Simulation of a 10 kW Photovoltaic System in Areas with High Solar Irradiation

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Abstract: Problem statement: This study investigates the design and the simulation of a 10 kW photovoltaic (PV) system in areas of high solar irradiation. The importance of this study is to explore the feasibility of connecting the PV system with a grid to generate electricity at campus of Hashemite University (Jordan) whose yearly global irradiation is 2000 kWh/m^2. **Approach:** In order to determine the size and the number of PV modules needed to achieve the energy needs of the campus, we apply both the METEONORM and the PV SOL simulation software. This study calculates the cost of one kWh generated by the PV system and then compares it with the public electricity tariff. The study also presents a comparison between the performances of different PV panel sizes with different inclination angles. **Results:** METEONORM software data proves to be accurate and reliable to be used in this study. The 300W-panel-size shows the maximum energy generation. The optimal inclination angle which gives the maximum power generation is 27°. **Conclusion:** The calculations show the cost for PV-generation is \$0.18 kWh^{-1} without public subsidy compared to \$0.086 kWh^{-1} from national electric power company. A total of 356 modules are calculated to meet the power needs of the campus.

Key words: Photovoltaic system, grid-connected, solar cell, solar panel, angle of inclination, inverter, METEONORM, valentin energy software, meteorological department

INTRODUCTION

Jordan imports approximately ninety seven percent of its primary energy, of which thirty percent is used to generate electrical energy (Hanitsch *et al*., 1998). Renewable-energy sources are becoming more and more attractive especially with the constant fluctuation in oil prices (Shafie-Pour *et al*., 2008). Photovoltaic (PV) system is considered one of the important alternative sources in this regard (Ibrahim *et al*., 2009). 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 (International Energy Agency, 2006).

The sun is the largest regenerative source of energy in our world. It is estimated that the annual sun exposure amounts to 3.9×10^{24} J $= 1.08 \times 10^{18}$ kWh. This corresponds to more than 10000 times of the present world energy needs (Quaschning, 2005).

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% (Luque and Hegedus, 2003).

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 (Quaschning, 2005; Luque and Hegedus, 2003).
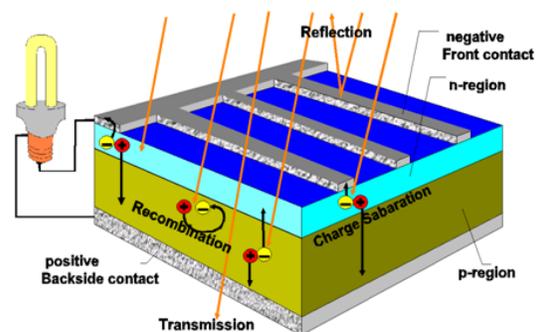

Fig. 1: Solar cell construction

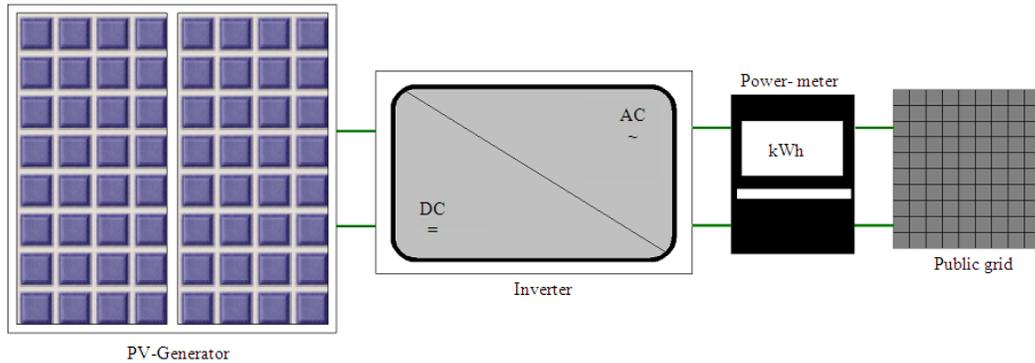**Corresponding Author:** Issa Etier, Department of Electrical Engineering, Hashemite University, Zarqa, Jordan

Fig. 2: Grid-connected PV system

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 Fig. 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 (Quaschning, 2005; Luque and Hegedus, 2003).

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 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 study, a 10-kW grid-connected PV-system is investigated as a case study in Hashemite University of Jordan. Many factors have motivated this study. 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 (Rehman *et al.*, 2005). Finally, constant increase of electric bill cost is due to the increase of oil prices.

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 (Hanitsch *et al.*, 1998; Marouani and Mami, 2010; Aliman *et al.*, 2007).

The second category is grid-connected PV-system where the generated electricity is directly used and there is no need for storage. This study investigates this category since Jordan national public-grid covers 99.8% of the populated areas in the country (National Electric Power Company, 2009).

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 (Luque and Hegedus, 2003).

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.

MATERIALS AND METHODS

System description: The study is based on Hashemite University campus located 25 km 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. Al Azraq station is chosen for this study since weather conditions are close to the conditions in the university campus (Royal Jordanian Geographic Centre, 2001). The campus obtains its electrical power from a public grid that is shared with other industrial and residential consumers.
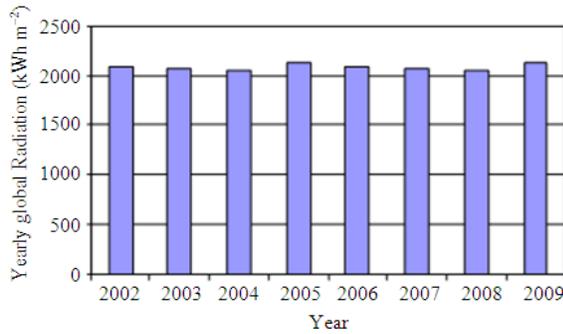
Fig. 3: Yearly global radiation in Al Azraq station

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 2009 is 6106 MWh with a cost of $529000 where the cost of 1 kWh is $0.087. Furthermore, the unused building flat-roof areas are 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 Fig. 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 (Valentin Energy Software, 2003). 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. Figure 3 shows the yearly global-radiation figures, which are exceeding 2000 kWh m^{-2}.

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 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.

RESULTS

Global-radiation and temperature data from Jordan Meteorological Department is compared with data
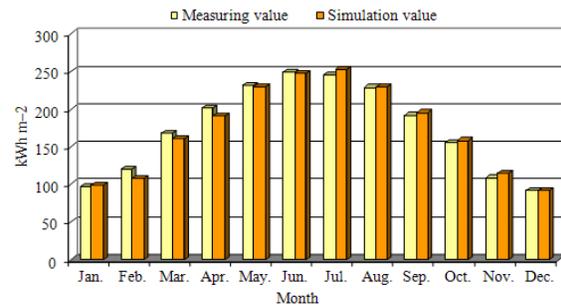

Fig. 4: Comparison of measuring and simulation values of the global radiation
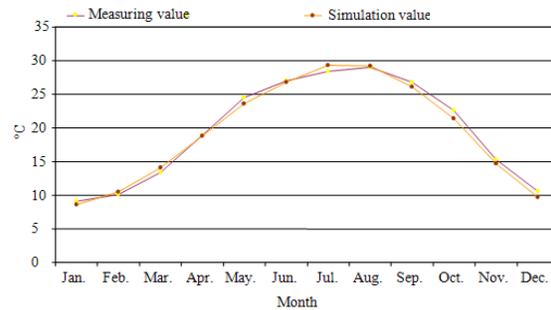

Fig. 5: Comparison of the measured and simulated monthly average values of the temperatures

available from METEONORM software. Result for this comparison is illustrated in Fig. 4 and 5 and showed very small differences. Therefore, METEONORM software data proves to be accurate and reliable to be used in this study.

The configuration of the PV system is illustrated in Fig. 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.

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 Fig. 6, it was determined that an angle of 27° gives the maximum power generation.

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 reflects standard inverters available in the market. SUNWAYS AG NT 4000 was chosen to be the best match for this application. Table 2 shows inverter data sheet.

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^{-1})	1486	1497	1754

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 %

Table 3: Simulation result of the final PV-system

	RWE shott solar GmbH
PV-modules:	ASE-300-DG-FT-300W
DC-AC Inverter:	Sunways AG NT 4000-3,4kW
Number module/inverter	33 3^{-1}
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^{-1})	1754
Avoided CO2-Emission (kg year^{-1})	15148
Inverter efficiency (%)	96.2
PV-Generator efficiency (%)	9.9
Cost (including maintenance)	$61200

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.
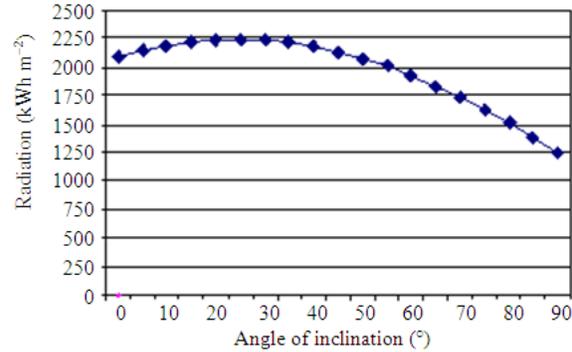

Fig. 6: Radiation versus panel angle of inclination

DISCUSSION

It is clear from the data shown in Table 3 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 $61,200 where 70% of this cost goes for the solar panels (Luque and Hegedus, 2003). Furthermore, the area required is 80 m^2 and plenty of safe areas are available in the campus.

CONCLUSION

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^{-1} without public subsidy compared to $0.086 kWh^{-1} from national electric power company (Jordan Meteorological Department, 2002; National Electric Power Company, 2008; 2004).

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. However, more modules can be connected to the grid to meet the additional needs. Note that a 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^{-1} 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 study 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.

ACKNOWLEDGMENT

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