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Performance Assessment of the First Residential Grid-Tie PV System in Jordan

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Abstract

In Jordan, exploration of energy sources has been initiated due to a sever power shortage. In this paper, a grid-connected photovoltaic solar system to supply a residence in Amman is implemented. The operational performance results of performance ratios are presented to study the effectiveness of the photovoltaic system without battery storage. Online monitoring is employed and real time data is collected to study the feasibility of grid-tied photovoltaic system. Experimental findings show the high efficiency and stability of the grid-connected photovoltaic system. Also the control unit shows a good performance of improving a flexible regulation of power factor using maximum power point tracking.

Keywords: grid-tie photovoltaic solar system; maximum power point tracking; single-stage inverter.

1. Introduction

Jordan faces a serious energy crisis which is the major obstacle for its economical development. Since Jordan is not an oil producing country, local authorities have started exploring new clean and renewable energy sources to overcome the energy shortage. Jordan is endowed with solar radiation intensity of about 5.5 kwh/m^2/day and an average sunshine duration of 3300 hrs/year with an average of 9-10 daylight hours for most geographical locations (Tarawneh 2007) as shown in Figure 1. This level of radiation is encouraging for all solar technology applications.

Among several other renewable energy systems, photovoltaic (PV) systems have drawn considerable attention by many countries around the world (Ulrike & Wolfgang 2004). The favor of solar power is due to environmental advantages, scalability, modularity, and location independency. Photovoltaic power systems are generally classified according to their operational requirements and component configurations, and how the equipment is connected to other power sources and loads. Off-Grid systems are independent of the utility power grid. Off-Grid systems use PV panels connected to a charge controller to charge a set of batteries. The stored energy from the batteries is usually converted to AC power by an inverter. Grid-Tied systems use PV panels to generate DC power. The DC power goes to a grid interactive inverter which converts the PV panel DC power to AC power that is compatible with the power grid (Swider *et al .2008*).

Numerous studies on effect of various parameters in the design of grid-connected PV systems have been achieved (Hamad & Alsaad 2010, Eltawil & Zhao 2010). It is well known that the main factors that influence the PV system growth rate are initial capital cost and selling price of the generated energy. Several researchers provided design optimization methods for grid connected PV system to determine optimal number of modules, array configurations, tilt angles, power converters, and distribution of PV modules in the installation area (Schaefer 1990, Solodovnik *et al.* 2004, Blaabjerg *et al.* 2006).

Enormous number of off-grid solar PV systems have been in-stalled throughout Jordan, but due to governmental restrictions, 2012 witnessed installation of the first residential grid-tied PV solar system. This is also interpreted by the high cost of installation and lack of experience in performance and reliability of PV systems. Several issues should be resolved to increase the contribution of PV systems to the national energy. This paper presents the implementation details of the first grid-tie PV solar system in a residential. The system design and components are described to study the feasibility and cost efficiency of the PV system using monitoring and control units. The fed energy to the network will be calculated and sold to the national grid, thus, the system becomes beneficial, and returns the value of the system during the period of convergence (4-5) years, with an estimated age of the system by about (25) years.

2. Background Information

2.1 Solar Energy in Jordan

While the imported energy in Jordan is currently about 96% is equivalent to 25% of the gross national product, solar radiation in Jordan ranging between 400 w\m^2 in winter and 1000w\m^2 in summer. Jordan located between (30-33) North latitude Allows exposure to sunlight for a long time, Because of that solar radiation intensity in Jordan ranging between (4.5 kwh\m^2\day) northern and (6 kwh\m^2\day) southern. Solar radiation intensity reaches 7.5 kw/m^2/day. Therefore, renewable energy is an urgent need for Jordan to reduce dependence on imported fossil fuels (Tarawneh 2007).

PV solar panels are highly reliable and have a lifespan between 30-40 years. Advanced silicon PV solar panels generate the same amount of electricity over their lifetime (50 years) as nuclear fuel rods, without the hazardous waste. Depending on the amount of sunlight a location receives throughout the year, a solar power plant requires 10% of the land area compared to a hydro reservoir. One kW of power generated from solar panels prevents: 150lbs of coal from being mined, 300 lbs of CO2 from being emitted and 105 gallons of water from being consumed. Wind is a form of solar power that's created by the uneven heating of the earth's surface.

2.2 Grid-Tie Photovoltaic Solar System

Grid-Tied systems use PV panels to generate DC power. The DC power goes to a grid interactive (grid-tied) inverter which converts the PV panel DC power to 240 volt AC power that is compatible with the power grid as shown in Figure 2.

The power from the PV panels goes (via the grid tie inverter) to supply the household power needs. If the PV system is generating more power than the house can use, the excess is sent out over the grid to supply others. If the house needs more power than the PV system can supply, then the extra is drawn from the grid as usual. Grid tied systems only work when the grid is up. If the grid power goes out, the grid tie inverter is required to shut down immediately. It has the advantages of: lowest initial cost (because there is no need for batteries and charge controller), the lowest ongoing maintenance cost (no batteries to maintain and replace), simplest to install, and most efficient (because there are losses associated with charging batteries).

3. System Components

3.1 Solar PV Panel

A solar panel (also solar module, photovoltaic module or photovoltaic panel) is a packaged, connected assembly of photovoltaic cells. The solar panel can be used as a component of a larger photovoltaic system to generate and supply electricity in commercial and residential applications. Each panel is rated by its DC output power under standard test conditions, and typically ranges from 100 to 320 watts. Because a single solar panel can produce only a limited amount of power, most installations contain multiple panels, which called solar array. The solar cells in each solar panel are semiconductor devices that can convert solar energy into DC electricity through the Photovoltaic Effect (is the creation of voltage or electric current in a material upon exposure to light.). Only the absorbed light generates electricity. PV cells come in many sizes and shapes, from smaller than a postage stamp to several inches across. They are often connected together to form PV modules that may be up to several feet long and a few feet wide. The bypass diodes are generally housed in the module junction box. In some cases the module junction box is sealed with silicon.

3.1.1 Photovoltaic Panel Characteristics

3.1.1.1 Short Circuit Current (I_{sc})

Short circuit current is current through the solar cell when the voltage across the solar cell is zero (i.e. when the solar cell is short circuited), usually written as I_{SC}. The short-circuit current depends on a number of factors which are described below: the area of the solar cell, the number of photons, Isc from a solar cell is directly dependent on the light intensity, the spectrum of the incident light and finally the optical properties (absorption and reflection) of the solar cell.

3.1.1.2 Open Circuit Voltage (V_{oc})

Open circuit voltage is the maximum voltage available from a solar cell, and this occurs at zero current. This value is normally 22 V for panels that are going to work in 12 V systems, and is directly proportional to the number of cells connected in series.

3.1.1.3 Maximum Power Point (P_{max}):

the Maximum Power Point (MPP) a point on the I-V Curve where the maximum power output is located. The voltage and current at this Maximum Power Point are designated as V_{mp} and I_{mp}. The values of V_{mp} and I_{mp} can be estimated from V_{oc} and I_{sc} as follows: $V_{mp} = (0.75 - 0.9)\ V_{oc}$, $I_{mp} = (0.85 - 0.95)\ I_{sc}$. The rated power of the PV / Solar Module in Watts (P_{max}) is derived from the above values of voltage V_{mp} and current Imp at this Maximum Power Point (MPP): Rated power in Watts, $P_{max} = V_{mp} \times I_{mp}$.

3.1.1.4 Fill Factor (FF)

The short-circuit current and the open-circuit voltage are the maximum current and voltage respectively from a solar cell. However, at both of these operating points, the power from the solar cell is zero. The fill factor is a parameter which, in conjunction with V_{oc} and I_{sc}, determines the maximum power from a solar cell. The FF is defined as the ratio of the maximum power from the solar cell to the product of V_{oc} and I_{sc}. FF is computed as $FF = V_{mp} \times I_{mp} / (I_{sc}. V_{oc})$. FF gives an idea of the quality of the panel because it is an indication of the type of IV characteristic curve. The closer FF is to 1, the more power a panel can provide. Common values usually are between (0.7) and (0.8).

3.1.1.5 The Characteristic Resistance (R_{CH})

The characteristic resistance of a solar cell is the output resistance of the solar cell at its maximum power point. If the resistance of the load is equal to the characteristic resistance of the solar cell, then the maximum power is transferred to the load and the solar cell operates at its maximum power point. It is a useful parameter in solar cell analysis, particularly when examining the impact of parasitic loss mechanisms.

3.1.1.6 Efficiency (η):

The efficiency of solar panels refers to the proportion of the energy input from the sunlight that is converted to power output from a solar module. The efficiency is depending on the type of cells and is the most commonly used parameter to compare the performance of one solar cell to another. There are various measures of solar cell efficiency to consider when looking at specific solar panels for your home. The most common ratings are:

(1) The standard test conditions (STC) or peak watt (W_p) rating is the maximum power of a PV module under laboratory conditions of high light, favorable air mass, and low cell temperature. These are the ideal conditions, but also not typical in reality. Standard test conditions are defined as:

- 1,000 watts per square meter of solar irradiance.
- Solar panel temperature of 25 degrees C (77 degrees F).

It is important that the power output of different solar panels is measured at STC in order to allow an accurate and fair comparison of the panels

(2) The normal operating cell temperature (NOCT) rating is determined under more realistic conditions and results in a lower efficiency value than the STC rating.

(3) The AMPM standard takes account of a whole day of sun rather than "peak" sunshine hours. The test parameters for light, temperature and air mass are based on a standard solar global-average day (Timbus *et al.* 2006).

3.2 Solar Inverter

The inverter is a very important element of the solar power system. It converts the direct current (DC) produced in the cells to alternating current (AC) suitable for the electricity grid and AC loads. The inverter manages the solar power system automatically shutting down and then re-starting the system if there is a blackout (power failure). It is important for output and a good return on investment to install a quality inverter. Solar inverters have special functions adapted for use with photovoltaic arrays, including maximum power point tracking and anti-islanding protection.

A Grid Tie Inverter is used with a grid-tied PV system. This type of solar power inverter takes the DC electricity generated by the solar panels and converts it to AC electricity directly. It channels the AC electricity to your home's breaker panel where it is either used by household loads or, if meter are signed ups for net-metering, sends it to the utility grid (Lohner *et al.* 1996). Solar inverters use maximum power point tracking (MPPT) to get the maximum possible power from the PV array. Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency known as the I-V curve. It is the purpose of the MPPT system to sample the output of the cells and determine a resistance (load) to obtain maximum power for any given environmental conditions (Timbus *et al.* 2006, Edris *et al.* 2011).

4. Hardware Implementation

The aim of this paper is to add the grid-tie PV system as a supplement to residential electricity network to prevent the voltage drop at peak times also sells back the excess produced energy from PV system to grid at off-peak times. In this application, we used 11 modules that are connected in series. We implemented two tilt angles of modules (15^0 and 30^0), to obtain the possible maximum power over that whole year, where the 15^0 tilted modules are suitable for summer season, and 30^0 Tilted modules are suitable for the whole seasons as in

Figure 3 (Audenaert *et al.* 2010, Mondol *et al.* 2007).

The relevant voltage of series-wired panels is V_{oc} = (11)(29.96 V) = 329.65 V , this exceeds the inverter rated start voltage of (100 V). V_{mp} = (11) (24.75 V) = 270.27 V, this is within the inverter rated V_{mp} range of (200—500) V.

The used series inverter utilizes the high-efficiency power component to achieve optimal MPPT with maximum recommended DC power of 2300 Watt, maximum DC voltage 550 V and total maximum input current of 11 A. The inverter is designed for single phase grid. AC Voltage range is 220V-230V with typical frequency of 50Hz.

Several requirements by the authorities is requested as: Micro-breaker should be installed between inverter and grid, and its rated fault current should be between 30 mA ≤ Ifn ≤ 300 mA, any load should not be connected with inverter directly. Moreover, length between AC side and grid connecting dot should be less than150m. RS485 cable is used to communicate and monitor the inverter as shown in Figure 4.

Another important component is the residual current device-earth leakage. It assures protection to people and installations against fault current to earth. The connection of the entire system is shown in Figure 5.

The system results of test applied on the one of modules is listed in table (1).

When changing tilt angle, the short circuit current is lowered due to decreasing the irradiance intensity and air mass ratio, this shows a difference between practical and standard readings (current must be equals approximately from short circuit state to maximum power at standard). We note a decrease in measured current of about 1.9 (A). This can be caused by many reasons such as personal errors in measurement and heating losses by dummy load (thermal load). The experimental current-voltage curve is shown in Figure 6.

The capacity of the system is studied over several days. Figure 7 shows the resulted report for date: 26/12/2012 which is typical winter day in Jordan.

As seen, the system starts to generate power (minimum power) at 7:15 approximately. Maximum power occurred at 12:30 (rush hour) by maximum efficiency at all day. Maximum Efficiency is found 65.73 %. At period (11.30 – 11.45) the power falls from (1224 W) to (314 W) because the presence of clouds leads to make shadows on the system. From 13.00 to 16.00 the power decreases gradually because of change of many parameters such as: sun elevation and air mass ratio, irradiance intensity and temperature of modules and ambient temperature.

PV systems work best on sunny days when direct sunlight is shining on the PV panels, but even on cloudy and dull days they can produce significant amounts of electricity. For example, in 2012 September the total generated power is 143KW, where the total consumed power is 117KW; therefore the power feed to grid is 26 KW.

5. Conclusion

In the grid interactive system, the solar power which may be available in excess of the demand during period of high sunshine is fed to the grid and is utilized elsewhere. This study is to explore the possibility of using solar PV systems in residential household. A grid-tie PV system has been used as supplement to grid to supply the load of residential property in Jordan. We aimed to support the national grid with grid-connected PV system to reduce the voltage drop at peak times. The development of a renewable system with reasonable cost to produce around 150kW without energy storage is used as a proper configuration. The actual values of PF are very close to the reference, which indicates the efficiency of this system. This system was the first project in Jordan connected to the national grid. The system is connected to world-wide network for monitoring. It can be summarized from the analysis that grid-tie photovoltaic solar system can play a fundamental role to solve power shortage problem in Jordan and can provide a reliability of power supply that is essential for critical loads.

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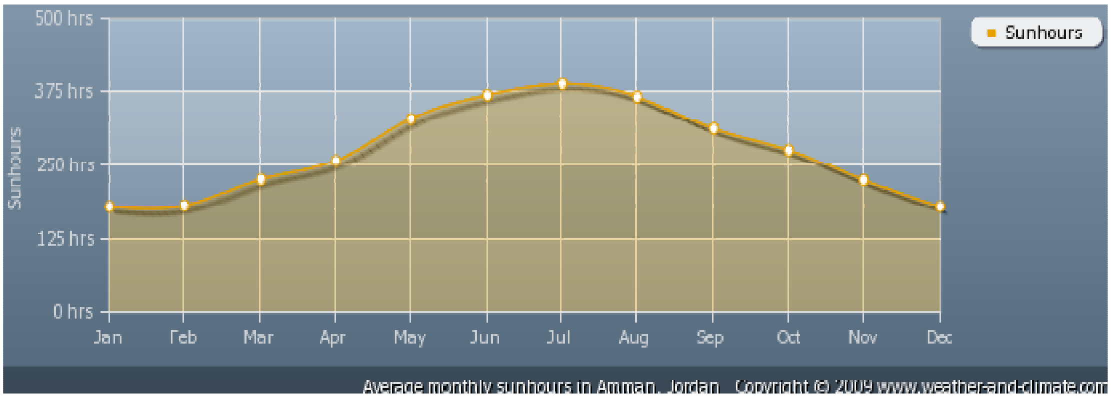

Figure 1. Average monthly hours of sunshine over the year in Amman, Jordan.

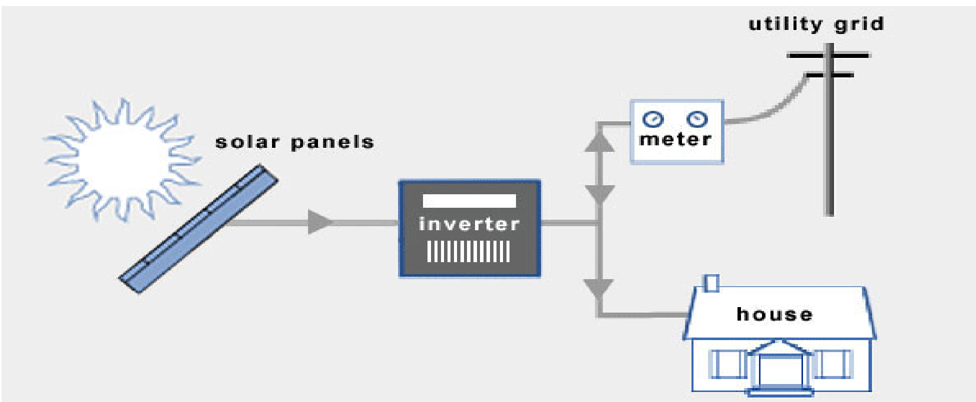

Figure 2. Schematic of grid-tied PV system

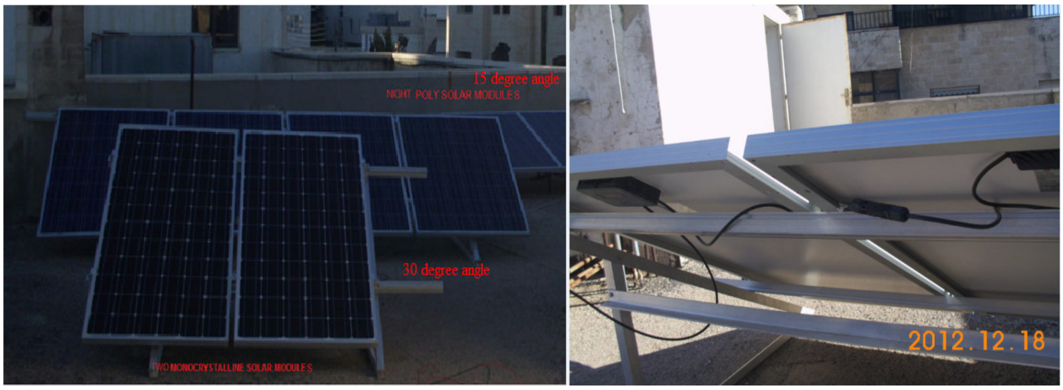

Figure 3. Ground mounting of PV panels by two tilts angle.

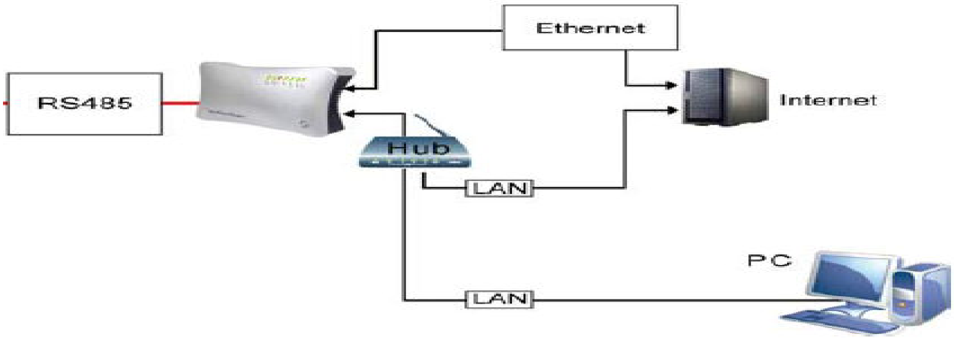

Figure 4. RS485 Communication

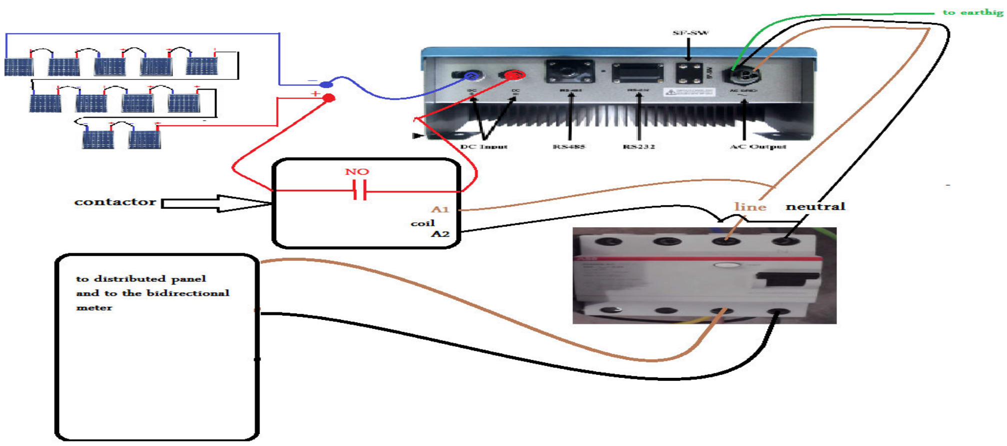

Figure 5. PV solar system layout.

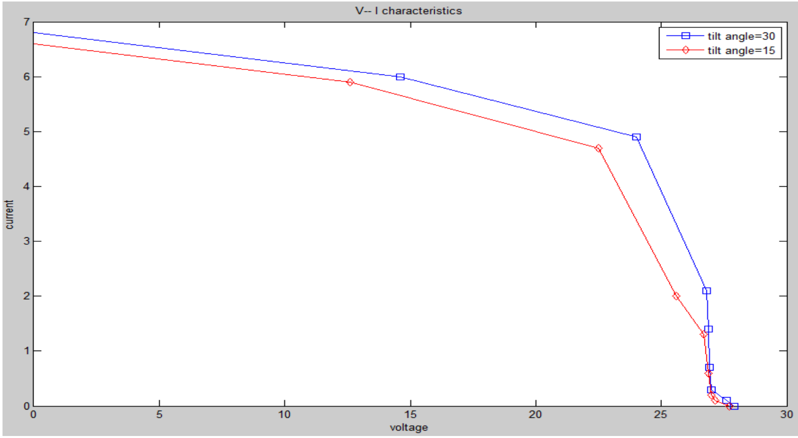

Figure 6. practical current- voltage curves.

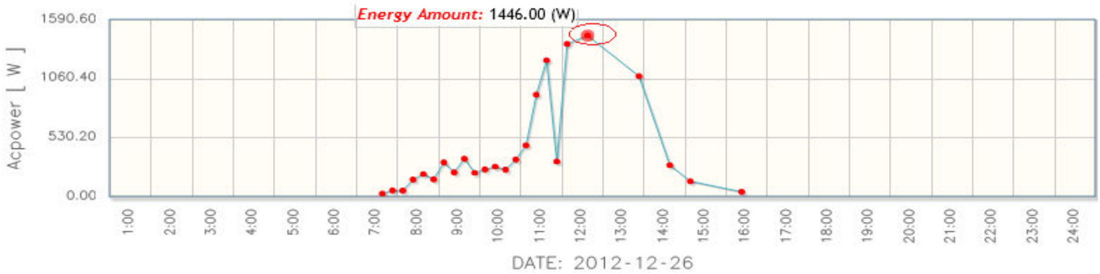

Figure 7. Device (26/12/2012) capacity of the statistical report

Table 1. Results of test applied on the one of modules. (At 17.00 hrs.16/12/2012)
Testing for (angel 30)

Resistance	**Voltage(V)**	**Current(A)**	**Power (w)**
S.C	0.0	6.8	0.0
Load 1	14.6	6	87.6
Load 2	24	4.9	117.6
Load 3	26.8	2.1	56.28
Load 4	26.9	1.4	37.66
Load 5	26.93	.7	18.851
Load 6	27	.3	8.1
Load 7	27.6	.1	2.76
O.C	27.9	0.0	0.0