria's land area lies within this range. The entire Algerian Sahara desert is a suitable area for constructing solar thermal power plant.

In the present study, a Dish Stirling system of 10 kWe is chosen to carry out investigations in three different sites that presented in Fig. 3.

Algiers: Located in the coaster region of Algeria (Latitude 36°.45'N, longitude3°.00'E, altitude 116 and the sum of direct normal irradiation is 1489 kWh/m^2/year).

Bechar: Located in the Southwestern of Algeria (latitude 31°.37'N, longitude 2°.14'W, altitude 772 and the sum of direct normal irradiation is 2417 kWh/m^2/year).

Tamanrasset: Located in the South of Algeria (latitude 22°.47'N, longitude 5°.31'E, altitude 1377 and sum of direct normal irradiation is 2691 kWh/m^2/year).

MATERIALS AND METHODS

Technical assessment of the system: The DNI versus net power output of the Euro Dish system during a typical operating day is nonlinear because it was designed for optimal performances at a DNI level of 800 W m^{-2}. But, in reality this system reaches the maximum of electricity production at 906 W m^{-2} (Nepveu, 2009).

The main purpose of this study is to investigate the appropriate sites for the implementation of Dish Stirling systems. In this way, in order to study the influence of direct solar irradiation on the power output of Dish Stirling system, only the direct normal irradiation for each of the three sites selected in Algeria is taken as the input for the performance calculation of the Dish Stirling system, as show the following 3rd order pronominal equation:

$$P_{net\_elec} = -2{,}341.10^{-08} \times (DNI)^{03} + 3{,}46.10^{-05} \times (DNI)^{02} + 3{,}19.10^{-04} \times (DNI) - 2{,}047358 \quad (1)$$

The global efficiency of a Dish Stirling system is done by:

$$\eta_{net,\ global} = \frac{P_{net,\ elec}}{A_{conc} \times DNI} \quad (2)$$

Economic analysis: The economical considerations of utilizing the solar energy for electric generation are the most important aspect in the selecting of the proper technology to be used in any project and location. If appropriate location is chosen, solar thermal power plants will be economically viable option for the production of electricity (Badran and Eck, 2006).

To study the economic feasibility of a power system, different methods could be used to evaluate different figures of merit of the systems. Each method has its own advantages, disadvantages, limitations and some conditions to be satisfied so that it can be applied (Tripathy *et al*., 1998).

For the evaluation of the investment, the two following indicators have been used:

Levelised Electricity Cost (LEC): The LEC is the most commonly used indicator for the analysis of the economic performances of a solar power plant, it can be significantly influenced by the methodology and the assumptions employed (Jurgen *et al*., 2004). It's the most largely used to evaluate the economical viability of a system. The following equation is used to calculating the LEC:

$$LEC = \frac{crf \times C_{inv} + C_{O\ and\ M} - C_{env}}{P_{el,Net}} \ (€\,kWh^{-1}) \quad (3)$$

The Capital recovery factor, it can be expressed as follows:

$$crf = \frac{k_d \times (k_d + 1)^N}{[(k_d + 1)^N - 1]} \quad (4)$$

It must be mentioned at this point that the discount rate that will be used for the LEC calculation is defined by the IEA (International Energy Agency), while that used in the NPV formula is defined by the project financier. For an analysis from the point of view of a public service, the calculation is simplified by omitting the different taxes (insurance…), the inflation is neglected and the land is offered by the state.

Net Present Value method (NPV): It represents the net total profit during the life of the project, i.e., the difference between the operational profit and the total amount of expenses (Giaccone and Canova, 2009). Its value actualized is done by the following equation:

$$NPV = \sum_{i=1}^{N} \left(P_{Net,el,i} \times Pr_{el} - O\ and\ M\right) \times \left(\frac{1-(1+i)^{-N}}{i}\right) - CC \quad (5)$$

RESULTS AND DISCUSSION

Technical assessment results: To simulate the daily performances, the monthly performances and the annual performances of a system, a MS Excel DSSIM program is developed. The design characteristics of the Euro dish Stirling system are presented in Table 2.

Table 2: Design characteristics of a 10 kWe Dish Stirling system

Characteristics	Values
Solar concentrator	
Type	Single segment of fiberglass resin
No. of segments	12
Reflecting area	Thin 0.8 mm thick glass mirror
Diameter	8.5 m
Projected area	56.7 m^2
Reflectivity	0.94
Concentration factor (peak)	9300
Receiver	
Type	Directly illuminated tubes
Aperture diameter	0.18 m
Receiver temperature	780-800°C
Stirling engine (kinematics)	
Type	Solo 161 (Alpha type V 90°)
Size	4 cylinders 160 cc
Working fluid	Hydrogen
Rotation speed	1500 rpm
Cooling	Fan water/air
Solar Dish-stirling system	
Maximal electrical output	10 kWe
Minimum insolation	250-300 W m^{-2}
Generator	Asynchronous

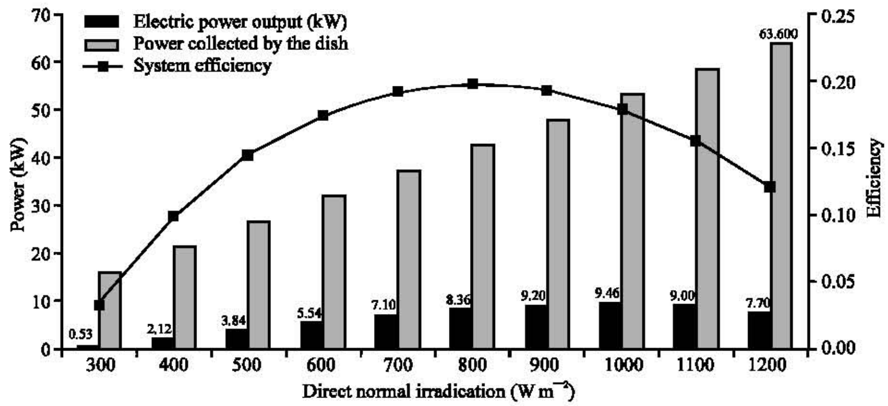

Fig. 4: Power collected by the dish, electric power output and efficiency vs. the DNI on 4 January for the site of Tamanrasset

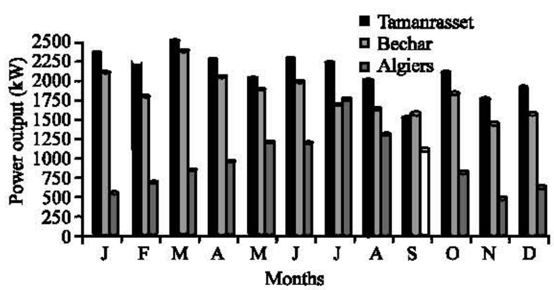

Fig. 5: Monthly net electric power plant production in the three sites proposed

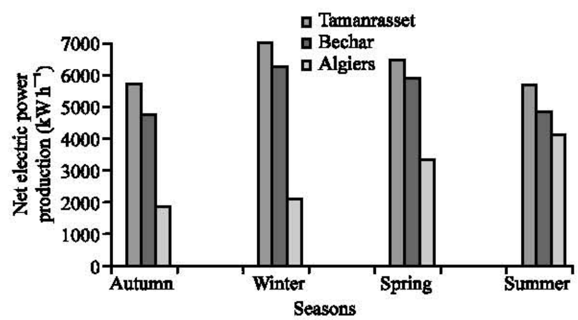

Fig. 6: Variation of net electric power plant production through seasons in the three sites proposed

Two of the main parameters taken into account in the technical evaluation of a Euro Dish Stirling system were evaluated in the three sites selected; the net electric power produced and the net conversion efficiency associated. Figure 4 shows, the solar power collected by the dish, the net electric power output and the net solar-electric conversion efficiency. We can see that the increase in the direct Normal Irradiation lead to an increase of the power intercepted by the dish, the electric power output and the net solar-electric conversion efficiency till it reaches the peak of 63.6, 9.46 and 0.20 kW, respectively.

An analysis of the monthly net electric output has been carried out; Fig. 5 presents, the system net electric power output for each month of the year for the three sites suggested. The electricity produced in Tamanrasset is almost equal to the one produced in Bechar and higher than the one produced in Algiers. The results show that the peak of the monthly plant production has been recorded in the month of July at Algiers site (nearly 1722 kWh), because it has a Mediterranean climate and in the month of March at Tamanrasset and Bechar sites (nearly 2462 and 2358 kWh, respectively) because they have a Saharean climate.

Figure 6 exhibits, the net electric power produced in different seasons for the three selected sites. It can be seen that the production reaches its maximum in summer in Algiers site and in winter for Tamanrasset and Bechar sites. These results can be explained by the local climate nature (Mediterranean in Algiers and Saharean in Tamanrasset and Bechar) and by the inhomogeneity nature of solar energy distribution. The highest production in Algiers can never reach the lower producyion in Tamanrasset and Bechar. The difference between the three sites is almost small in summer, while during the other seasons it's considerable between Tamanrasset, Bechar and Algiers sites.

Finally, an analysis of the annual net electric power output has been carried out for the three sites proposed. As presented by Table 3, the annual net electric power produced by the Dish Stirling system unit in Tamanrasset and Bechar site is 2.2 and 1.92 times higher than that produced in Algiers site.

Economic analysis results: The cost of the actual 10 kWe Euro Dish Stirling unit except transportation and installation cost and excluding foundations is

Table 3: Annual net electric power production of EuroDish Stirling system in the sites suggested

Sites	Tamanrasset	Bechar	Algiers
Annual net electric power production (kWh)	24777.50	21623.57	11240.29

Table 4: Assumptions and data used in economic study

Parameters	Prototype unit	Commercial unit
Unit cost (€ kWe^{-1})	14000	1125
Specific cost (€) (Transport and installation)	28000	2250
O and M cost (% of total investment cost)	5	3
Life time (years)	10	25
Annual discount rate (%)	8	8
Sale price electricity (€ kWe^{-1})	0.45	0.45

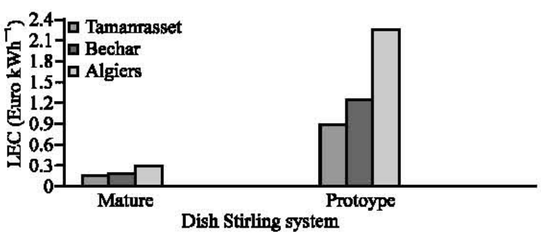

Fig. 7: LEC evaluation in the three sites proposed

approximately, 14,000 € kW^{-1} (Abbas *et al.*, 2009). The cost projections at production rates of 500 and 5000 units per year are 1875 and 1125 € kW^{-1}, respectively (Manuel and Zarza, 2007). According to these cost estimations, we have selected two scenarios of development of the Dish Stirling system in this study; the first scenario is reserved to the prototype of the system existing actually, a commercial system (>5000 units $year^{-1}$) has been selected to study in the second scenario. The different parameters used in this study are shown in Table 4.

The results of the LEC calculation are shown in Fig. 7. Obviously, the tamanrasset site presents the lowest LEC in all cases. Bechar site is almost similar to Tamanrasset, while Algiers site presents the highest LEC. These results are justified by the significant linear variation of the LEC with the annual electric power production and not with the DNI.

The LEC of the Dish Stirling prototype existing actually is about 0.88 € kW^{-1} in Tamanrasset, 1.23 € kW^{-1} in Bechar and 2.25 in Algiers. These high values are due to high O and M cost, transport and installation cost and low electric power production.

The LEC of the mature and commercial Dish Stirling is approximately, 0.15, 0.17 and 0.29 € kW^{-1} in Tamanrasset, Bechar and Algiers sites, respectively. These values are lower than those (0.28 € kW^{-1}) of ECOSTAR (Pitz-Paal *et al.*, 2005).

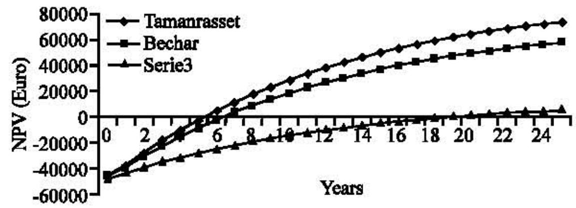

Fig. 8: NPV evaluation for mature Dish Stirling system in the three sites proposed

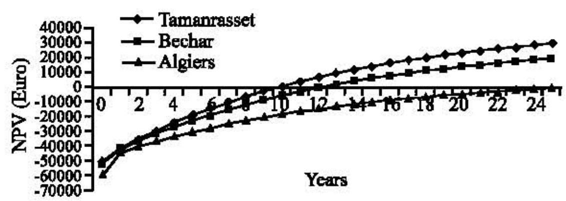

Fig. 9: NPV evaluation for prototype Dish Stirling system in the three sites proposed

The NPV evaluation of the both mature and prototype Dish Stirling system is presented in Fig. 8 and 9, respectively the NPV of mature system is 6 years in Tamanresset site, 7 years in Bechar and 15 years in Algiers. Concerning the prototype system, the NPV is 8 and 13 years in Tamanrasset and Bechar sites, respectively.

CONCLUSION

Solar energy is the most abundant natural resource in Algeria, for that, it has to exploit it through different plans, like building a number of concentrating solar power plants. From this study we can conclude that:

- The LEC is found to vary in the range of 0.15-2.25 € kWh^{-1} depending on the site and the configuration of the system
- The results of both thermal and economical studies show that both Tamanrasset and Bechar sites (and all the Algerian Sahara) are more suitable than Algiers site to implement the Dish Stirling systems (the LEC of the mature system in Tamanrasset is 0.15 € kWh^{-1}, in Bechar is 0.17 and is 0.29 € kWh^{-1} in Algiers, the NPV is 6, 7 and 15 years in Tamanrasset, Bechar and Algiers, respectively)
- The Dish Stirling system is a feasible technically and an economical viable solution to the electricity problems in the south of Algeria

- Since, the habitations are scattered in the large Algerian Sahara, the implementation of decentralized and small scale solar thermal power plant (~20 kWe) such as Dish Stirling system is economical and appropriate to provide electricity to the people's live in these regions
- The entire Algerian South is the best suitable sites for the implementation of the Dish Stirling technology for both centralized and decentralized electricity generation
- The annual solar radiation is the most important parameter to determine the suitability of a region for solar thermal power plants, as it has a major impact on the electricity generation and thus, the energy cost

Finally, we note that from this study that the use of the Dish Stirling system for electricity production is competitive to both photovoltaic and conventional technology in the Algerian south. Consequently, it is suitable notably for rural application where it is far away from the grid.

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Nomenclature:

A_{con}	=	Concentrator area (m^2)
C_{inv}	=	Total investment of the plant (€)
$C_{O\ and\ M}$	=	Annual operating and maintenance costs (€)
C_{env}	=	Environmental cost according to CO_2 rejected (€)
crf	=	Capital recovery factor
DNI	=	Direct Normal Irradiation ($W\ m^{-2}$)
k_d	=	Annual discount rate (%)
LEC	=	Levelised Electricity Cost (€/kWh)
N	=	Depreciation operation time of the system (years)
NPV	=	Net Present Value (years)
$P_{net\ electric}$	=	Net power electric production (kWh)
Pr_{el}	=	Sale price of the electricity (€ kWh^{-1})

REFERENCES

Abbas, M. *et al.*, 2009. Techno economic analysis of solar Dish Stirling technology for decentralized electricity generation in Algeria. In: Proceedings of the 15th Solar PACES International Symposium, Berlin, Germany. Paper No. 16278. ISBN: 978-3-00-028755-8.

Alnaser, W.E. *et al.*, 2004. First solar radiation atlas for the Arab world. J. Renewable Energy, 29: 1085-1107.

Badran, O. and M. Eck, 2006. The application of parabolic trough technology under Jordanian climate. J. Renewable Energy, 31: 791-802.

Benatiallah, A., R. Mostefaou and K. Bradja, 2007. Performance of photovoltaic solar system in Algeria. J. Desalination, 209: 39-42.

Beerbaum, S. and G. Weinrebe, 2000. Solar thermal power generation in India: A techno-economic analysis. J. Renewable Energy, 21: 153-174.

Bouzidi, B., M. Haddadi and O. Belmokhtar, 2009. Assessment of photovoltaic pumping system in the areas of the Algerian Sahara. J. Renewable and Sustainable Energy Rev., 4 (13): 879-886.

Fraser, R., 2008. Stirling Dish system prediction model, thesis of Master of Science, University of Wisconsin Madison. https://www.nrel.gov/analysis/sam/pdfs/thesis€fraser08.pdf.

Giaccone, L. and A. Canova, 2009. Economical comparison of CHP systems for industrial user with large steam demand. J. Applied Energy, 86: 904-914.

Geyer, M., 2003. Report on the SolarPACES Start Mission to Algeria, SolarPaces Start Mission to Algeria, IEA SolarPACES. http://www.solarpaces.org/_Libary/START_Algeria_2003.pdf.

Harouadi, F., B. Mahmah, M. Belhamel, S. Chader, A. M'raoui and C. Etiviant, 2007. Les potentialites d'exploitation d'hydrogene solaire en Algerie dans un cadre Euro-Magrebin, Partie I: Phase d'etude d'opportunite et de faisabilite. J. Revue des Energies Renouvelables, 10 (2): 181-190.

Himri, Y., A.B. Stambouli, B. Draoui and S. Himri, 2009a. Review of wind energy use in Algeria. J. Renewable and Sustainable Energy Rev., 13 (4): 910-914.

Himri, Y., A.B. Stambouli, B. Draoui and S. Himri, 2009b. Review and use of the Algerian renewable energy for sustainable development. J. Renewable and Sustainable Energy Rev., 13 (6-7): 1584-1591.

Jurgen, D. *et al.*, 2004. Trough integration into power plants: A study on the performance and economy of integrated solar combined cycle systems. J. Energy, 29: 947-959.

Mancini, T. *et al.*, 2003. Dish Stirling system: An overview of development and status. J. Solar Energy Eng., 125 (2): 135-151. DOI: 10.1115/1.1562634.

Manuel, R.A. and E. Zarza, 2007. Chapter 21: Concentrating solar thermal power, in Hand book of Energy Efficiency and Renewable Energy, by Taylor and Francis group, LLC., pp: 1-92. ISBN: 0-8493-1730-4. http://www.astro.hr/library/Energy/alternative.../1730_c021.pdf.

Nepveu, F., 2009. Thermal model of a Dish/Stirling systems. J. Solar Energy, 83 (1): 81-89.

Pitz-Paal R. *et al*., 2005. European concentrated solat thermal road mapping, ECOSTAR, SES-CT-2003-502578for, European Commission, 6th Framework Programme, German Aerospace Center. Cologne. http://ftp.dlr.de/ecostar/ECOSTAR€Roadmap2005.pdf.

Schlaich, J., 1999. Tension structure for solar electricity generation. J. Eng. Struct., 21: 658-668.

Stine, W. and R.B. Diver, 1994. A Compendium of Solar Dish Stirling Technology. Report SAND 937026; Sandia National Laboratories, Albuquerque, New Mexico. http://www.osti.gov/bridge/servlets/purl/10130410xiVU1V/native/10130410.pdf.

Theocharis, T. *et al*., 2003. Technical and economical evaluation of solar thermal power generation. J. Renewable Energy, 28: 873-886.

Thombare, D.G. and S.K. Verma, 2008. Technological development in the Stirling cycle engine. J. Renewable and Sustainable Energy Reviews, 12: 1-38. DOI: 10.1016/j.rser.2004.11.002.

Tripathy, S.C., S.R. Lakshmi and R. Balasubramanian, 1998. Production costing and economic analysis of power systems containing wind energy conversion systems. J. Energy Conversion Manage., 39 (7): 649-659.