World Academy of Science, Engineering and Technology
International Journal of Energy and Environmental Engineering
Vol:7, No:12, 2013

Evaluation of A 50MW Two-Axis Tracking Photovoltaic Power Plant for AL-Jagbob, Libya: Energetic, Economic, and Environmental Impact Analysis

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***Abstract*—**This paper investigates the application of large scale (LS-PV) two-axis tracking photovoltaic power plant in Al-Jagbob, Libya. A 50MW PV-grid connected (two-axis tracking) power plant design in Al-Jagbob, Libya has been carried out presently. A hetero-junction with intrinsic thin layer (HIT) type PV module has been selected and modeled. A Microsoft Excel-VBA program has been constructed to compute slope radiation, dew-point, sky temperature, and then cell temperature, maximum power output and module efficiency for this system, for tracking system. The results for energy production show that the total energy output is 128.5 GWh/year. The average module efficiency is 16.6%. The electricity generation capacity factor (CF) and solar capacity factor (SCF) were found to be 29.3% and 70.4% respectively. A 50MW two axis tracking power plant with a total energy output of 128.5 GW h/year would reduce CO_2 pollution by 85,581 tonnes of each year. The payback time for the proposed LS-PV photovoltaic power plant was found to be 4 years.

***Keywords*—**Large PV power plant, solar energy, environmental impact, Dual-axis tracking system.

I. Introduction

THERE are many good reasons for building solar power plants in the Libyan desert, firstly the prevalent solar energy income and secondly, the available area. The Libyan Desert covers the entire range of Libyan longitude 11^o 44' to 23^o 58'E and a latitude range of 24^o 17' through to 30^o 3'N. Long-term meteorological parameters for Al-Jagbob oasis (29°42'N, 24°38'E) have been collected from Renewable Energy Authority of Libya (REAOL) and the results confirm that Al-Jagbob has high levels of annual solar radiation. The rain fall averages a few mm every 30 years. With no cloud cover throughout the year and availability of large volumes of potable water from underground aquifers, large-scale electrical generation warrants a serious feasibility study.

PV technology is one of the most attractive options of the renewable energy technologies. As a result, the small-scale dispersed stand-alone as PV power systems, moreover the small and medium-sized building-integrated grid-connected PV power systems have proven great potentials, and consequently Large Scale Photovoltaic systems (LS-PV) may represent a future option for the world energy supply.

LS-PV systems consist of one plant or an aggregation of multiple units operating in harmony and distributing in the same district with outputs which range between 10MW to several gigawatts. The following are the advantages of LS-PV systems [1]:

A. Desert and semi-arid lands are available and normally have high potential irradiance.
B. The estimated potential of such areas can easily supply the estimated world energy needs by the middle of the 21st century.
C. In accordance with the world energy demand, LS-PV capacity can be increased step by step.
D. LS-PV systems have near zero carbon emission and do not pollute the environment.

According to Duffie and Beckman [2], Photovoltaic modules which are to provide maximum generation over the year should be inclined at an angle equal to the latitude of the site.

According to Markvart [3], the amount of total energy output can be increased if the PV modules track the sun. For instance, Full two-axis tracking will increase the energy available by almost 40% over a stationary PV module, at the angle of latitude at the expense, however, of increased complexity and cost. Also, according to Kurokawa et al. [1], the maximum output of tracking PV modules, at all times of the year, is higher and spread over more daylight hours than in the case of stationary modules. Furthermore, the highest capacity factors are generated with trackers which follow the sun throughout the day to keep the panel optimally oriented towards the sun.

However, it has two disadvantages. The first is that considerably more land area is required in order for the PV modules not to shade one another.

This means that the total energy output per land usage for LS-PV of PV power plant based on two-axis trackers would therefore be considerably lower than for stationary system. The second drawback is that, each tracker requires two motors in order to keep it locked on the sun's changing position.

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II. DESIGN SYSTEM

The most commonly used system in sun tracking systems is controlling the motor which moves the panel by evaluating the signals received from photo sensors.

This section discusses the system which employs full two-axis tracking, ensuring that the PV modules always face directly towards the sun's position in the sky. An HIT type PV module from Sanyo rated at 200W has been selected and modeled. The selected module specifications are summarized in Table I.

TABLE I
SPECIFICATIONS OF THE PV MODULE [5]

Electrical specification	
Model	HIT Power 200
Rated Power (Pmax)[1]	200 W
Maximum Power Voltage (Vpm)	55.8 V
Maximum Power Current (Ipm)	3.59 A
Open Circuit Voltage (Voc)	68.7 V
Short Circuit Current (Isc)	68.7 V
Temperature Coefficient (Pmax)	-0.29% / °C
Temperature Coefficient (Voc)	-0.172 V / °C
Temperature Coefficient (Isc)	0.88 mA / °C
Cell Efficiency	19.7%
Module Efficiency	17.2%
Mechanical specification	
Module Area	1.16m^2
Weight	15kg
Dimensions LxWxH	1319x880x46mm
Operating conditions	
Ambient Operating Temperature	-20°C to 46°C
NOCT	46.9°C
1	STC: Cell Temp. 25oC, AM1.5, 1000W/m^2

Aldali et al. [4] has been developed and presented a model to compute dew-point, slope radiation, sky and cell temperature, module efficiency and maximum power for operation of the PV modules for stationary PV system and slope radiation sky and dew -point, cell te mperature, module efficiency and maximum power for operati on of the PV modules for two-axis tracking system. Furthermore, the model calculates the current, voltage and fill factor for both stationary and two-axis tracking system. The model is designed to compute results for ten hours each day for a period of one year.

A detailed flow chart of the model for two-axis tracking system is shown in Fig. 1. The model of the PV module was implemented using Visual Basic f or Applications (VBA), which also made use of the processing features of Microsoft Excel.

The DegerTraker 6000NT module has been selected as the sun-tracker system. DegerEnergy Company designed and constructed a programmable sun-tracker. Table II shows the specification of the DegerTraker 6000NT-Dual-axis.

The proposed of solar tracking system for the 50 MW photovoltaic power plant would be d ivided into 50 sub-stations of 1MW each and each 1MW su bstation would be divided into 125 solar trackers each rated at 8k W. Each substation would feed the gener ated electricity to the 11kV grid through a 1000kVA transformer and each 8kW PV channel has been equipped with a grid-connected inverter to convert the DC power from the PV into three - ph ase AC power for the primary of the 1000kVA transformer. The output from the 50MW station connects to the national grid (220kV) through a 5 0MVA transformer. Each 1MW substation therefore consists of 5000 modules. The specification of the proposed inverter is shown in Table I.

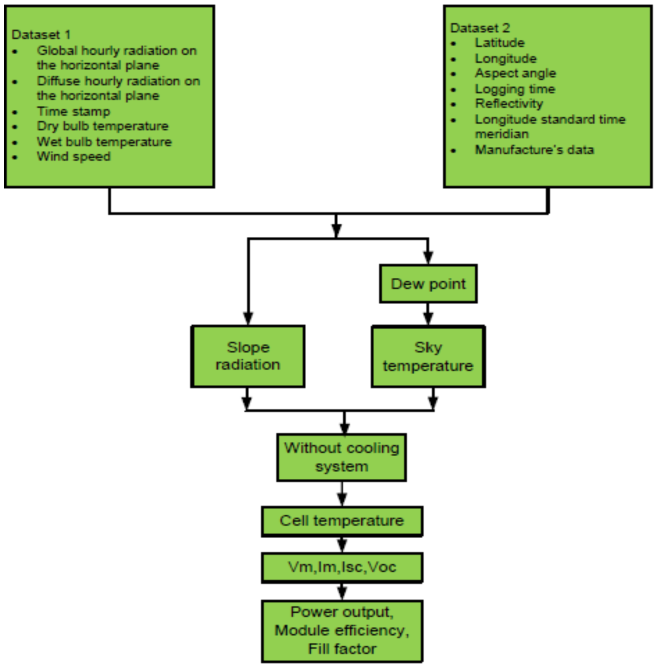

Fig. 1 Flow chart for the computer model for two-axis tracking system

TABLE II
SPECIFICATIONS OF THE DEGERTRAKER 6000NT-DUAL-AXIS [6]

Module area up to	53m²
Rotation angle east – west	360° with adjustable limit switches
Elevation	15°-90°
Control unit	DEGERconecter
Operating voltage	80 … 265 VAC / 80 … 380 VDC
East –west drive	drive integrated in the rotating head
Elevation drive	1,100 mm stroke path
Internal power consumption:	
Control mode	1 Watt
With operating drives approx.	7 Watts
Power consumption per year. approx.	9 kWh
Mast height	4 m … 5,5 m
Load capacity	130 … 300 km/h
Weight (excluding mast)	1,000 kg
Art.no.	1600001

TABLE III
SPECIFICATIONS OF PROPOSED DC/AC INVERTER [7]

Rated power (kVA)	200
Maximum power (kVA)	245
Rated input DC voltage (V)	640
Maximum input DC voltage (V)	800
Rated input DC current (A)	400
AC output	Three-phase 415V±10%
Output frequency	50Hz
Efficiency	10%load:90% 50%:load96% 100%load:96%
Size (mm)	2000x2100x800
Weight	1400kg

The system was designed to optimize performance for the annual energy output (i.e., modules facing due south) and to maximize reliability. For example, in designing the 1MW system it was determined that 125 x 8kW arrays would increase the reliability of the system. If anyone array should fail, the system would still be operating at 90% capacity.

A. Field Requirements

It is important that the PV modules do not shade each other. On the other hand, for sun tracking systems (Two-axis), the situation is more complex because the modules also move. In order to ensure that the solar trackers do not shade each other, hexagonal structures have been used in this study [8]. Fig. 2 shows the field design for the proposed 50MW power station (Two-axis) and configuration of the PV array; each array consists of 40 PV modules.

The total area occupied by the solar tracking system power plant is 2.44km^2 and the total module area is 290,180 m^2.

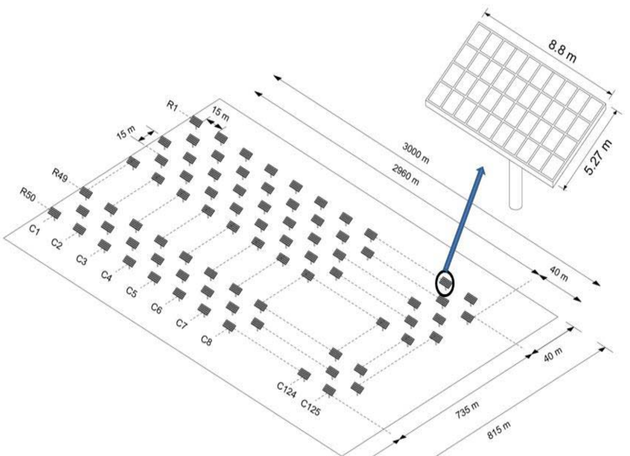

Fig. 2 Schematic of hexagonal field layout of 50MW PV power plant (for two-axis tracking system)

B. Capacity Factor and Solar Capacity Factor

The capacity factor, CF, is defined as the ratio of the net electrical generation for the time considered to the energy that could have been generated if the system were generating at continuous full power during the same period. The solar capacity factor SCF is defined as the ratio of the actual output of the PV power plant over a period of time, and its output if it had operated at full nameplate capacity throughout the time of the day.

The capacity factor for sun tracking system (two-axis) was found to be 29.3% and the solar capacity factor SCF was 70.3%.

C. Greenhouse Gas Pollution

Electric power plants that burn fossil fuels emit several pollutants linked to the environmental problems of acid rain, urban ozone (smog), and global climate change.

The main emitters of CO_2 in Libya are fuel combustion in the power generation sector, the transport sector and in industry. In total, energy-related emissions are responsible for almost all CO_2 emissions in the country.

In 2009 petroleum accounted for more than 53% of carbon emissions in Libya and natural gas was responsible for around 47% [9]. In the same year, the total generation in Libya was 29TWh, and taking into account the fact that the production of 1kWh of electricity creates 0.760kg CO_2 for oil and 0.560kg CO_2 for natural gas [10], emissions of CO_2 from the generation of electricity at oil-fired plants and natural gas-fired plants were estimated at 19.3 billion tones in 2009.

Hence a 50MW PV system with a total energy output of 128.5GWh would reduce CO_2 pollution by 85,527 tones of CO_2 each year.

D. Financial Analysis and Payback Period

A number of economic criteria are available for evaluating solar energy systems. In order to conduct a financial analysis for this project, the total cost of the PV power plant is calculated based on the U.S. Department of Energy (DOE) report [11]. The cost per WP of LS- PV power plant, C_w, includes the cost per WP of: PV module cost (C_m), design cost C_d($0.08), inverters cost C_i($0.4), balance of system (BOS) development cost C_b($0.25) and installation cost C_{in}($0.4). The cost of PV modules is changing lastingly.

According to Gupta [12], for the year 2010 the module cost was Cm=$1.7/ W_P. Thus, the total cost of LS-PV power plant is the product of cost per WP and the rated power.

According to the US DOE, the cost per WP is, C_w =$2.8/ W_P.

In addition to the costs C_w, the cost of the system tracker is C_T=$1.79/WP.

According to a study by David et al [13], operation and maintenance cost (O&M) of PV solar power plant using tracking system is $C_{O\&M}$=$0.058/W. Thus, the total cost of LS-PV power plant using tracking system is the product of cost per Watt and the rated power. The cost per Watt is, C_w= $4.65/W.

The total cost for 50MW PV power plant using tracking system would thus be $232.4 million.

- Feed-in tariff $0.45/kWh and interest rate 2%

The payback period was found to be 4 years as illustrated in Fig. 3.

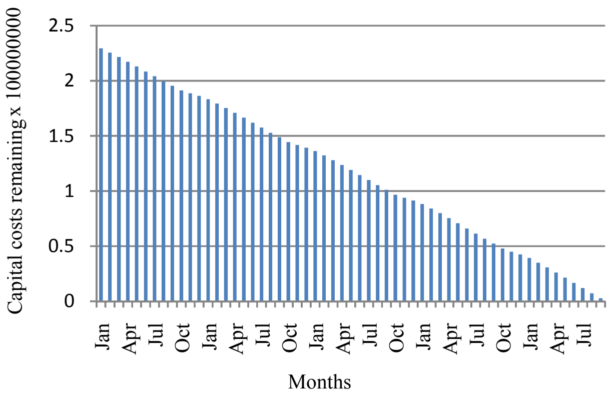

Fig. 3 System construction payback period for tracking system

E. Landscape Impact

The key factor in designing the PV plant is to gain, for any specific site, the optimal ground cover ratio (GCR) without valuable reduction of expected performance ratio. The GCR is defined as the ratio of the PV array area to the total ground area [14].

The GCR for tracking system installation localized in Libya, Al-Jagbob was found to be 0.12.

The estimated ground area needed to build a 50MW PV plant amounts to approx. 2.44km^2 for tracking system PV field constituted by HIT PV arrays and approx. 20.5MW/ km^2.

III. Results and Discussion

The results obtained from the computer model for two-axis tracking system, for conditions at Al-Jagbob are shown in Figs. 4 and 5. For comparison purposes, the hourly variation of the total energy output, average cell temperature, and average efficiency of PV module operation are shown in Fig. 4 for July and in Fig. 5 for December.

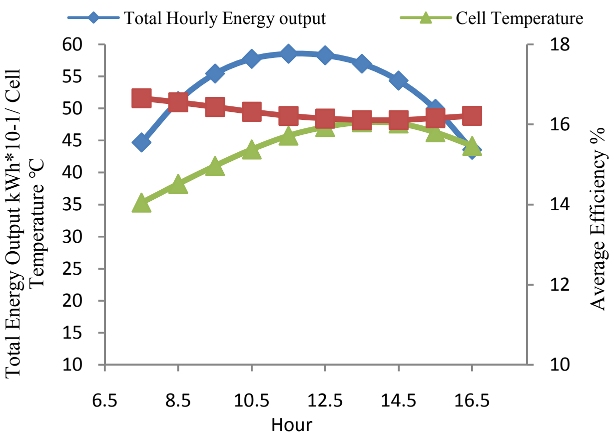

Fig. 4 Variation in total energy output, average cell temperature and average module efficiency for July

It is observed that the total energy output in July and December has been found to be 12.95 GWh and 6.68 GWh respectively.

The maximum cell temperature in June and December has been found to be 51.8°C and 35.6 °C respectively. The total energy output of 50MW two-axis tracking plant is 128.5 GWh.

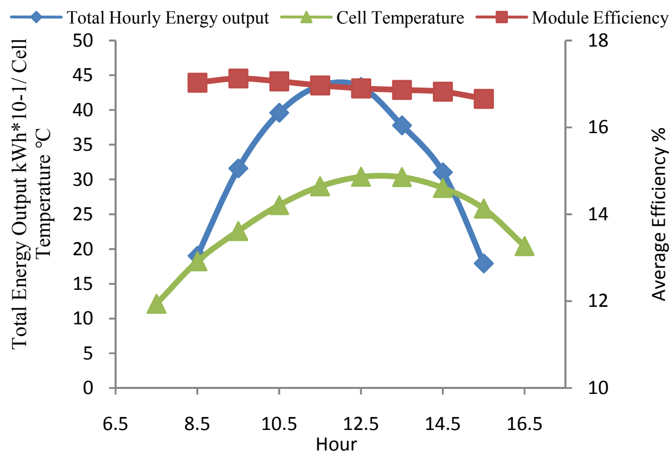

Fig. 5 Variation in total energy output, average cell temperature and average module efficiency for December

IV. Conclusion

This paper presented an extended analysis for installing a 50MW PV-grid connected (tracking) power plant in, Libya. The HIT solar PV module from Sanyo, rated at 200W, has been used in this study due to its high efficiency.

Long-term meteorological parameters for Al-Jagbob region have been collected from Renewable Energy Authority of Libya (REAOL) and the results confirm that Al-Jagbob has high levels of annual solar radiation. The collected meteorological parameters were: long-term average daily global radiation, average daily sunshine hours, long-term hourly ambient temperature and average daily wind speed.

A Microsoft Excel-VBA program has been developed to compute slope radiation, dew-point, sky temperature, and then cell temperature, maximum power output and module efficiency, for tracking system.

The results for energy production show that the total energy output is 128.5 GWh/year. Also the maximum cell temperature is 51.8°C on 1 June at noon and the minimum temperature cell temperature is 5.4°C on January at 7.30 am. The average module efficiency is 16.5%.

The values of electricity generation capacity factor (CF) and solar capacity factor (SCF) for tracking system were found to be 29.3% and 70.3% respectively. The payback time for the proposed LS-PV power plant was found to be 4 years for the tracking system.

Acknowledgment

The authors wish to thank Omar Al Mokhtar University and the Libyan Government for their support of this work.

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