322. Performance Evaluation and Model Development of Solar Photovoltaic System: A Case Study for Hyderabad

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Abstract

One of the major causes for the environmental degradation is the use of fossil fuels to produce electric energy. Thus, people of developing countries such as Pakistan still depend upon the use of grid system and uninterruptible power supply (UPS) system for the supplying of electrical energy. These systems are not only harmful to their surroundings but very expensive too. Solar photovoltaic system (SPV) can be best substitute to conventional energy generation and supply methods. SPV system is a renewable energy system that generates and supply electricity simultaneously from solar radiation, as solar energy is not only cheap but it is also environmental friendly. The prime object of this research is to generate electric energy from solar radiations. This study is carried out by developing the mathematical model of solar photovoltaic (SPV) system for Hyderabad. Due to recent advance in technology and falling price of SPV system, these systems are more reasonable for use to generate and supply electricity, especially in rural areas where other power sources are unreachable. From this research it was found that electricity supply from SPV system is more significant and cost saving than grid and UPS systems.

Keywords: *"Model development, evaluation, solar photovoltaic system, renewable energy;"*

1. Introduction

Pakistan is facing energy crisis as a consequence of tremendous growth in population and heavy reliance on imported fuel. Our national economy has been under a tremendous pressure due to the change in international oil markets and because of these changes unit cost of electricity keeps on fluctuating and inflation rate has become difficult to manage. The addiction to conventional sources for electricity generation has hit Pakistan's economy badly. Currently, Pakistan relies on completely on conventional energy resources to fulfill its energy demand; the share of renewable energy is even less than 1% as shown in Table 1.

Table 1. Existing Energy Mix of Pakistan's electricity generation

S. No.	Existing Energy Mix	MW
1	Public Hydro	7013
2	Public thermal	5861
3	Nuclear	665
4	IPPs Hydro	84
5	IPPs Thermal	8678
6	K- Electric	2422

Electric-machines have become essential part of human life. Many rural areas in developing countries will not have access to cheap electricity for several years to come. Urban and rural areas of Pakistan are becoming automated and require continuous supply of energy for the better development. There is a direct relation between the energy consumption and development of a country. The 80% of primary energy supply are met by fossil fuels and remaining 20% by other sources [1] & [2]. The rise in demand for energy is necessary for the safe world for future generation. The fossil fuel resources are decreasing continuously and the cost of production of electricity using fossil fuels is higher. Another disadvantage of the utilization of fossil fuel resources is increase in greenhouse gases. The increase in greenhouse gases is causing increase in global warming and environmental pollution. The utilization of renewable energy is increasing due to the environmental damage caused by greenhouse gases. The solar energy being a renewable energy source has received worldwide attention as it is a sustainable solution to meet energy needs. The solar light reaches the surfzace of earth in the form of electromagnetic waves. The solar radiation is a carbon- free and environmental friendly source of energy. It has been observed that the amount of solar energy reaches the earth is about (4.3×1020 J) and that is greater than 5% of the total annual energy consumption of the world. Solar photovoltaic (PV) cells convert the solar radiation in the form of electric energy. Solar PV cells are easily available solar technology. Despite huge potential, solar photovoltaics do not yet have significant contribution in the energy mix of developing countries and emerging economies. The use of solar PV cells is increasing due to the advancement in solar panel manufacturing and efficiency. Electric current is produced when electrons are released from the atomic bonds of the semiconductor material of the PV cells when the solar radiation strikes on it. The solar PV cell has a life period of about 20 years. Hyderabad is the second largest city of Pakistan and is situated at 25.3792 Latitude and 68.3683 Longitude. Hyderabad receives a handsome amount of solar radiation annually and receives annual radiation between 4.0-4.5 kWh/m/2/day. The solar PV cell has negligible maintenance and no moving parts. The power output from solar PV cell is maximum when the sun is directly above the solar PV cell. If a mechanical device is fiited with the solar PV cell that allows it change the orientation by tracking the sun's position, efficiency of solar PV cell is increased since the power output from solar PV cell is maximum when the sun light is dirctley above the surface at 90° angle.

2. Methodology

A solar PV technology coverts the solar radiation in the form of electrical energy, it has no moving parts and no or less maintenance as compared to conventional fossil fuels.

2.1. Solar Photovoltaic System

During the last decade, there has been some promising progress in photovoltaic systems in Pakistan. Appreciable advancement is achieved in the solar cells, modules and systems fabrication expertise of the institutes of the country. Photovoltaic systems are more suitable for remote areas and small power requirements. First large scale solar power generation project is in operation in Pakistan, having 100MW capacity in first phase and additional 900MW in next two phases. It is named as Quaid-e-Azam Solar Power (QASP) park and is located in Bahawalpur, Punjab [6]. Three thousand solar power systems are set up in villages of district Tharparkar, Sindh. During the last fifteen years private companies have imported almost 54.77 MW Solar panels. AEDB has approved and received many project feasibility studies conducted by different companies [7]

The main components of solar photovoltaic system are battery, solar panel, inverter and solar charge controller as shown in Fig 1. A solar panel is the most important component of a solar photovoltaic system.

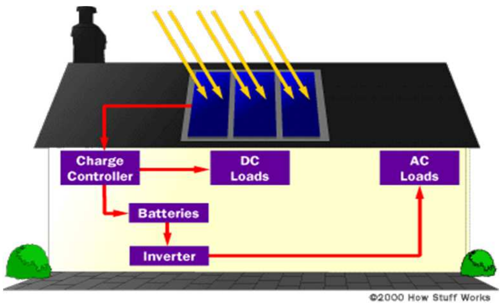


Fig. 1: Schematic diagram for solar photovoltaic system

The input of a solar panel is heat energy from the sun and output is the electrical energy [3]. The generation of electrical energy from solar panel is dependent on the amount solar radiation being strike on the solar panel surface. The electrical energy from solar panel is in the form of DC current. The DC electrical energy from the solar panel can be utilized by home appliances only if they are working on DC current. Since most of the home appliances in our country are working on AC current therefore an inventor is used to convert DC current from solar panel in to AC current so that home appliances can utilize it. DC current from solar panel is stored in battery, and then DC current from battery is converted to AC current by inventor. Charge controller is used to regulate current and voltage.

2.2. Solar photovoltaic system's mathematical formulation

The following steps are taken in to consideration while designing of solar photovoltaic.

2.2.1 Determination of power consumption demands

This is the basic step in order to design a solar photovoltaic system for any home, office or any building. The load of each appliance is measured in Watts and the running (operating) time on daily basis of that appliance is measured in hours [2]. Load and the running time vary from appliance to appliance.

For calculating the total energy consumption demand,

The load of each appliance and its corresponding running time both are multiplied to give individual load for the appliance.

Load for appliance (Watt-hours) =Power (Watts) x Running time (Hours)

Total Load (Watt-hours)=Summation of Individual loads for appliances

$$\mathrm{E_t} = \mathrm{P_a} \times \mathrm{t} \tag{1}$$

2.2.2 Determining the size of PV Module

A PV module is rated in peak-watts. Peak-watts produced by the PV panels depend upon the size of the panel and the climate conditions of the location selected.

Knowing the fact that PV panel can't be used to run directly the AC appliances, the battery, solar charge controller and inverter must be used along with PV panel. Hence, in order to determine the peak-watts for a solar panel, the efficiency of battery, solar charge controller and inverter must be counted. The efficiency of most of the batteries ranges from 80% to 90% while the efficiency of solar charge controllers is about 90% [3].When this efficiency is counted, A solar panel must produce an additional thirty percent (30%) energy. Secondly, amount of energy produced by the PV panel depends upon the location where it is going to operate. Number of hours of day sunlight varies from one location to the other.

The mathematical formula for determining the size of PV panel can be given as

$$E_{pv,t} = E_t \times 1.3 \tag{2}$$

2.2.3 Determining the size of Battery

When determining the size of battery, it is essential to remember that Battery is the alone energy source for running the appliances for some duration. Size of battery depends upon total load of appliances, the efficiency of the inverter, the days of autonomy, depth of discharge and the nominal voltage of the battery. The load of appliances can be calculated as discussed in section (2.2.1). Efficiency of an inverter plays a vital role because battery needs an inverter to run any AC appliance. Inverters are not 100% efficient because of the losses. Efficiency of most of the inverters is from 85% to 90% (10 to 15 percent power wasted).The days of autonomy are the days without sun or cloudy days in which there will be no power generation from the PV panel. Battery will be the only source of power. The days of autonomy depends upon the location selected. As a standard, there are 1.5 to 3 days of autonomy. Hence, the size of battery should be increased by a factor of 1.5 to 3.Depth of discharge ranges from 40 % to 80 %[4].The battery capacity is highly effected by the time at which it is discharged. The discharging time should be as high as possible within the limits. Finally, nominal voltage of battery also needs to be counted while selecting a proper battery capacity.

Considering all above variables a mathematical formula can be formulated for determining the battery size

$$E_{bc} = \left[\frac{E_t}{(0.85 \times 0.6 \times V_n)}\right] \times t_{au} \quad (3)$$

2.2.4 Determining the size of solar charge controller

Overcharging and discharging are two main problems associated with the batteries. These two problems can be overcome by utilizing a solar charge controller between a solar panel and a battery [5]. It controls the current and voltage coming from the panel to a battery and avoids chances of back current to the solar panel. The size of a solar charge controller is measured in units of amperage and voltage [6]. Amperage is obtained from the PV panel or array while the voltage is the same as the nominal voltage of a battery.

Mathematically, the size of a solar charge controller can be expressed by the formula

$$I_{sc} = I_{s.t} \times 1.3 \quad (4)$$

2.2.5 Determining the size of Inverter

All the household appliances take AC power as an input. A solar panel generates DC power which is stored in a battery. This stored DC power is converted into AC power by a device named inverter. For ensuring safety, the inverter size should be designed 25 % - 30 % greater as compared to the power to be utilized by the appliances. If a motor or a compressor is to in any appliance, the size of inverter is considered as 5 times the energy demanded by the appliance [7].

$$P_i = P_t \times 5 \quad (5)$$

3. Result and discussion

A huge variation of Direct and Diffuse radiation intensities is because of cloudy conditions. These varying intensities results are plotted and presented in Fig 2. The figure clearly defines the trend of direct and diffuse solar radiations. The direct radiations values are highest in the month of April and November. The effect of diffuse radiation to global radiation is small during winter season because during these months sky is sunny and clear and does not surpass 40% even in the cloudy condition.

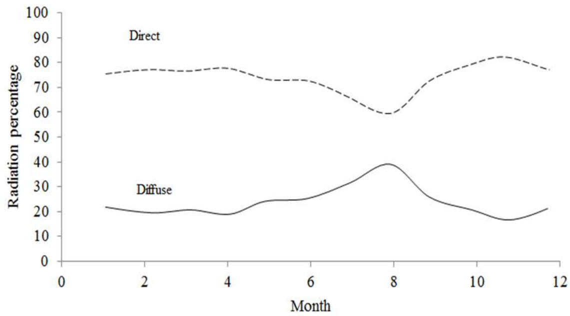
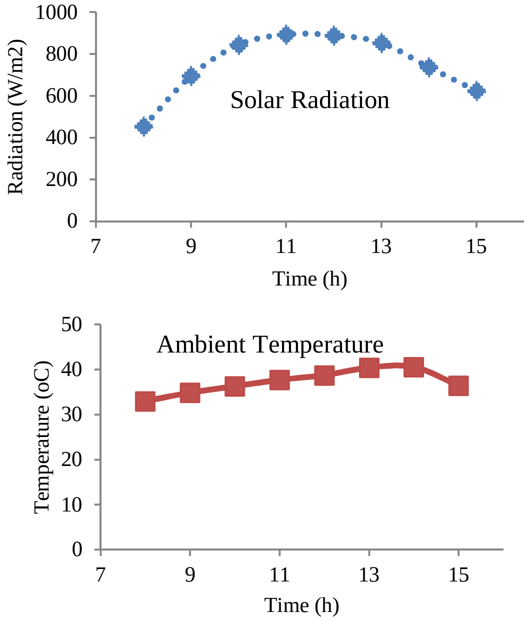


Fig. 2. Profile of direct and diffuse radiation

Pakistan Council of Scientific and Industrial Research provided the data for daily radiation and temperature conditions as presented in Fig. 3 (a) and (b). This data is average for the year of 2011 in winter and summer seasons of Hyderabad.



(a) (b)

Fig. 3. Climatic condition of Hyderabad

Average radiation for a week was about 728.1953 WATT/m2 in the month of June for Hyderabad.

Design and analysis of solar system of current study is done by considering a small house having two washrooms, two dining rooms and a kitchen as given in Table 2.However, electrical appliance power consumption and solar panel's produced power for an identified number of hours is given in Table 3. Table 2 shows physical features of solar panel for finding electricity requirements.

Table 2: House appliance characteristic

Utilizations	Number	Power (W)	Hours (Average)	Watt Hours (Total)
Ceiling fan	2	1.80×102	8	1.44×103
Refrigerator	1	5.0×102	12	6.0×103
Electric iron	1	1×103	1	1.0×103
Television	1	2.0×102	6	1.2×103
Energy savers	8	1.92×102	8	1.536×103
Computer	1	1.2×102	5	6×102
Total	14	2.192×103	40	11.776×103

Table 3. Power required and generated description

S. No.	Factors	Value and unit
1	Total power consumption	1.53×104 Wh/day
2	Battery capacity	2.89×103 Wh
3	solar charge controller size	45.5A
4	Total power consumption per day	1.2×104 Wh
5	Generated power by solar panel	1.8×104 Wh/day
6	Inverter size	6.6×103W

Whereas price description for solar panel is presented in Table 4

Table 4. Prices solar panel components

S. No	Components of Solar Panel	Price
1	2900 Ah battery cost	0.46 Million Rupees
2	2kW solar panel array	0.20 Million Rupees
3	12V 50A solar charge controller	0.42 Million Rupees
4	7kW inverter cost	0.98 Million Rupees
	Total	0.80 Million Rupees

The Table 5 shows electrical appliance power requirements via grid system and bill paid for each unit.

Table 5. Grid System Characteristics

S. No	Grid System Characteristics	Value & unit
1	Daily consumption of power = 11776Wh	1.2×104 Wh
2	Monthly consumption	3.5×102 kWh
3	Monthly bill paid	0.045 Million Rupees
4	Annually bill	0.54 Million Rupees

Characteristics of solar panel are presented in Table 6

Table 6. Solar Panel System Characteristics

S. No	Solar Panel System Characteristics	Value & unit
1	Energy generated (on daily basis)	1.8×104 Wh
2	Energy generated (on monthly basis)	0.54×103 kWh
3	Cost saved per month	Rs. 2,240
4	Cost saved annuay	0.027 Million Rupees

Total Cost Saved by Solar Panel System WAS 0.027 Million Rupees.

The cost for solar panel system and the parts of UPS system for 25 years is presented in following tables.

Table 7. Rate list for the UPS system

S.No	Element	Price
1	48V 400 Ah liquid battery	0.035 Million Rupees
2	for 25 years	1.75 Million Rupees
3	7000W inverter	0.098 Million Rupees
4	for 25 years	2.45 Million Rupees
	Total UPS system cost for 25 years	4.2 Million Rupees

Table 8. Rate list for solar panel system

S.No	Component	Price
1	2 kW panel array	0.20 Million Rupees
2	12V 2900 Ah battery	0.46 Million Rupees
3	for 25 years	2.3 Million Rupees
4	12 V 50 A solar charge controller	0.042 Million Rupees
5	for 25 years	0.21 Million Rupees
6	7 kW power inverter	0.098 Million Rupees
7	for 25 years	0.49 Million Rupees
	Total solar power system cost for 25 years	3.2 Million Rupees

The comparison of cost saving show that the solar power system will save RS 980,000 in 25 years as compared to UPS system.

As UPS requires electric power from external source which is water and power development authority (WAPDA) therefore for the comparison electric bills were not considered. If yearly bills are also considered then amount of capital cost saved by solar system will also be huge cost of UPS system depends upon these bills. As UPS requires electric power from external source which is water and power development authority (WAPDA) therefore for the comparison electric bills were not considered.

4. Conclusion

It is observed from the obtained results that the operating cost of grid power and UPS system is higher than solar based power system, while the initial cost of solar power based system is higher than grid power and UPS system. The UPS system is less appropriate than the solar power based system because the life of battery and invertor in solar power based system is higher than the UPS system. In solar system the dry batteries are used which require no water filling while in the UPS system batteries require change of water regularly. Solar system does not depend upon grid power hence it work continuously whereas UPS system function depends upon grid power hence due to load shedding its operation will also be affected.

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