Yanbu Journal of Engineering and Science

Volume 16 | Issue 1 Article 2

2018

ECONOMICAL AND TECHNICAL ASSESSMENTS OF GRID CONNECTED SOLAR PV POWER GENERATION SYSTEM IN SAUDI ARABIA

Mohammed Alsumiri
Yanbu Industrial College, SA, alsumiri@rcyci.edu.sa

Follow this and additional works at: https://yjes.researchcommons.org/yjes

The journal in which this article appears is hosted on Digital Commons, an Elsevier platform.

Recommended Citation

Alsumiri, Mohammed (2018), ECONOMICAL AND TECHNICAL ASSESSMENTS OF GRID CONNECTED SOLAR PV POWER GENERATION SYSTEM IN SAUDI ARABIA, *Yanbu Journal of Engineering and Science*: Vol. 16: Iss. 1, 11-22.
DOI: https://doi.org/10.53370/001c.24339
Available at: https://yjes.researchcommons.org/yjes/vol16/iss1/2

This Research Article is brought to you for free and open access by Yanbu Journal of Engineering and Science. It has been accepted for inclusion in Yanbu Journal of Engineering and Science by an authorized editor of Yanbu Journal of Engineering and Science.

Yanbu Journal
of
Engineering
and Science
ISSN: 1658-5321

Vol. 16, June 2018 (1439H)
www.yjes.org.sa

ECONOMICAL AND TECHNICAL ASSESSMENTS OF GRID CONNECTED SOLAR PV POWER GENERATION SYSTEM IN SAUDI ARABIA

Mohammed Alsumiri

Electrical and Electronics Engineering Technology Department, Yanbu Industrial College
Yanbu, Saudi Arabia
E-mail: alsumiri@rcyci.edu.sa

ABSTRACT

Recently, electricity cogeneration and regulatory authority (ECRA) announced the approval of small-scale solar PV system regulation for solar grid connected systems in the distribution system. As a result, this research paper will focus on testing the effect of using utility interactive solar system in reducing electricity consumption from the utility grid. Also, the environmental effects such as temperature and solar irradiance on the performance of the solar system will be analyzed. A 3 kW grid tie solar system for a residential building has been designed and simulated. The system has been investigated from technical prospective in terms of soiling and temperature effect on the system energy production. Also, the economic impacts from saving energy that is imported from the grid have been outlined. These studies focused on the system parameters such as voltage and current during different weather conditions. Throughout this research, the small-scale solar PV system regulation for solar grid connected systems in Saudi Arabia has been described. Finally, different article of National Electric Code for solar grid-tie system for residential buildings have been addressed.

Keywords: *Solar energy, PV cell, Grid tie, PV system, Inverter, ECRA*

1. INTRODUCTION

Saudi Arabia is a large country with an area of approximately 2.3 million km² where most of the land is unpopulated. Saudi Arabia is located between latitude of 16.57° N and 31.67° which makes it one of the most promising places for solar energy applications due to high solar irradiation. The average annual solar irradiation is more than 2200 kWh/m^2 per year [1]. Due to the large geographical area of the Kingdom, there are many remote populated places far from each other. It is considered to be uneconomical to connect those places to the national grid. However, those places are supplied using off-grid systems typically diesel generators. In order to meet the peak-load demand during summer months as well as the demands of the remote places, which are not connected to the national grid, the need of adding more renewable energy generation system is realized. As a result, a number of new initiatives have been introduced in the Saudi vision 2030 [2]. The Saudi Electricity market is a monopoly structure where Saudi Electric Company (SEC) carries out the responsibility of electricity generation and transmission, as well as distributing electricity over the Kingdom. Using 8,750 miles of transmission lines, the Kingdom's power grid system considered to be a huge system with an

Received: 10 Jan 2018, Accepted: 27 Mar 2018

electricity distribution network that extends to cities, towns and villages across the Kingdom. Moreover, the grid system uses about 52,000 miles of distribution lines and over 53,000 miles of service connections centers [3].

1.1 Electricity Generation and Consumption in Saudi Arabia

The generation capacity in Saudi Arabia has increased in 2016 to reach 87.8 GW. It can be seen that there was a dramatic increase in the total installed generation capacity from 2012 to 2016, and that was due to huge investment in developing the country infrastructure which led to a total installed capacity of 23.5 GW in four consecutive years as shown in Figure 1. The Saudi Arabian demand for electricity is growing fast. It can be considered the fastest growing demand in the region. Because of high average temperature during summer, the use of air-conditioning is increased which increases the demand of electricity around 66% than in the winter months. In fact, there are large deviations of base-load and peak-load demands during day and night. As a result, total installed power capacity needs to be considerably above base-load requirements. During winter time the average load demand is around 35 GW while during summer, is around 55 GW. In addition, it can be observed that out of the total installed generation capacity is in the eastern region has the highest installed generation capacity by 38% and western regions by 35%. On the other hand, central region total installed capacity is only 21% of total; while the lowest installed capacity can be found on the southern region by only 6%. As we can see in Figure 2 below, the load demand during summer is about double the winter months load demand. In 2015, the peak load in the summer was 62,260 MW and the peak load in the winter was 34,274 MW, a reduction of 44.95% is occurred.

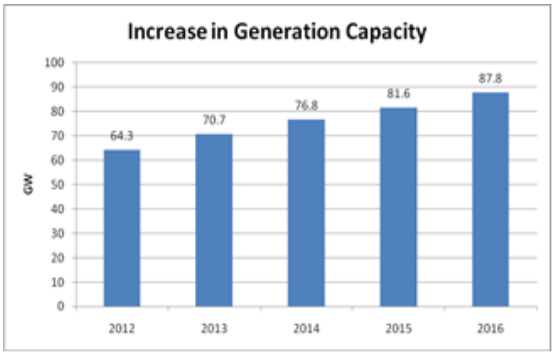

Fig. 1. Annual growth of Generation Capacity

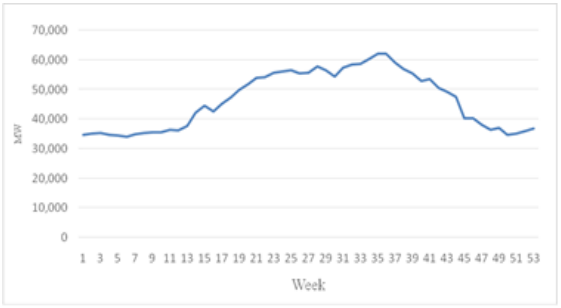

Fig. 2. Load variations in Saudi Arabia, 2015

Saudi government provided high subsidy to energy by providing fuel to SEC at the production cost. Based on ECRA, the total energy sold in 2016 was 296,673 GW with 0.68% increase from previous year. An Electric power transmission and distribution losses (% of sold electricity) in Saudi Arabia was 7.05% as of 2013. Its highest value over the past 42 years was 14.24 in 1976, while its lowest value was 1.56 in 1986. Moreover, the losses increased in 2016 to 8% of the total energy sent on network as seen in Figure 3.

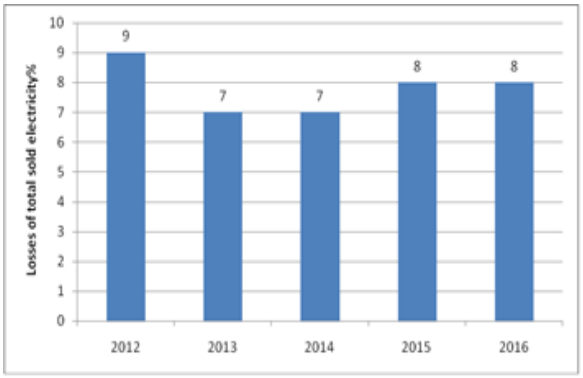

Fig. 3. Transmission and distribution losses of Saudi Grid

It is estimated in 2016 by ECRA that currently electricity generation are 8.6% derived from diesel power stations, 50.7% from Natural Gas stations, 16.5% from heavy oil and 24.2% from crude oil as shown in Figure 4.

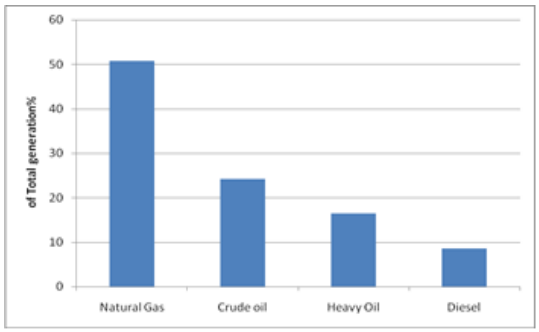

Fig. 4. The contribution of generation by fuel type (2016)

Economically, the Kingdom's oil export is affected when the electricity demand is increased since the power plant will consume more oil; especially while the oil price increasing. In fact, it has been argued that Saudi Arabia might turn into an oil importer by 2030, if the growth in demand continues at same rate. As a result, Saudi Arabia and GCC countries (Cooperation Council for the Arab States of the Gulf) start working to link their national grids. Moreover, there is a plan to study the benefit of linking the GCC grid with the rest of the Arab world and Europe, through Turkey and Egypt.

2. SOLAR ENERGY POTENTIALS IN SAUDI ARABIA

It is true that Saudi Arabia is the largest oil producer country in the world. But as the demand of electricity increasing, Saudi Arabia starts considering renewable energy as a source of electricity. Solar energy to be exact is the one that has been studied in the recent years. Saudi Arabia's solar power potential is enormous. Its solar irradiances are among the highest in the world. The land elevation varies between 0 and 2600m above the mean sea level. Complex terrain is found in the southwest region of the Kingdom. The East and the West coasts of the Kingdom are located on the Arabian Gulf and Red Sea, respectively. Mainly two seasons, winter and summer, are observed during the year. The vast open land experiences high intensities of solar radiation and long hours of sunshine duration. Rehman et al. found that the average global solar radiation in Saudi Arabia varied between a minimum of 1.63 MWh/m^2-yr and a maximum of 2.65 MWh/m^2-yr at Tabuk and Bisha, respectively. The Kingdom of Saudi Arabia is subject to heavy solar radiation intensity and has several hours of intense sunlight. From April to September, the average daily global solar insulation in the Kingdom exceeds 6 kWh/m^2-day. As a merit, the heavy solar insulation coincides with high load demand that is during summer months. Hence, solar energy generation can be utilized for the peak load sharing for the national grid. It has been founded that the average sunshine duration across 41 locations in Saudi Arabia was 8.89 hours per day. Moreover, the mean value of the specific yield was 260.83 kWh/m^2. Most of the year's days are sunny due to the geographical location. In conclusion, the average solar radiation is about (4-5.5 kWh/m^2/day) in winter and (6-7.7 kWh/m^2/day) in summer.

2.1 PEAK SUN HOURS (PSH) AND TEMPERATURE FOR DIFFERENT CITIES IN KSA

The first step to accurately design a solar system is to know the solar irradiation in the project location. The following tables show the average solar irradiation in different cities Saudi Arabia [4]. Irradiation is energy in Wh. It is often expressed as peak sun hours (psh). The psh is simply the length of time in hours at an irradiance level of 1kWh/m^2 needed to produce. The daily irradiation obtained from integration of irradiance over all daylight hours.

2.2 EFFICIENCY OF A SOLAR PV CELL

Shockley–Queisser limit or detailed balance limit refers to the calculation of the maximum theoretical efficiency of a solar cell made from a single pn junction. It was first calculated by William Shockley and Hans Queisser. According to their calculations, the maximum efficiency of any type of single p-n junction cell is 33.7 percent at a bandgap of 1.34 eV [11]. The theoretical S-Q limit of non concentrating silicon is 29.7 percent power conversion efficiency at a bandgap of 1.1 eV, which means conventional commercial silicon is nearing the practical limit. Figure 5 shows different solar cell technologies efficiency limit [11].

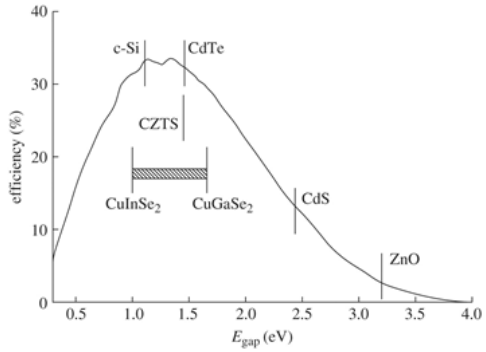

Fig. 5. Maximum theoretical efficiency (Shockley–Queisser limit) for different PV solar cells technologies under AM1.5 illumination

In recent years and due to the development of solar cell, the experimental lab efficiency has increased to a high level near to the theoretical limit. Table 1 shows different recorded experimental solar cell efficiency of different technologies [12].

TABLE 1: SOLAR CELL EFFICIENCY OF DIFFERENT TECHNOLOGIES

Category	As of Aug 6th, 2015	Record holder
C-Si	25.6%	Si-Hetrostructure (Panasonic)
µ-Si	20.8%	µ-Si (TrinaSolar)
CIGS	21.7%	CIGS (ZSW)
CdTe	21.5%	First Solar

3. GRID-TIE SOLAR PV SYSTEM DESIGN

3.1 SOLAR PV MODEL

A simplified model has been used as follows:

$$Ppv = \text{Pref} + [\text{Pref X Cp (Tcell-Tref)}] \quad (1)$$

Where, Ppv is the output power (W), Pref is the module reference power at standard test conditions (1000 W/m^2, 25°C), Cp is the temperature coefficient at maximum power (/Co), and T$c$ell is the cell temperature (Co). Also, the cell temperature can be calculated using equation (2) below:

$$\theta c = Ta + [(NOCT - 20)\, 800 \times Ga] \quad (2)$$

As we discussed previously, we need the PSH for each month and also the average daily temperature to approximately find the energy generated. Since the project location is at Yanbu city we use the irradiation data for Yanbu. Table A.7 in appendix, shows the temperature variation at Yanbu. Since temperature of the solar cell affect the power output and the highest temperature are always recorded when the sun is near or at solar noon, we will select the maximum temperature value for each month in calculating the output power of the solar array.

3.2 SOLAR ARRAY SIZING

To size solar array we need first to quantify three main categories:

a. The customer electricity consumption
b. Is there an enough space
c. Is there an enough budget

The electricity consumption of the Renewable Energy Center building is shown in Table 2. To calculate the solar array size in kW that will generate annually 80,300 kWh, we need to assume the fixed system losses as well as power loss due to temperature. Fixed system losses are shown in Table 3.

To calculate the DC-AC derating of the solar array, we need to select the solar module manufacturer. The following manufacturer in Table 4 is used. Since we know the power temperature coefficient, we can calculate the losses due to temperature increase.

TABLE 2: THE ELECTRICITY CONSUMPTION OF THE RENEWABLE ENERGY CENTER BUILDING

Month	kWh
Jan	5300
Feb	6800
Mar	7200
Apr	8300
May	8200
Jun	8100
Jul	3800
Aug	6700
Sep	7900
Oct	7300
Nov	5600
Dec	5100
Total	80,300

TABLE 3: SYSTEM LOSSES

Type of losses	% losses from total
Soiling	5%
Wiring	3%
LIC	2%
Inverter	3%
Shading	2%
Total losses	15%

TABLE 4: MANUFACTURER SPECIFICATIONS

CSI Model Number	FS-4102-2
STC Rating (Watt)	102.5 W
Open Circuit Voltage (Voc)	88 V
Short Circuit Current (Isc)	1.57 A
VMP	70 V
IMP	1.47 A
NOCT	45 C
Efficiency	14.24 %
Voltage Temp Coefficient	-0.246%/K
Power Temp Coefficient	-0.29%/K
Width (in)	60 cm
Length	120 cm

For example: Aug, average maximum temperature is 40.3°C. Thus, to calculate the power,

$$P_{mp} = P_{mp} + \left(P_{mp} \times \left(\frac{\Delta P_{mp}}{°C}\right) \times (T_c - T_{ref})\right)$$

$$T_c = T_a + \left(\frac{NOCT - 20}{800}\right),$$

For G=1000,

$$T_c = 40.3 + \left(\frac{45 - 20}{800}\right) \times 1000 = 71.55°C$$

$$P_{mp} = 102.5 + (102.5 \times (-0.0029) \times (71.55 - 25))$$

$$P_{mp} = 88.62\ Watt$$

Around 30 modules has been used in this paper, so total rated power is as below:

$$102.5 \times 30 = 3075\ W$$

Total DC power losses due to temperature are as follows;

$$\left(1 - \frac{88.62 * 30}{3075}\right) \times 100\% = 13.54\%$$

The DC-AC de-rating is calculated as below:

$$1 - (0.15 + 0.1354) = 0.715$$

So, in Aug month the average kWh-ac per kW-dc installed:

kWhac per kWdc = $PSH_{45°}$(Aug) x (DC-AC derating) = 6.57 x 0.715 = 4.7kWhac/day

We have 3.075 kW, so the total kWh ac =3.075x4.7=14.45 kWhac/day in August.

The following design methodology in Figure 6 has been develop using MATLAB M-Files.

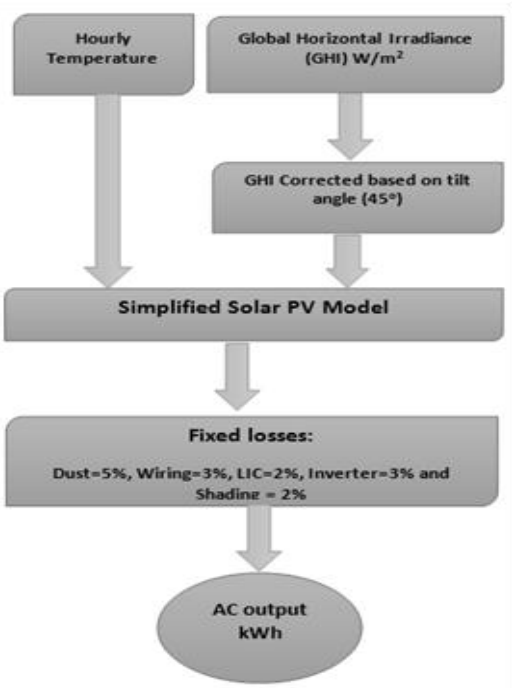

Fig. 6. Flow chart of design methodology

3.3 SOLAR SYSTEM ENERGY PERFORMANCE

The system performance is given in Figures 7,8 and 9 below. Figure 7, shows the total generated power per month from the solar array. We can observe from Figures 7 and 8 the monthly output AC power from solar PV system which increase with increase in irradiation. However, temperature has a negative impact in system performance as in Figure 9.



Fig. 7. The DC output power and AC output power

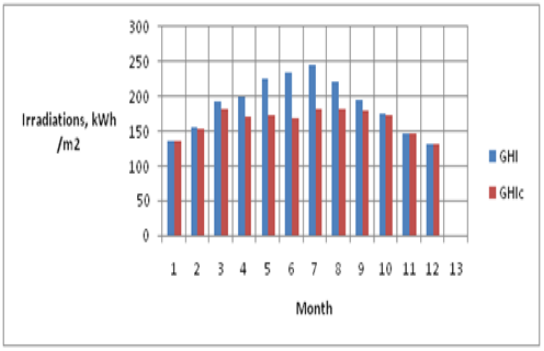

Fig. 8. Effect of tilt angle on solar irradiation

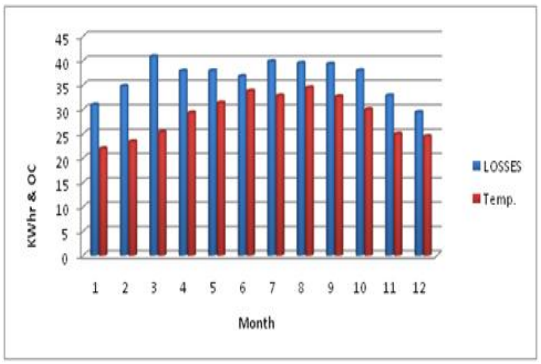

Fig.9. The effect of temperature on system losses

4. FEASIBILITY STUDY OF THE SYSTEM

The system budget will be provided by the REC of RCYCI based on the available fund for next semester. The system total cost is 11,300 SR not including panels cost. To study the feasibility of the system, we need to calculate the initial cost, operation and maintenance cost of the system over 25 years. Table 5 is used to find the NPV of the system and payback period. Table A.6 (See Appendix) shows cash flow, payback period and NPV.

TABLE 5- PAYBACK PERIOD ANALYSIS

Economical Variable	Value
Discount rate	3.5 %
Operation & Maintenance cost	1% of energy cost.
Initial cost	11300 SR
Replacement cost	3000 SR inverter after 15 years.

5. CONCLUSION

In conclusion, to reduce the electricity bill a 3kW solar grid tie system was used on the building roof. The 3 kW solar systems will generate a total 160000 kWh annually which reduce the electricity bill by 20%. We found that the system will generate 5157 kWh annually. The payback period is 8.5 years and a NPV of 6457.9 SR. It is recommended to install the REC system. We also examine the effect of temperature and tilt angle for solar power production was examined. The temperature rise increases solar module losses and reduces efficiency.

REFERENCES

[1] S. Rehman, 'Prospects of wind farm development in Saudi Arabia', Renewable Energy, vol. 30, no. 3, pp. 447-463, 2005.

[2] Rahman F, Rehman S, Arif M, Majeed A., "Overview of energy storage systems for storing electricity from renewable energy sources in Saudi Arabia." Renew. Sustain. Energy Rev., Vol. 16, pp.274–283, 2012.

[3] S. Rehman, T. Halawani and T. Husain, 'Weibull parameters for wind speed distribution in Saudi Arabia', Solar Energy, vol. 53, no. 6, pp. 473-479, 1994.

[4] S. Rehman, T. Halawani and M. Mohandes, 'Wind power cost assessment at twenty locations in the kingdom of Saudi Arabia', Renewable Energy, vol. 28, no. 4, pp. 573-583, 2003.

[5] King Abdullah University of Science and Technology (KAUST), 2009.

[6] S. Alawaji, "Evaluation of solar energy research and its applications in Saudi Arabia 20 years of experience", Renewable and Sustainable Energy Reviews, vol. 5, no. 1, pp. 59-77, 2001.

[7] Middle East Economic Survey, "KACARE Outlines Saudi Electricity Energy Source Scenario" (May 3, 2013), page 7.

[8] King Abdullah Economic City (KAEC), 2009.

[9] Saudi Arabia energy efficiency report, ABB global, April, 2012. (Online, 2015)

[10] Saudi Electricity Company, "Saudi Electricity Company Annual Report 2013", 2014. [Online].

[11] L.M. Peter (Apr. 4, 2011). "Towards sustainable photovoltaics: the search for new materials." Philosophical Trans A, Vol. 369.

[12] L. Kazmerski (Aug. 6, 2015). Best Research Solar Cell Efficiencies. National Renewable Energy Laboratory. Retrieved from www.nrel.gov/ncpv/images/efficiency_chart.jpg

APPENDIX

TABLE A.1: PAYBACK PERIOD

Year	kWhac	Cash flow	Discounted Cash Flow	Remaining of Investment
1	5121.7	1622.57	1565.78	-9734.21
2	5085.66	1611.13	1498.35	-8235.85
3	5049.5	1599.69	1431.73	-6804.12
4	5013.45	1588.260	1365.90	-5438.2
5	4977.3	1576.82	1300.87	-4137.34
6	4941.2	1565.38	1236.65	-2900.69
7	4905.1	1553.94	1173.2	-1727.46
8	4869	1542.5	1110.60	-616.85
9	4832.9	1531.07	1048.78	431.92
10	4796.8	1519.63	987.76	1419.68
11	4760.7	1508.19	927.53	2347.22
12	4724.6	1496.75	868.11	3215.34
13	4688.5	1485.31	809.49	4024.84
14	4652.3	1473.87	751.67	4776.52
15	4616.2	1462.44	694.65	2471.18
16	4580.1	1451	638.44	3109.62
17	4544.0	1439.56	583.02	3692.65
18	4507.9	1428.12	528.4	4221.05
19	4471.87	1416.68	474.59	4695.64
20	4435.76	1405.25	421.57	5117.22
21	4399.66	1393.81	369.36	5486.58
22	4363.55	1382.37	317.94	5804.53
23	4327.45	1370.93	267.33	6071.86
24	4291.34	1359.49	217.51	6289.38
25	4255.24	1348.06	168.50	6457.89

TABLE A.2: RADIATION IN RIYADH CITY

Monthly Averaged Radiation Incident On An Equator-Pointed Tilted Surface kWh/m^2/day													
Lat 24.774	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
DHI	1.22	1.41	1.74	1.98	1.95	1.75	1.80	1.71	1.56	1.28	1.19	1.15	1.56
DNI	5.05	5.69	5.76	6.20	7.49	8.80	8.33	7.92	7.33	7.12	5.84	4.90	6.71
Tilt 0	3.65	4.59	5.32	6.07	7.12	7.84	7.56	6.99	6.25	5.42	4.08	3.43	5.70
Tilt 9	4.08	5.00	5.57	6.15	7.01	7.61	7.39	7.01	6.48	5.87	4.55	3.87	5.89
Tilt 24	4.61	5.46	5.75	6.04	6.54	6.92	6.79	6.76	6.59	6.36	5.12	4.43	5.95
Tilt 39	4.89	5.63	5.64	5.62	5.75	5.89	5.86	6.15	6.35	6.50	5.42	4.75	5.70
Tilt 90	3.89	4.03	3.31	2.49	1.95	1.71	1.79	2.26	3.27	4.39	4.20	3.90	3.09
OPT	4.94	5.63	5.76	6.15	7.12	7.84	7.56	7.02	6.60	6.50	5.45	4.82	6.28
OPT ANG	47.0	40.0	26.0	11.0	0.00	0.00	0.00	6.00	21.0	37.0	46.0	50.0	23.5

TABLE A.3: RADIATION IN JEDDAH CITY

Monthly Averaged Radiation Incident On An Equator-Pointed Tilted Surface (kWh/m^2/day)													
Lat 21.542	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
DHI	1.15	1.33	1.57	1.78	1.94	2.01	2.01	1.98	1.72	1.40	1.23	1.13	1.61
DNI	6.40	6.79	7.11	7.41	7.49	7.33	7.21	6.54	6.66	6.82	6.17	5.90	6.82
Tilt 0	4.38	5.28	6.11	6.75	7.13	7.09	7.01	6.39	6.08	5.51	4.57	4.02	5.86
Tilt 6	4.72	5.59	6.30	6.80	7.05	7.16	6.89	6.39	6.21	5.78	4.91	4.36	6.02
Tilt 21	5.40	6.15	6.55	6.68	6.58	7.09	6.36	6.17	6.30	6.24	5.58	5.03	6.18
Tilt 36	5.78	6.37	6.44	6.21	5.78	6.66	5.52	5.63	6.06	6.35	5.95	5.43	6.01
Tilt 90	4.47	4.37	3.49	2.37	1.77	2.73	1.71	2.01	2.93	4.07	4.56	4.34	3.23
OPT	5.85	6.37	6.55	6.81	7.13	7.18	7.01	6.40	6.31	6.36	6.01	5.53	6.46
OPT ANG	46.0	38.0	24.0	8.00	0.00	11.0	0.00	3.00	18.0	34.0	45.0	48.0	22.8

TABLE A.4: RADIATION IN DAMMAM CITY

Monthly Averaged Radiation Incident On An Equator-Pointed Tilted Surface kWh/m^2/day													
Lat 26.434	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
DHI	1.16	1.37	1.75	2.00	2.00	1.85	1.96	1.76	1.43	1.23	1.15	1.10	1.57
DNI	4.94	5.51	5.44	5.99	7.28	8.49	7.65	7.63	7.78	7.11	5.65	4.65	6.51
Tilt 0	3.47	4.39	5.07	5.91	7.00	7.69	7.23	6.93	6.36	5.29	3.88	3.21	5.54
Tilt 11	3.99	4.87	5.36	6.01	6.88	7.44	7.05	6.94	6.67	5.84	4.44	3.72	5.77
Tilt 26	4.51	5.31	5.53	5.89	6.42	6.77	6.49	6.64	6.79	6.33	4.99	4.25	5.83
Tilt 41	4.78	5.47	5.41	5.47	5.63	5.76	5.60	5.99	6.53	6.45	5.27	4.55	5.58
Tilt 90	3.87	3.99	3.27	2.56	2.06	1.81	1.92	2.40	3.48	4.47	4.16	3.79	3.14
OPT	4.82	5.47	5.53	6.01	7.00	7.69	7.23	6.96	6.79	6.46	5.30	4.61	6.16
OPT ANG	49.0	41.0	27.0	12.0	0.00	0.00	0.00	6.00	23.0	39.0	48.0	51.0	24.5

TABLE A.5: RADIATION IN ABHA CITY

Monthly Averaged Radiation Incident On An Equator-Pointed Tilted Surface (kWh/m^2/day)													
Lat 18.217	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Diffuse	1.30	1.48	1.70	1.91	1.98	1.99	2.06	2.10	1.80	1.42	1.28	1.17	1.68
Direct	6.01	6.36	6.69	6.82	7.13	7.06	6.61	5.86	6.47	7.06	6.45	6.38	6.58
Tilt 0	4.60	5.31	6.07	6.54	6.82	6.88	6.64	6.09	6.11	5.81	4.92	4.57	5.87
Tilt 3	4.78	5.45	6.15	6.56	6.84	6.93	6.69	6.08	6.17	5.95	5.09	4.76	5.96
Tilt 18	5.47	5.96	6.37	6.44	6.74	6.99	6.69	5.87	6.25	6.41	5.79	5.56	6.21
Tilt 33	5.87	6.15	6.26	5.99	6.29	6.69	6.36	5.38	6.01	6.53	6.16	6.06	6.14
Tilt 90	4.47	4.01	3.17	2.10	2.22	2.87	2.63	1.82	2.68	3.95	4.54	4.83	3.27
OPT	5.96	6.15	6.38	6.56	6.85	7.01	6.73	6.09	6.26	6.54	6.23	6.21	6.42
OPT ANG	44.0	34.0	20.0	5.00	6.00	13.0	11.0	0.00	14.0	30.0	42.0	47.0	22.1

TABLE A.6: RADIATION IN YANBU

Monthly Averaged Radiation Incident On An Equator-Pointed Tilted Surface kWh/m^2/day													
Lat 24.7	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Diffuse	1.01	1.16	1.50	1.79	2.00	1.93	1.93	1.89	1.66	1.32	1.13	0.98	1.53
Direct	6.67	7.29	7.18	7.28	7.23	8.01	7.72	6.99	6.80	6.90	6.23	6.29	7.05
Tilt 0	4.23	5.24	5.97	6.60	6.99	7.46	7.27	6.55	6.01	5.33	4.23	3.92	5.82
Tilt 9	4.80	5.76	6.28	6.70	6.88	7.25	7.11	6.57	6.23	5.77	4.72	4.48	6.05
Tilt 24	5.52	6.38	6.54	6.58	6.43	6.61	6.55	6.33	6.32	6.24	5.34	5.22	6.17
Tilt 39	5.93	6.63	6.44	6.11	5.65	5.65	5.67	5.78	6.08	6.36	5.66	5.66	5.96
Tilt 90	4.79	4.78	3.72	2.59	1.95	1.75	1.82	2.22	3.16	4.29	4.40	4.72	3.34
OPT	6.02	6.64	6.55	6.70	6.99	7.46	7.27	6.57	6.33	6.36	5.70	5.78	6.53
OPT ANG	49.0	42.0	27.0	11.0	0.00	0.00	0.00	6.00	21.0	37.0	47.0	52.0	24.2

TABLE A.7: TEMPERATURE VARIATION AT YANBU.

Monthly Averaged Air Temperature At 10 m Above The Surface Of The Earth (°C)													
Lat 24.7	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Minimum	13.1	13.5	16.1	19.9	23.8	25.9	26.4	27.5	26.8	23.3	19.1	15.3	20.9
Maximum	22.7	24.2	27.4	32.1	36.4	39.5	39.5	40.3	39.6	34.9	28.7	24.4	32.5