Numerical Simulations of Parabolic Through Collectors

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Abstract:

This study aims to model and simulate a power plant to generate electricity utilizing solar Parabolic Trough Collector [PTC] in the Tazarbu region at the southern area of Libya. Multiple generating stations are developed to produce two Giga watts of electric energy each one has a generation capacity of 200 Megawatts. These simulations carried out via the SAM software, which solves the transient model of convection and radiation to measure the station's detailed design specification including total cost for generating capacity of the station. The SAM software is used to solve the transient numerical model of solar Parabolic Trough Collector [PTC]. The outcomes are utilized to estimate the amount of solar energy received, wind speed, geographical location, and other information of the selected area, Tazerbu. To ensure that the energy supply remains stable in the whole day, the feasibility of storing energy through Photonic Votic [PV] is also simulated.

Keywords: Simulation, Solar collector, Transient.

الملخص

تهدف هذه الدراسة إلى تصميم ومحاكاة محطة توليد طاقة كهربائية باستخدام مُجمِّع القطع المكافئ الشمسي (PTC) في منطقة تازربو جنوب ليبيا. تم تطوير عدة محطات توليد لإنتاج 2 جيجاوات من الطاقة الكهربائية، حيث تبلغ قدرة كل محطة 200 ميجاوات. أُجريت هذه المحاكاة باستخدام برنامجSAM ، الذي يحل النموذج العابر للحمل الحراري والإشعاع لقياس مواصفات التصميم التفصيلية للمحطة، بما في ذلك التكلفة الإجمالية لقدرة التوليد. استُخدم برنامج SAM لحل النموذج العددي العابر لمُجمِّع القطع المكافئ الشمسي .(PTC) استُخدمت النتائج لتقدير كمية الطاقة الشمسية المُستقبلة، وسرعة الرياح، والموقع الجغرافي، وغيرها من المعلومات الخاصة بمنطقة تازربو. ولضمان استقرار إمدادات الطاقة على مدار اليوم، تمت أيضًا محاكاة جدوى تخزين الطاقة باستخدام الخلايا الكهروضوئية.(PV)

الكلمات المفتاحية: المحاكاة، جامع الطاقة الشمسية، العابر.

1. Introduction:

The use of a concentrated solar energy system has been addressed to generate electrical energy in this study, with the intention of establishing a power generation station in the Tazarbo in the south of Libya. In this study the SAM program is implemented to estimate the amount of energy generated and the project's material costs. This is achieved by entering details about the Tazarbo area's geographical position. We use a SAM software to simulate this project by looking at the prices of the land there and calculating the power of solar radiation in that region.

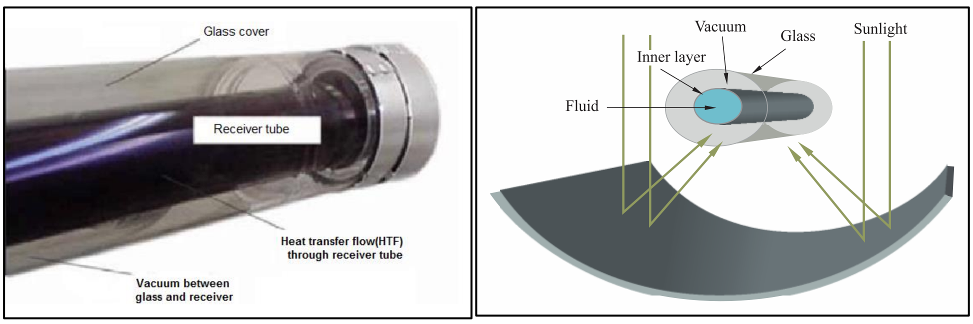
The intensity of solar radiation changes from location to the other on the earth. Also the intensity of the solar radiation varies with the atmosphere position due to absorption, scattering, and reflection of the atmospheric environment on solar ray that reaches the earth's surface. Because of absorption and dispersion, the frequency of solar radiation is reduced. Solar energy is reduced when some of the sun's rays are reflected. In clear days, when solar radiation strength on the ground is about 1000 W/m^2, energy loss of around 800 W/m^2 is occurring, while only 200 W/m^2 of energy is diffused (Thomas, 1995). Photovoltaic [PV] cells are used to directly generate electrical energy. Concentrated solar energy systems are considered, which produce electricity using the sun's heat. This device generates far more electricity than solar photovoltaic cells. Concentrated solar power systems, as shown in Figures (1. a, b, and c) that are in use as following: central receiver tower, parabolic dishes and parabolic trough system. The sun monitoring device is used by the majority of these systems in order to obtain the most sun energy during the day. Energy can be concentrated to heat water and generate steam, which is used to drive turbines in electric power plants. The challenges of utilizing concentrated solar power systems are the equipment used is still very costly, and the amount of solar energy needed might not be available due to clouds, weather conditions (Omar, 2013).

(a) (b) (c)

Figures 1 (a) central receiver tower ; (b) parabolic dishes ; (c)) parabolic trough system

Although fossil fuels have been used as a source of energy for a long time, doing so has a number of negative consequences. Fossil fuels, which include coal, oil, and gas, are by far the biggest cause of climate change, contributing more than 75% of all greenhouse gas emissions worldwide and 90% of all carbon dioxide emissions, which capture solar heat. Up to 25% of all carbon pollution caused by humans is absorbed by the oceans. The ocean's acidity rises. The quantity of calcium carbonate and other essential components for marine life decreases as water acidity increases.

Concentrated Solar Power [CSP] is working in the way as a concentrate of solar radiation in the focus. By locating a transparency pipe at the focus and passing liquid such as oil through the transparency pipe, the oil temperature rises to high temperatures in the range of 400 to 1000^{o}C. The hot oil used to exchange the heat with water liquid in steam generator and produces a superheated steam, which operates steam turbine and produce electrical energy. The working fluid absorbs the concentrated energy in the absorber tubes, and then it passes through heat exchanger to exchange the heat energy with water. The water absorbs the heat from the working fluid and becomes a superheated steam, which is non-burning boiler technology. The produced super-heated steam operates steam turbines and generates electric power. The tracking device must be effective and accurate to increase the reception efficiency. The results indicate that the average efficiency in all solar concentrating systems is 65% (Thomas, 1995). It is the special part for absorbing energy from solar radiation consisting of a stainless steel tube that is a selective absorbing surface that provides the required optical and radiation characteristics and is coated with a vacuum glass tube extending along the focal line of the solar collector, as shown in Figures (2 a, b). The tube helps in this process, and the vacuum glass cover prevents heat from leaking to the outside and reduces heat loss.



(a) (b)

Figure 2 a- receiver for Parabolic Trough b- receiver including collector

2. System advisor model (SAM)

SAM program is a model for generating electric power using renewable energy systems and provides all information about the amount of energy produced and its cost. The operation of the SAM program includes creating a file for the project. The program fills in the data and enters the variables based on the user's choices, the type of equipment in the required system, the cost of installation and operation, financial values and incentives. Then the program performs the simulation process, analyzes and outputs the results. The Sam program is available as an application on the computer, and it is a free program that everyone can use. The program consists of a user interface and a programming interface. The user can enter data and variables through the user interface so that he can access the simulation procedure and obtain the results in the form of tables and graphs. Having provided variables that describe the physical characteristics of the system and the cost and financial assumptions of the project are introduced. These values are included within the program to simulate the project and thus obtain the outputs and results (Nate Blair, 2015).

Intensive research activities had been undergoing in the last four decades in numerical modeling of solar Parabolic Trough Collector [PTC] (Fernández, 2010). This results in several approaches had been embarked in the literature to investigate their thermal performance (Jebasingh, 2016). Bouhal, (2018) conduct numerical simulation based on steady state solution and proved that the location and the climate are important parameters on the thermal performance of the solar collector. Kumar (2015) developed a one dimensional steady state heat transfer model is to investigate the thermal and optical performance of a solar PTC during a year under climatic conditions of India and they validated their results with the experimental results of Sandia National Laboratories (SNL) (Dudley,1994). They concluded that thermal efficiency of the PTC is maximum during the month of July and could reach 66.78% and minimum thermal efficiency is obtained during the month of December. Bellos (2017) numerically studied a case based on steady state thermal conditions reporting that the thermal efficiency of the solar PTC increases as the solar beam radiation increases and the Nusselt number increases. However, thermal efficiency of the solar PTC decreases as HTF inlet temperature increases. Guo (2018) conducted numerical simulations based on steady state conditions and predicted that there is an optimal mass flow rate for thermal efficiency. They also found that increasing of ambient temperature and solar incident angle leads to a decrease in heat losses of solar receiver. There is another approach (Kalogirou, 2012) that numerically investigated the performance of PTC based on steady state solution.

Ouagued (2013) utilized a heat transfer numerical model based on steady state solution. They studied and compared different synthetic oils, and results indicate that synthetic oil (Syltherm 800) is suitable as working fluid over the year compared to the other synthetic working fluids. Several numerical studies are presented to investigate the thermal performance of solar PTC. However, most of the proposed numerical models are simplified and developed under steady state conditions.

A detailed transient heat model to predict the thermal performance of a solar PTC under transient conditions is developed (Lamrani , 2018). Due to the abundant solar radiation, about 5.5 kWh/m^2/day, Tangier city is selected to become the second most important industrial center in Morocco and thermal performance of the solar PTC during four periods of year is investigated. The effect of the mass flow rate of Heat Transfer Fluid (HTF), the length of the receiver thermal performance of the solar PTC is assessed (Kousksou, 2015).

3. Results and Discussions

All important information related the chosen locality which is Tazrbou city, are tabulated in Table (1).

Table 1 location and resource parameter setting

User defined parameters	
City	Tazirbu
State	Al-kufra
Country	Libya
Time zone	2 GMT
Latitude	25.8 N
Longitude	21.133 E
Elevation	261m
Average temperature	21.8 C
Average wind speed	2.7 m/s
Global horizontal	6.33 kwh/m^2/day
Direct normal	1.68 kwh/m^2/day
Diffuse horizontal	6.84 kwh/m^2/day

The highest solar radiation energy occurs on the month of June and reaches to around 1100 W/m^2 on June 15th, while it has its minimum value in the month of December and it reaches to 700 W/m^2 on December 15. The general trend of solar radiation is probed as shown in Figure (3) from early morning at around seven.

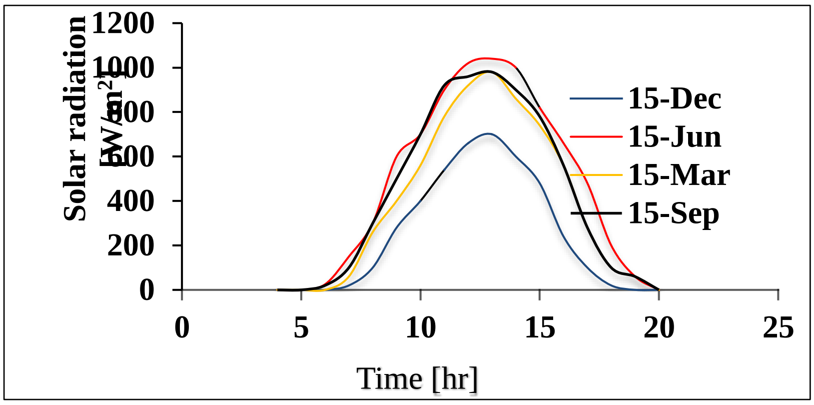


Figure (3) Solar radiation for 4- days in a year in Tazrbou

The solar field parameter are presented in Table (2).

Table 2 solar field parameter setting

User defined parameters	Terminal VP-1
Design Loop Internal temperature	**293 C**
Design loop outlet temp	**C391**
Min single loop flow rate	**1 kg/s**
Max single loop flow rate	**12 kg/s**
Freeze protection temp	**150 C**
Number of field subsections	**2**
Min header velocity	**2 m/s**
Max header velocity	**3 m/s**
Collector tilt	**0**
Collector azimuth	**0**
Number of SCA/HCE	**8**

The power cycle design parameters setting are presented in Table (3).

Table 3. power cycle parameter setting

User defined parameters	Terminal VP-1
Design gross output	200 MW
Boiler operation pressure	100 bar
Ambient temperature design	42 C
ITD at design point	16 C
Steam operating temperature	391 C
Annual energy produced for one year	690,679,232 KW

The thermal storage parameter setting are presented in Table (4).

Table 4 the thermal storage parameter setting

User defined parameters	Terminal VP-1
Full load hours TES	12
Storage VOLUME	91187 m^2
Tank height	20 m
Cold tank heater set point	250 ºC
Hot tank heater set point	365 ºC
Initial TES fiuid temp	300 ºC
Tank diameter	76.18 m

The solar storage system has the highest cost , which is around 450 Millions of dollars , second highest cost is the power plant and the solar field. The total cost of the PTC power plant is 1.359 Billions of dollars to produce 200 MW of electric power.

Table 5. The total cost

User defined parameters	Quantity	Price	Total
Site improvements	1705600 m^2	25 $/$m^2$	42640000 $
Solar field	1705600 m^2	150 $/$m^2$	255840000 $
HTF system	1705600 m^2	60 $/$m^2$	102336000 $
Storage thermal	6741.6 MWH	65$/kwh	438202240 $
Fossil backup	200 MW	0	0
Power plant	200 MW	1150$/kw	230000000$
Balance of plant	200 MW	120 $/kw	24000000$
land cost	1475 acres	10000$/acres	14,750,881 $
Sub total		1,093,018,240 $	
Contingency 7% of Sub total		76511280 $	
Total direct cost		1,169,529,472 $	
EPC owner cost(11%)		128,648,240 $	
Total land cost		14,750,881 $	
Sales tax rate(5%)		46,781,180 $	
Total cost		**1,359,709,824**	

The capacity, quantity, and quality of the batteries are calculated when the storage system is introduced, as shown in Table (6)

Table 6. Battery storage system

User defined parameters	Value
Battery type	Lithium ion nickel cobalt Aluminum
Desired bank capacity	1200000 KWh
Desired bank power	200000 KWh
Cell capacity	20000 Ah
Nominal bank capacity	1200000 KWh dc
Nominal bank voltage	500 v dc
Total of number cells	16680
Cells in series	139
Strings in parallel	120
Time at maximum power	6 h
Maximum value current	400000 A

The total cost of the project and the cost of each stage are computed using a simulation of the project, as shown in Table (7)

Table 7. System cost

User defined parameters	Value
Modules cost	72,000,000 $
Inverters cost	20,000,000 $
Batteries cost	70,056,000
Balance of system equipment	127,412,720 $
Installation labor	126,714,320.00 $
Installer margin and overhead	63,357,160 $
Contingency 4%	19,181,608 $
Permitting and environmental studies	67,995,176 $
Engineering and developer over ad	42,791,996 $
Grid interconnection	50,139,276 $
Land area (115.050 acres)	10,739,706 $
Land prep and transmission	6,712,964 $
Sales tax basis, percent of direct cost(15%)	$2805310
Sales tax rate(5%)	$935103
Total installed cost	**680,841,344 $**
Total installed cost per capacity	54.03 $/W dc

4. Conclusion

System cost is also displayed in table (7), which shows that the batteries cost is the highest and it reaches to 70 Millions of dollars. However, the energy storage by batteries is much sleeper when compare with that of thermal energy storage for Tazrbu to store same power of 200 MW, which cost around 500 Millions. It means that utilizing batteries could safe more than 80 % of the cost. The PV system utilized to produce 200 MW in Tazrbou has first cost approximately 681 Millions of Dollars, while PTC system costs around 1500 Millions. Based on the first cost, it could be concluded that the PV system is more economic than the PTC system since it could safe in average of 45 % of the cost. The final decision of which system is the best economically cannot be taken until weighting for the other affecting parameters, which are the life time of the system, the operation costs, and maintenance costs.

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