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Linear Fresnel/Parabolic Trough Solar Thermal Plant in Algeria: Optimization and Performances Assessments

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***Abstract*— This paper describes a procedure to determine the optimum design and configuration of future solar thermal plant with minimum levelized cost of electricity (LCOE) and maximum annual electricity output as objectives. Our study is based on a technology of Linear concentration - Linear Fresnel and Parabolic Trough- of capacity of 50 MW erected in three regions (Hassi R'mel, Tamanrasset and InSalah), in the south of Algeria. In this study, the size of the solar field, the Fossil Fill Fraction of backup system and Full Load Hours of storage are optimized for the minimum LCOE using the concept of solar multiple using System Advisor Model software. Moreover, different models, technologies and scenarios are presented. From results, Linear Fresnel Solar Plant with 24 % of backup system is the best and optimum solution under Algerian climates.**

***Keywords*— Parabolic Trough Plant, Optimization, Linear Fresnel Plant, Performances.**

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 as well as for smaller electricity and heat generating devices.

A. Parabolic Trough Concentrating Solar Thermal Power Plant (PTCSTPP) consists of trough solar collector arrays and a conventional power block with steam turbine and generator. A receiver pipe at the focal point of the parabolic troughs absorbs the concentrated solar energy. The collector fields are aligned in parallel rows on a north-south axis and pivot on a single axis to track the sun throughout the day **[6]**. A heat transfer fluid (HTF), currently synthetic thermo oil, is pumped through the collector array and heated up to 400 °C. This oil is used to produce steam in heat exchangers before being circulated back to the array.

*B. Linear Fresnel Solar Thermal Power Plant (**LFSTPP**)* simplifies the concentration system by using a plain surface of nearly flat mirror facets, which track the sun with only a single axis and approximate the classic parabolic mirror. The efficiency is smaller than with a classic parabolic mirror **[7].** The idea is that the lower costs over-compensate the energy losses in the final economic assessment.

C. *Thermal energy storage (TES)*

The thermal storage systems are seen as a key factor for cost reduction of solar power plants. In general storage development needs several scale-up steps generally linked to an extended development time before a market acceptance can be reached. Requirements for storage systems are **[8]:**

- Efficient in terms of energy and exergy losses
- Low cost
- Long service life
- Low parasitic power requirements

II. SOLAR FIELD SIZING AND DESIGN REQUIREMENTS

The components of CSP plants should have an optimized design to better fit with HTF, TES system, and parameters of solar field, storage and power block. The parameters that determine the optimal plant design are many. The solar multiple (SM) is an important parameter to optimize the plant design and the thermal energy needed to ensure that the power block is effectively utilized throughout the year. From a technical point of view, design requirements are the solar multiple factor, capacity factor (CF) and storage system capacity.

The capacity factor is the ratio of the system's predicted electrical output in the first year of operation to the nameplate output, which is equivalent to the quantity of energy the system would generate if it operated at its nameplate capacity for every hour of the year.

III. METHODOLOGY

In this study, the selected locations are Hassi R'mel, Tamanrasset and Insalah, in the south of Algeria; weather data of this location, such as DNI and ambient temperature are taken from NREL database; an hourly timeframe is selected due to TMY3 standard format.

TABLE 1
SITES PARAMETERS

	Hassi R'mel	Tamanrasset	Insalah
Latitude [°]	33,8	22,80N	27,23
Longitude [°]	3E	5,43E	2,50
Altitude [m]	77,6	1362	268
DNI [kWh/m²/year]	2008,4	2759,4	1947,0

A. *Mathematical model of LCOE*

The method of levelized cost of electricity makes it possible to compare power plants of different generation and cost structures with each other. The basic thought is that one forms the sum of all accumulated costs for building and operating a plant and comparing this figure to the sum of the annual power generation. The calculation of the average LCOE is done on the basis of the net present value method, in which the expenses for investment and the payment streams from earnings and expenditures during the plant's lifetime are calculated based on discounting from a shared reference date **[9]**. For calculating the LCOE for new plants, the following applies **[10]**:

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{A_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{M_{t,el}}{(1+i)^t}}$$

LCOE Levelized cost of electricity
I_0 Investment expenditures
A_t Annual total costs in year t
$M_{t,el}$ Produced quantity of electricity in the respective year in kWh
i Real interest rate in %
n Economic operational lifetime in years
t Year of lifetime (1, 2, ...n)
Annual total costs At= Fixed operating costs + Variable operating costs (+ residual value/disposal of the plant).

B. *Plants optimization (configurations, technologies, models and scenarios)*

The optimization method used in simulation that is integrated in SAM software. Different configurations have been chosen for all plants based on HTF type (Synthetic Oil, molten salt, superheated steam, saturated steam), condenser type (wet cooling: evaporative, dry cooling: air cooled) , and loop flow configuration(once trough , recirculated boiler) , in order to determine the best configuration, for different models:

Model 1 (M1): solar field only (without storage and without backup system).
Model 2 (M2): integration of backup system (without storage).
Model 3 (M3): integration of solar thermal storage STE (without backup system) for PTCSTPP.
Model 4 (M4): integration of backup system and STE for PTCSTPP.

TABLE II
TECHNOLOGIES, CONFIGURATIONS AND MODELS

CSP technology	**Technology options and configuration**	**scenarios**
Linear Fresnel	T1: Superheated steam as HTF T2: Saturated steam as HTF	S1: Wet cooling technology and recirculated boiler configuration S2: Dry cooling technology and recirculated boiler configuration S3: Wet cooling technology and once trough configuration S4: Dry cooling technology and once trough configuration
Parabolic Trough	T1:Terminal VP-1 oil as HTF T2: Molten salt as HTF	S1: Wet cooling technology S2: Dry cooling technology

Table 3 represents all fixed financing parameters for the anticipated financial terms for the investment in normal conditions with no incentives provided by the government used in simulation.

TABLE IIII
FIXED FINANCING PARAMETERS **[11]**

Financing data	**value**	**unit**
Analysis Period	30	years
Loan Term	20	years
Loan Rate	8	%/year
Inflation Rate	8.9	%/year in 2013
Real Discount Rate	4	%/year in 2013
Nominal Discount Rate	13.26	%/year
Minimum Required IRR	12	%
Assessed Percent	80	% of installed cost
Insurance Rate	0.30	% of installed cost
Sales Tax	5	% of installed cost
State Income Tax Rate	15	%/year

IV. Results and Discussion

Using the input parameters of tables 3 and 4, the simulation was done with a project's lifetime of 30 year, as estimated by many studies **[12].** Moreover, an inflation rate of 8,9 % per year was used in the economic calculations and with no incentives provided by the government.

The table 4 shows an overview of the technical data used in the simulation.

Unlike parabolic system designs, which can be based on modular designs of individual components, linear Fresnel system designs require optimization of total aperture area, and length of collector

TABLE V
THE OPTIMUM LENGTH OF COLLECTOR FOR LFSTPP: T: TECHNOLOGY AND S: SCENARIO

	T1				**T2**			
lenght	**S1**	**S2**	**S3**	**S4**	**S1**	**S2**	**S3**	**S4**
Hassi r'mel	30	30	30	30	30	30	30	30
Tamanrasset	30	30	30	30	30	30	30	30
InSalah	30	30	30	30	30	30	30	30

TABLE VI
THE OPTIMUM REFLECTIVE APERTURE AREA OF COLLECTOR FOR LFSTPP

	T1				**T2**			
RAA	**S1**	**S2**	**S3**	**S4**	**S1**	**S2**	**S3**	**S4**
Hassi r'mel	550	550	540	**530**	550	550	540	540
Tamanrasset	510	490	500	**470**	540	540	550	550
InSalah	550	550	**500**	500	540	540	550	550

Tables 5 and 6 show the optimum geometry of collector as well as length and reflective aperture area, it's can be seen that:

1- The length of collector is constant for all configurations and sites.
2- The value of reflective aperture area depends of DNI, and increases in site which DNI is low, i.e: site with low amount of DNI requires collector with big reflective area, in order to capture grand quantity of radiation and increases temperature in absorber.

TABLE IV
FIXED DESIGN PARAMETERS

Technical data	value	Technical Data	Value
Parabolic Trough		**Linear Fresnel Plant**	
a-Solar Field Parameters:		**a-Collector**	
Row Spacing (m)	15	Width (m)	16,56
Stow Angle (deg)	170	Length (m)	44,8
b-Collector Geometry		Height of primary reflector (m)	0,75-1,05
Reflective Aperture Area (m2)	817.5	Aperture surface of primary reflectors (m2)	513,6
Aperture Width (m)	5.75	**b- Steam conditions at design**	
Length of Collector Assembly (m)	150	Field inlet temperature (°C)	244,5
Number of Modules per Assembly	12	Field outlet temperature (°C)	500
Mirror reflectance	0.935	Turbine inlet pressure (bar)	90
Washes per Year	63	**c-Design Point**	
Water usage per wash (L/m2),aperture	0.7	Total solar field pressure drop (bar)	14,85
c-Receiver: Schott PTR70		Loop optical efficiency	0,642
Absorber Tube Inner Diameter (m)	0.066	Loop thermal efficiency	0,961
Absorber Tube Outer Diameter (m)	0.07	Piping thermal efficiency	0,999
Glass Envelope Inner Diameter (m)	0.109		
Glass Envelope Outer Diameter (m)	0.115		

The optimum performances of both plants with different models, configurations and scenarios are given in tables 7 and 8:

TABLE VII
OPTIMAL PERFORMANCES OF PTCSTPP

	Insalah				**Tamanrasset**				**Hassi r'mel**			
	M1	M2	M3	M4	M1	M2	M3	M4	M1	M2	M3	M4
SM_{opt}	1.6	1.4	2.8	2.2	1.6	1.2	2.4	1.8	1.6	1.3	3	2.4
FLH_{opt} (h)	-	-	7.5	7.5	-	-	7.5	7.5	-	-	8	8
FFF_{opt} (%)	-	0.25	-	0.25	-	0.25	-	0.25	-	0.25	-	0.25
LCOE (cent$/kWh)	33.5	19.5	32.5	29	26.8	15	23	21	36	19.6	29	27
CF (%)	24	36	42	42	29	45	56	54	22	36	41	44
Annual Energy (GWh/y)	106	158	182	185	128	197	244	236	97	158	190	192

TABLE VIII
OPTIMAL PERFORMANCES OF LFSTPP

	Insalah		**Tamanrasset**		**Hassi r'mel**	
	M1	M2	M1	M2	M1	M2
SM_{opt}	1.8	1.6	1.6	1.4	1.8	1.5
FFF_{opt} (%)	-	0.24	-	0.24	-	0.24
LCOE (cent$/kWh)	33.3	13.72	18.24	11.79	24.67	13.27
CF (%)	27	43	32	47	28	44
Annual Energy (GWh/y)	118	185	145	214	119	188

From Tables, it can be seen that:
1- The storage requires large solar field (M3).
2 -The benefits of BS can be seen in small solar field, with reduction in LCOE and increasing of CF.
3-The integration of storage and BS (M4) increases CF with small solar field compared to M1 and M3.
4-The effect of BS began seen beyond FFF=0.24 for LF plants and FFF=0.25 for PTC plants. Moreover, LCOE decreases when increasing FFF, due to enough thermal energy produced, but it increases with increasing SM.

V. Conclusion

In this study, we have determined the optimum design and operation of CSP plant in three regions from Algeria, based on different technologies and scenarios, using the concept of solar multiple and backup system. SAM (System Advisor Model) is used to determine the optimum design parameters (SM, CF, and Annual Energy) of plants.

From the results presented in this paper, we can conclude that:

(i) The solar field of Linear Fresnel plant depends on geometry and cost of maintenance of collector and receiver, which are important to be optimized it in order to improve and strengthen the economic viability of the plants.

(ii) The wet cooling is the best technology for all plants under Algerian climates.

(iii) The integration of backup system in both plants leads to decrease in solar field, increase of capacity factor and the annual energy, which can allow the power block to operate at better part load conditions.

(iv) The site of Tamanrasset is the best and suitable for installing CSP plant in Algeria.

(v) Linear Fresnel Solar Plant with 24 % of backup system is the best and optimum solution under Algerian climates, with minimum LCOE and TIC, and maximum efficiency and annual energy output.

(vi) Parabolic Trough Solar Plant with 7.5 h of storage and 25% of backup system tend to perform slightly less than Linear Fresnel Solar Plant with 24 % of backup system.

Finally, these results can hopefully help Algerian government to decide the use of these technologies.

References

[1] Ghoneim. A.A., A.M. Mohammedein and Kandil M. Kandil, Performance Analysis of Parabolic Trough Collector in Hot Climate ; *British Journal of Applied Science & Technology*, vol 4,N°14, pp.2038-2058, 2014.

[2] Renewable energy policy network for the 21stcentury (REN21) , (2012). Global status report. [Online]. Available: http://www.map.ren21.net/GSR/GSR2012_low.pdfS.

[3] Abbas M, Kasbadji Merzouk N, *Techno economic study of* solar thermal power plants for centralized electricity generation in Algeria. 2nd international symposium on environment-friendly energies and applications,EFEA . pp. 179-83, 2012.

[4] Ministry of Energy and Mines, Renewable energy and energy efficiency program (2011). www.mem-algeria.org.

[5] S.J.Wagner, E.S.Rubin, Economic implications of thermal energy storage for concentrated solar thermal power. *Renewable Energy*, Elsevier, pp1-15, 2012.

[6] IRENA ; (2012). Renewable energy technologies: cost analysis series. Volume 1: power sector issue 2/5, Concentrating solar power. IRENA, June; 2012.

[7] N.Elgharbi, H.Derbal, B.Sofiane, N.Said. A comparative study between parabolic trough collector and linear Fresnel reflector technologies ; *Energy Procedia. Vol* 6. pp565-572.

[8] P.Viebahn and al. *Technical data, costs and life cycle inventories of solar thermal power plants*, New Energy Externalities Developments for Sustainability (NEEDS); 31-03-2008.

[9] Kost Christoph,(2013). *Levelized cost of electricity, renewable energy technologies*, ; fraunhofer institut for solar energy systems ISE. technical report.

[10] Konstantin P, (2009). Energiewirtschaft Praxisbuch. Energieumwandlung, -transport und -beschaffung im liberalisierten Markt. Springer.

[11] OECD Developpment centre,(2013). African Economic Outlook 2013,structural transformation and natural resources ,Doi:10.1787/aeo-2013-9-en.

[12] Nezammahalleh H, Farhadi F, and Tanhaemami M. Conceptual design and techno-economic assessment of integrated solar combined cycle system with DSG technology. *Solar Energy*, vol 84, pp1696-1705, 2010.