Proceedings of the Third International Conference on
Thermal Engineering: Theory and Applications
May 21-23, 2007, Amman, Jordan

Photovoltaic system as an alternative source of electricity generation: A case study in Hashemite University / Jordan

Issa Etier [a], Mohammad Ababneh [b]

[a] *Department of Electrical Engineering, Hashemite University, Zarqa, Jordan*
[b] *Department of Mechatronics Engineering, Hashemite University, Zarqa, Jordan*

Abstract

Jordan imports approximately ninety seven percent of its primary energy, of which thirty percent is used to generate electrical energy [12]. Renewable-energy sources are becoming more and more attractive especially with the constant increase in oil prices. Photovoltaic (PV) system is considered one of the important alternative sources in this regard. This clean and environment-friendly energy-source is looking very useful to be utilized in Jordan where solar global-radiation is one of the highest in the world [2].

A study case of designing and simulation of a photovoltaic system in the Hashemite University is investigated in this paper. This study investigates the feasibility of using the solar energy in Jordan where a grid-connected photovoltaic-system is used. This study is important because we believe that investment in this field is unavoidable in Jordan in the near future and may have many ecological, political, and economical advantages.

Keywords: photovoltaic system, grid-connected, solar cell.

1. Introduction

The sun is the largest regenerative source of energy in our world. It is estimated that the annual sun exposure amounts to $3.9\times10^{24}J = 1.08\times10^{18}kWh$. This corresponds to more than 10000 times of the present world energy needs [18].

The history of photovoltaic goes back to the year 1839, when Becquerel discovered the photovoltaic effect, but no technology was available in the 19th century to exploit this discovery. The semiconductor age only began about 100 years later. After Shockley had developed a model for the pn junction, Bell Laboratories produced the first solar cell in 1954; the efficiency of this, in converting light into electricity, was about 5% [11].

To understand PV operation, we need to state that the solar cells are made of semiconductors material, which have some weakly bonded electrons. Electrons and holes usually appear in pairs within solid matter. And the characteristics of the semiconductor material make it easy for incoming photons of sunlight to release electrons from the electron hole binding. Leaving the holes behind them, the released electrons can move freely within the solid material [11, 18].

However the electron movements have no clear direction; therefore, to create electricity, it is necessary to collect electrons. The semiconductor material is therefore polluted with ‘impure’ atoms. Two different kinds of atom produce an n-type and a p-type region inside the semiconductor, and these two neighboring regions generate an electrical field as shown in Figure 1. This field can then collect electrons, and draws free electrons released by the photons to the n-type region. And the holes move in the opposite direction, into the p-type region [11, 18].

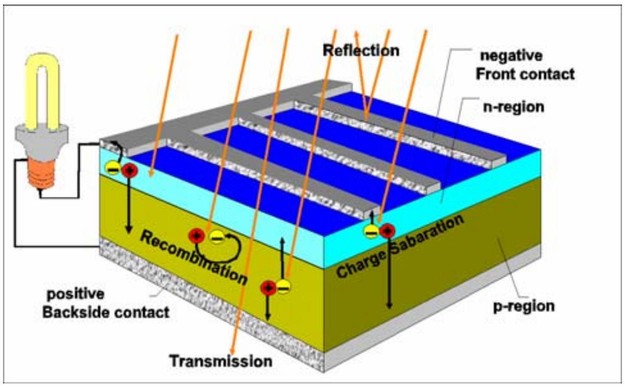

Fig. 1. Solar cell construction

However, not all of the energy from the sunlight can generate free electrons. There are several reasons for this. Part of the sunlight is reflected at the surface of the

---

[*] Corresponding author. Tel.: +962 5 390 3333 ext. 4648
Fax: +962 5 382 6613; E-mail: `etier@hu.edu.jo`

solar cell, or passes through the cell. In some cases, electrons and holes recombine before arriving at the n-type and p-type regions. Furthermore, if the energy of the photon is too low – which is the case with light of long wavelengths, such as infrared – it is not sufficient to release the electron. On the other hand, if the photon energy is too high, only a part of its energy is needed to release the electron, and the rest converts to heat. Figure 1 shows these processes in a photovoltaic (PV) cell.

In this work, a 10-kW grid-connected PV-system is investigated as a case study in the Hashemite University of Jordan. Many factors have motivated this work. Firstly, the campus is located in a desert area where the global radiation numbers are ones of the highest in the world. Secondly, the campus has plenty of safe building flat-roof areas to install solar panels. Thirdly, most of the power demand is during the daytime so that implementing grid-connected PV system would save considerably in the electric bill. And finally, constant increase of electric bill cost due to increase of oil prices.

The rest of this paper is divided as follows: Section 2 discusses Photovoltaic system and focuses on the grid-connected PV-system. Section 3 presents the system components and utilizes actual and simulated metrological data to define and optimize different parts of the system. Finally, section 4 presents the conclusions and future work.

2. Photovoltaic System

In general, PV electrical power generation can be categorized in two categories; stand-alone PV-system and grid-connected PV-system. The first category is used in remote area where it is too expensive to be reached by public grid system. Big disadvantage of this system is the use of batteries for night supply, since battery energy-loss is too high [1].

The second category is grid-connected PV-system where the generated electricity is directly used and there is no need for storage. This work investigates this category since Jordan national public-grid covers 99.8% of the populated areas in the country [12].

Figure 2 shows the main components of grid-connected PV-system. The connection to the public grid is achieved by using proper inverters . Care must be exercised to choose inverter units with the highest efficiency. During the daytime, the solar generator provides power for the electrical equipment and lighting and excess energy is supplied to the public grid. In addition, during the nighttime, the load gets its electricity from the public-grid [11].

Grid-connected PV-system can be installed in different establishments where the range of power needs can be in magnitude of watts to magnitudes of megawatts. This can be achieved by installing enough PV-generators for different establishments.

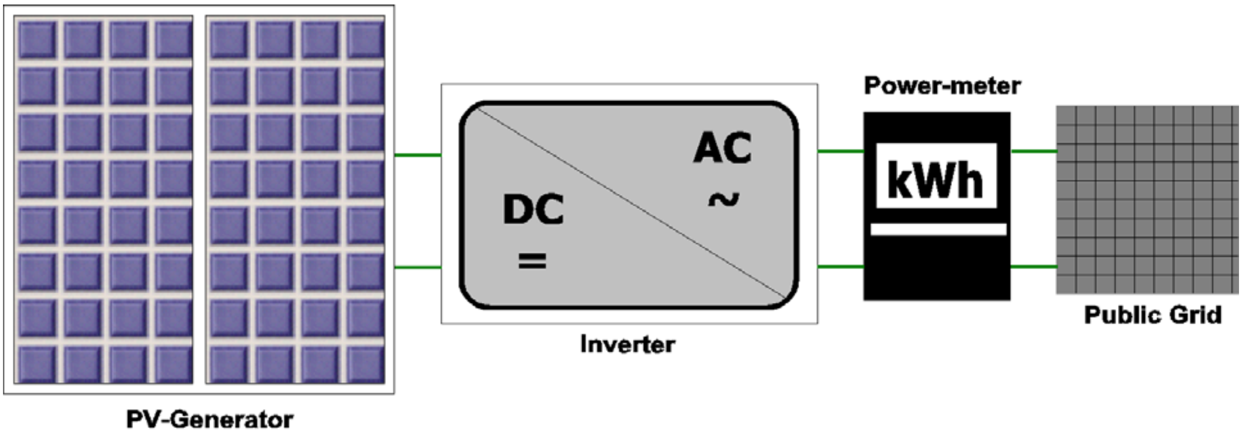

Fig. 2. Grid-connected PV system

3. System Description

This section provide detailed description of the proposed modular 10 kW PV system. The study is based on The Hashemite University campus located 25 kilometers north of Amman, Jordan. This area is a desert area where radiation is one of the highest in the world, which makes solar energy an attractive source of energy. Jordan Meteorological Department has around fifteen weather stations in the country that collect regular metrological data including sun radiation. Azraq station is chosen for this study since weather conditions are close to the conditions in the university campus [19]. The campus obtains its electrical power from a public grid that is shared with other industrial and residential consumers. And the peak consumption in the campus occurred during the daytime where PV power generation is conveniently can be generated. The university power consumption for year 2006 is 6106 MWh with a cost of $529000 where the cost of 1 kWh is $0.087. Furthermore, the unused building flat-roof areas is close to 53600 m^2, which provide safe location for huge number of PV panels.

The principal objective of this simulation study is to provide a modular 10 kW PV system that will be connected to the public power grid as shown in Figure 2. Additional PV modules can be added in the future as needed to meet campus needs.

The software used for the simulation is PV*SOL [21]. This simulation program is used to design and perform calculations of grid-connected and stand-alone systems.

It calculates the output of a PV system, depending on its location, and determines its economic efficiency.

Monthly metrological data, global radiations and temperatures, from Jordan Meteorological Department, was obtained for the last eight years [3], [4], [5], [6], [7], [8], [9], [10], . Figure 3 shows the yearly global-radiation figures, which are exceeding 2000 kWh/ m^2.

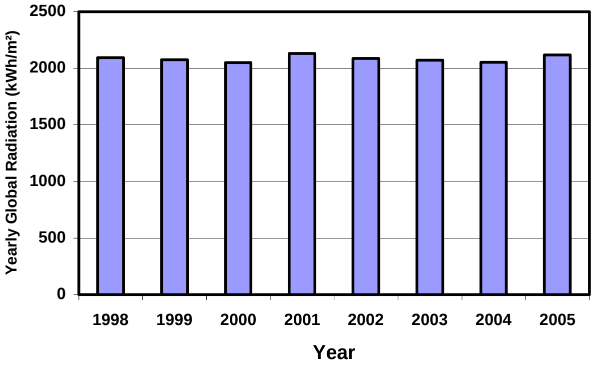

Fig. 3. **Yearly global radiation in Azraq station**

The actual PV system yields can vary due to a variation in weather conditions, and module and inverter efficiencies. In addition, The data fed to PV*SOL is based on hourly data. However, the data obtained from Jordan Meteorological Department is monthly averages and not hourly. Therefore, METEONORM software is used to obtain the hourly data needed for the simulation.

METEONORM 5.0 (Edition 2003) is a comprehensive meteorological reference, incorporating a catalogue of meteorological data and calculation procedures for solar applications and system design at any desired location in the world [20].

Global-radiation and temperature data from Jordan Meteorological Department is compared with data available from METEONORM software. Result for this comparison is illustrated in Figure 4 and Figure 5 and showed very small differences. Therefore, METEONORM software data proves to be accurate and reliable to be used in this work.

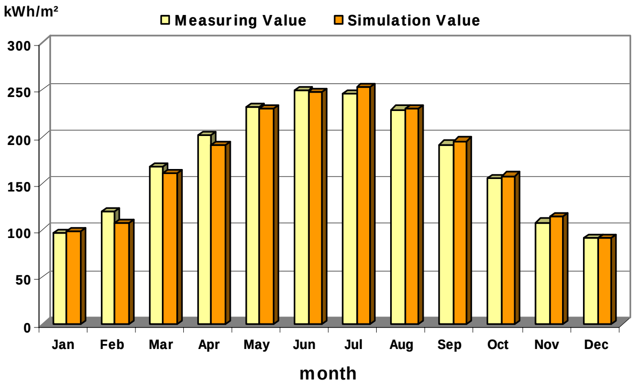

Fig. 4. **Comparison of measuring and simulation values of the global radiation**

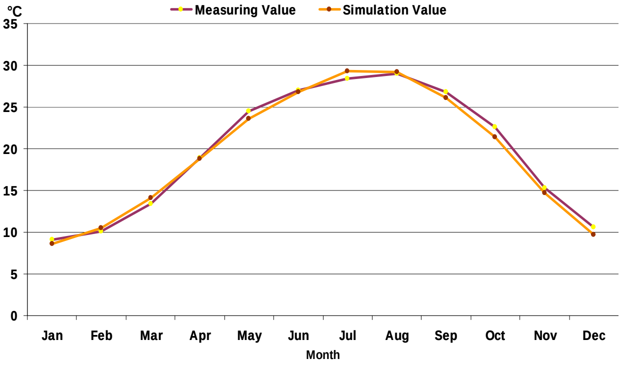

Fig. 5. **Comparison of the measured and simulated monthly average values of the temperatures**

The configuration of the PV system is illustrated in Figure 2. This proposed 10 KW PV system will be made of number of panels. Initially, it is important to determine the optimal panel-size. Many panel sizes were tried using PV*SOL software to choose the optimal panel-size. Table 1 shows the simulation results of one of the best runs. And 300W-panel-size shows the maximum energy generation.

Table 1. **Comparison between three panel sizes**

PV-Modules:	Shell SM50 50W	Shell SM110-12 110W	ASE-300-DG-FT 300W
DC-AC Inverter	SP1500 E-48 1.7 kW	SP 3000 E-48 3.4 kW	NT 4000 3.4 kW
Number of module /inverter	200/5	90/3	33/3
Panel in series	5	6	11
PV-Power [kW]	10.13	9.92	9.97
PV surface [m²]	85.10	78.17	80.10
PV-Generator, radiation [kWh]	195161	177484	182115
PV generator, produced energy [KWh]	15216	15069	17515
Specific Annual Yield [kWh / kWp]	1486	1497	1754

One important factor of PV generation is the panel inclination angle. A simulation was performed to obtain the optimal inclination angle as shown in the Figure 6, it was determined that an angle of 27º gives the maximum power generation.

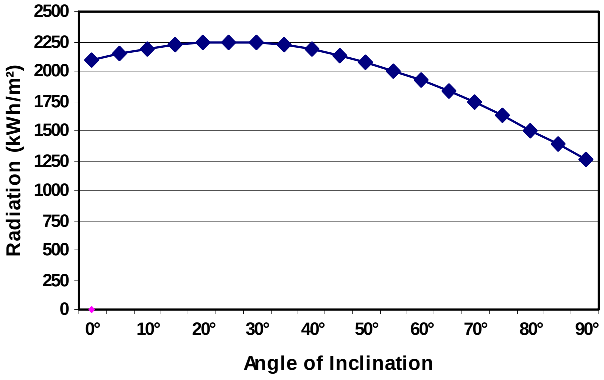

Fig. 6. **Radiation versus panel angle of inclination.**

Another aspect of PV generation is to choose suitable inverter from a list of inverter database available in PV*SOL. The selection of the inverter is based on operating power and highest efficiency possible. This list reflect standard inverters available in the market. SUNWAYS AG NT 4000 was chosen to be the best match for this application. Table 2 below shows inverter data sheet.

Table 2. Inverter data sheet

Name: SUNWAYS AG NT 4000
Company: SUNWAYS AG
Type: NT 4000
DC-Power: 3.40 kW
Maximum PV-power: 4.00 kW
Minimum voltage limit: 350.0 V
Maximum voltage limit: 650.0 V
DC-operating voltage: 400.0 V
DC-operating current: 8.50 A
Maximum input voltage: 750.0 V
Maximum input current: 10.00 A
Operating efficiency: 97.0 %

Now, we are ready to run the final simulation, the inputs needed to run the simulation are the module power, PV-module size, inverter type, place, and angle of inclination. The resultant 10-KW PV-system configuration is PV generator obtained from 33 panels and 3 inverters of NT 4000 3.4 kW as shown in Table 3 below.

Table 3. Simulation result of the final PV-system

PV-Modules: RWE Shott Solar GmbH ASE-300-DG-FT-300W
DC-AC Inverter: Sunways AG NT 4000- 3,4kW

Number module/inverter	33/ 3
Number in row	11
Place	Zarqa
angle of inclination	27
PV-Power [kW]	9.97
PV surface [m²]	80.1
PV-Generator, radiation [kWh]	180352
PV Generator, Produced Energy(AC) [kWh]	17131
System efficiency [%]	9.5
Specific Annual Yield [kWh / kWp]	1754
avoided CO2-Emission [kg/year]	15148
inverter efficiency [%]	96.2
PV-Generator efficiency [%]	9.9
Cost (including maintenance)	$61200

It is clear from the findings above that the system efficiency, percentage of PV-generated energy to PV radiation, is 9.5% where it has a big room for improvement. In addition, the system cost is $61200 where 70% of this cost goes for the solar panels [11]. Furthermore, the area required is 80 m^2 and plenty of safe areas are available in the campus.

4. Conclusions

We discussed the optimal configuration of modular PV system in the Hashemite University of Jordan. Calculations show the cost for PV-generation is $0.18/kWh without public subsidy compares to $0.086/kWh from national electric power company [12], [13], [14], [15], [16], [17].

However, Most of the PV-system cost comes from the hardware, i.e. the initial cost, and portion of it might be covered from public subsidies in the future. Furthermore, the hardware cost is decreasing with time and oil prices are increasing. And this cost ratio, between PV-generation and grid supply, might be reversed in near future.

We focused on implementing a PV-system in 10-kW modules. Then more modules are connected to the grid as they are available and to meet the additional needs. Total of 356 modules are calculated to meet the power needs of the campus.

Furthermore, considering the environmental impact, the PV system does not produce CO_2 emission and maintain clean and healthy environment. As shown in Table 3 this PV-module avoided emission of 15148 kg/year of CO_2. In addition, it is important to mention that global radiation in Jordan is much higher than the values in Europe, for example the yearly global radiation in Germany is around 1000 kWh/ m^2 compare to 2000 kWh/ m^2 in Jordan.

Future work might include improving system-efficiency and optimizing system components. This might be achieved by investigating a new mechanism to keep the sun radiation vertical to solar-panels, or using newer technologies for solar cells and inverters.

Acknowledgments

We would like to thank Jordan Meteorological Department, Jordan National Electric Power Company, And the HU Engineering and Maintenance Department for their support. Without their help and support, this work might not have been completed.

References

[1] Hanitsch, R., Etier, I., Ertürk, N., Heumann, K., Munschauer, M., Simulation and comparrion of a tracked PV system with a model based on the measurement of the sky irradiance distribution, EuroSun98, 2nd ISES-Europe, Portoroz, Slovenia. 1998.

[2] International Energy Agency: World Energy Outlook. OECD/IEA, France, 2006.

[3] Jordan Meteorological Department: Jordan Annual Climate Bulletin, JMD, Amman, Jordan, 2005.

[4] Jordan Meteorological Department: Jordan Annual Climate Bulletin, JMD, Amman, Jordan, 2004.

[5] Jordan Meteorological Department: Jordan Annual Climate Bulletin, JMD, Amman, Jordan, 2003.

[6] Jordan Meteorological Department: Jordan Annual Climate Bulletin, JMD, Amman, Jordan, 2002.

[7] Jordan Meteorological Department: Jordan Annual Climate Bulletin, JMD, Amman, Jordan, 2001.

[8] Jordan Meteorological Department: Jordan Annual Climate Bulletin, JMD, Amman, Jordan, 2000.

[9] Jordan Meteorological Department: Jordan Annual Climate Bulletin, JMD, Amman, Jordan, 1999.

[10] Jordan Meteorological Department: Jordan Annual Climate Bulletin, JMD, Amman, Jordan, 1998.

[11] Luque, A., Hegedus, S.: Handbook of Photovoltaic Science and Engineering. John Wiley & Sons Ltd, 2003.

[12] National Electric Power Company: Annual Report, Ad-dustour Commercial Press, Amman, Jordan, 2005.

[13] National Electric Power Company: Annual Report, Ad-dustour Commercial Press, Amman, Jordan, 2004.

[14] National Electric Power Company: Annual Report, Ad-dustour Commercial Press, Amman, Jordan, 2003.

[15] National Electric Power Company: Annual Report, Ad-dustour Commercial Press, Amman, Jordan, 2002.

[16] National Electric Power Company: Annual Report, Ad-dustour Commercial Press, Amman, Jordan, 2001.

[17] National Electric Power Company: Annual Report, Ad-dustour Commercial Press, Amman, Jordan, 2000.

[18] Quaschning, V.: Understanding Renewable Energy Systems. Earthscan London, 2005.

[19] Royal Jordanian Geographic Centre: Jordanian School Atlas, RJGC, Amman, Jordan, 2001.

[20] Switzerland, Meteotest: METEONORM Global Meteorological Database for Engineers, Planners and Education, Version 5.0, Edition 2003.

[21] Valentin Energy Software: PV SOL Simulation Program for Photovoltaic Systems, Berlin, Version 2.4, 2003.