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Performance of a Stand-Alone Residential Photovoltaic Power System at Dhaka

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Abstract

The performance of a stand-alone photovoltaic power system operating in different residential appliances is studied. The system is designed using standard methods before installation. The operation of the system using fluorescent lamp, incandescent light and a ceiling fan as a load is monitored for different months of the year 1997 & 1998 in various weather conditions in Dhaka. The performance of the system is found to be satisfactory and the experimental results agree well with the theoretical estimates. The charging time of the battery is found to decrease by about 12% when the azimuth angle of the array is changed from 0^0 to $\pm45^0$ facing south, thus increasing the output power for the PV modules.

Introduction

Energy obtained from sources, which are not depleted after their utilization and can be renewed by using the energy from the sun, are usually termed as renewable energy. The total energy radiated by the sun over the entire earth is enormous. Bangladesh has an excellent solar energy potential. The amount of available solar radiation on the horizontal area per year is 1.7MWh/m^2 [1]. The total energy reaching Bangladesh is 2.44×10^{11} MWh which is 2.9×10^4 times higher [2] than our present annual consumption. A very small amount of the available solar energy is now being used traditionally in Bangladesh for open air drying of agricultural products, production of salts from sea water, drying of cloths etc.. Electricity is an essential part for modern living. Per capita consumption of electricity has become the yardstick of the state of development. From the data compiled by the International Energy Agency of the Organization for Economic Co-operation and Development (OECD), the per capita consumption of electrical energy is about 80 kWh for Bangladesh [3]. This, however, does not represent the real picture since the electric supply is mainly limited to the urban areas and to only about 16,864 village's [4] out of 68000 villages. In our country per capita consumption of energy needs to be increased to standard level in order to attain sustainable socio-economic development. The present deficit of around 20% in the national energy supply is likely to increase to 80% or more in 2020 [5] unless the energy supply is increased to keep up with the increased demand. Renewable energy resources can supply electrical energy and reduce the fossil fuel consumption [6], which pollutes the environment by adding carbon dioxide to the atmosphere. Worldwide activities have been started to use photovoltaic energy. The situation in developing countries in respect of renewable energy use is comparatively better. High solar insolation, decentralized uses of energy and low energy demand favour the use of solar PV energy [7]. Photovoltaic cell can supply energy in the form of electricity, which is essential for some special uses even for the developing countries in view of modern electronic age. Different developing countries like India, Indonesia and Srilanka have installed PV power systems of various shapes to supply electricity to the rural areas. The use of PV power system covers a wide range from a small wristwatch to a megawatt power station. Rural power requirements for lighting, operating TV, radio and communication to the community centers, bazars, households, schools etc. can be met by solar electricity. Solar light can be used for navigation safety for fisherman and boats on the water. Solar powered refrigerator in remote areas can store medicine for livestock and for human beings. It can be used for irrigation, remote weather forecast centers, in remote health complexes and houses in remote locations as well as in operating small-scale machinery's. Thus, the use of solar PV system could contribute significantly towards improving the living conditions of the rural population and minimize social problems by preventing the undesired migration to urban areas. The low income of the rural population in developing countries, the high initial investment needed for solar technologies however, remains a barrier to their wide applications. To overcome the barriers to the use of PV power system one important factor is to increase the efficiency of the system. The performance study is therefore, important for the application of PV system under different environmental conditions and requirements. Of the three theoretical designs reported in our paper [8], we considered the third design where tilt angle was 10^0 for summer and 40^0 for winter with azimuth angle $\pm 45^0$ facing south. The justification for this optimum arrangement is supported by the papers [9,10].

System Description

A stand-alone photovoltaic power system is designed to operate residential loads. This system consists of PV modules, batteries, inverter, system controller, panel meter board with switching circuits, connecting wires and loads as incandescent light, ceiling fan and fluorescent tube light. The arrangement of the components of the PV power system is shown in the block diagram in Fig. 1 with different sub-systems. There are six-module model M75 and each module contains 33 cells in series. This module is suitable to our temperature and climatic conditions. The modules are attached with the supporting structure of variable angles, 10^0, 15^0, 20^0, 25^o, 30^0, 35^0, 40^0, 45^0, 50^0 with horizontal surface facing the south. The azimuth angle was changed manually.

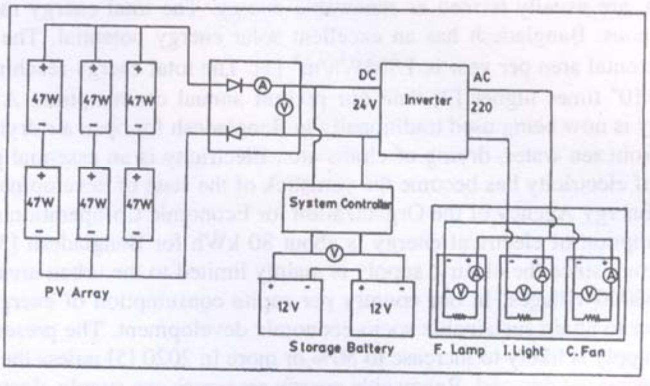

Fig. 1. Block diagram of the experimental PV system

Module specifications (at standard test conditions):

Rated power (typical ±10%)	47Wp
Open Circuit voltage	19.7 volts
Short circuit current, typical	3.33 Amps
Voltage at load, typical	16.0 volts
Current at load, typical	2.94 Amps

Inverter specifications

Model:	IN 1005
Capacity:	850 W
Input voltage:	24V±10%, DC
Out put Voltage:	220V±10%, AC
Frequency:	50 Hz±2%
Power factor:	0.8
Wave form:	Modified Square wave
Phase:	Single

Results and Discussion

The charging characteristics of the 24V deep cycle battery is studied by 6×47Wp PV array. After connecting the PV array with battery, the voltage is taken in one hour and half an hour of interval. The data of solar radiation is taken at five minutes interval. A sample graph for the month of December 1997 is shown in Fig. 2. The increase in battery voltage depends on the intensity of insolation falling on the solar PV array. This graph is obtained for 2nd and 3rd December from 8 am to 4 p. m. It is seen that the charging starts from 23V and increases with increasing insolation. The voltage becomes nearly steady at a value of about 26V. The battery state of charge reaches nearly 100% when the voltage is raised to 26V as per manufacturers specifications. The discharging characteristics of 128Ah battery is also studied by discharging it through a 40 watt fluorescent tube light, a 60 watt incandescent light and a 60 watt ceiling fan as load. When the battery is being discharged the voltage of the battery is reduced. The battery voltage is decreased from 25V to 22.3V, after 8 hours of operation of the loads without charging. The depth of discharge of the battery is about 60% at 22.5V. It is seen that the battery DOD is about 25% after 4 hours operation of the loads without charging the battery.

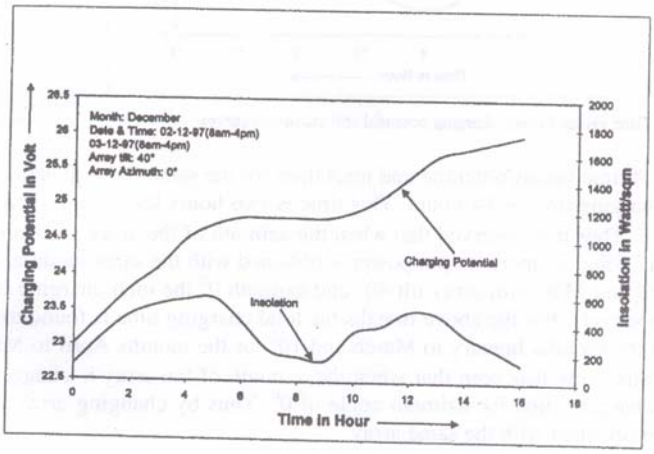

Fig. 2. Time versus battery charging potential and insolation curves

Effects of Array Azimuth Angle on Battery Charging Time

The output power of a PV array depends on the amount of solar insolation falling on the array. A PV module in tilted position gives more output power than its horizontal position for the same amount of solar radiation. The output power of a module can be increased by choosing proper tilt angle. The path of the sun rays changes with time. For this reason the tilt angle of the module is to be changed to proper values to get more output power in different months of a year. Again by changing both the tilt and azimuth angle of the PV module more output power can be obtained compared to the tilted module. Thus by choosing suitable tilt and azimuth angle, the output power of a PV array can be maximized.

An attempt has been made to investigate the effect of changing azimuth angle of the PV modules on the charging rate of our experimental battery for different months of the year in 1997 &1998. The azimuth angle of the PV array is kept at-45^0 towards east during morning hours and +45^0 towards west during afternoon hours. Fig. 2 shows the time versus battery potential and insolation curves by the experimental PV array for tilt and azimuth angle at 40^0 and 0^0 respectively for the months of December 1997. This graph shows that the battery is at 23 volts when charging starts and becomes 26 volts after two days. The total charging time is found to be 16 hours.

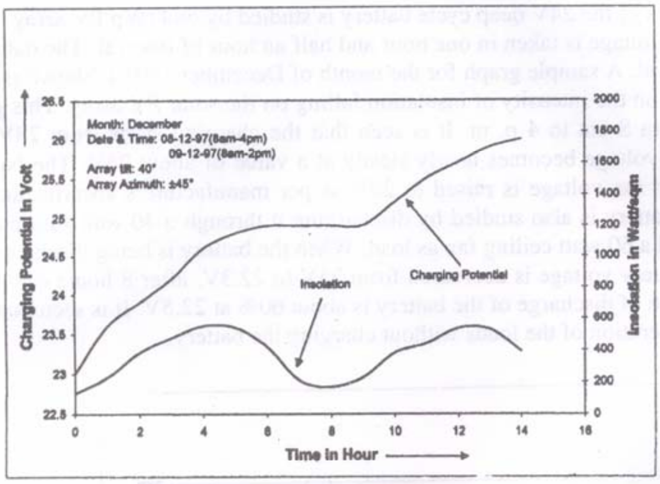

Fig. 3. Time versus battery charging potential and insolation curves

Fig. 3 shows the sample graph of time versus potential and insolation for the same tilt with azimuth ±45.^{0} In this graph it is seen that the total charging time is 14 hours. This time is two hours less than the previous charging time when azimuth angle was 0^0. Thus it is observed that when the azimuth of the array is changed by ±45^0, the charging time is decreased by 12.5%. i.e., more output power is obtained with the same module. For the months January, February, March, April and May with array tilt 40^0 and azimuth 0^0 the total charging time is found to be 16,14,13,14, 14.4 hours respectively. For the above months the total charging time is found to be 14,12,11,12 and 12.5 hours with tilt 40^0 for the months January to March and 10^0 for the months April to May and azimuth ±45^0 for both the cases. From this study it is seen that when the azimuth of the array is changed by ± 45^0, the charging time is less than the charging time for azimuth angle of 0^0. Thus by changing array tilt and azimuth angle more output power can be obtained with the same array.

Performance of PV System through Battery Discharging for Household Appliances.

In this experiment three AC appliances one 40 watt fluorescent lamp, one 60 watt incandescent light and a 60 watt ceiling fan is used as a load. In this experiment the array and battery are properly sized so that they can supply power to these loads for four hours per day. The battery autonomy is taken to be two days as it can supply power to these load for two days without charging the battery and then allowable depth of discharge of the battery was taken to be 65%. To test this battery autonomy it was charged fully on 5th and 6th December 1997 and then discharged through these loads for 8 hours of operation.

Fig. 4 shows the time versus load power curves through discharging the battery. It is seen that before running the loads the battery voltage is 26V and with loads the voltage falls down rapidly to about 25V. In the 1st one hour of operation the voltage of the battery decreases quickly and then becomes nearly steady and the voltage again decreases slowly. In the last one and half an hour the battery voltage decreases quickly but at the middle hours, the battery voltage falls very slowly. For this reason the output power of these loads falls quickly at 1st and last hours and slowly in the middle hours. It is found that the output power of fluorescent lamp, incandescent light and ceiling fan is decreased by about 16%,17%,18% after 8 hours of operation.

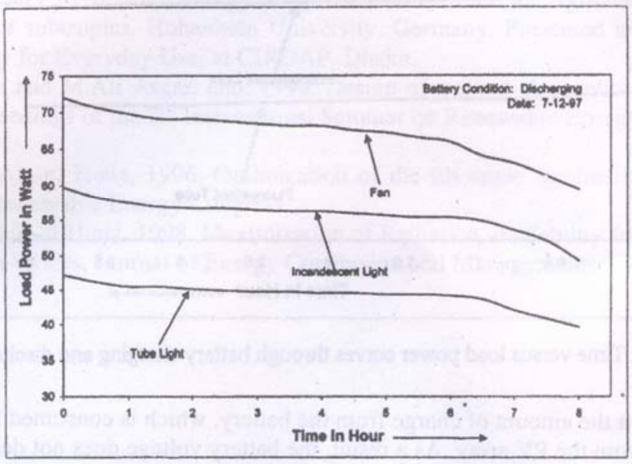

Fig. 4. Time versus load power curves through battery discharging

The battery voltage is decreased from 26V to 23.3 V i,e DOD is 67% . In the theoretical design the battery DOD is taken to be 65% for 2 days of autonomy. Thus it is seen that the practical performance of the battery is very close to the theoretical design. In this graph it is observed that after 4 hours of operation the battery voltage decreases to 22.3V from 25V and the load power of fluorescent tube incandescent light and ceiling fan decreases by 5%, 6%, 5.5% respectively without charging battery.

Performance of PV System through Battery Charging and Discharging Appliances.

When load is on and battery is charging through PV array, the battery voltage decreases slowly. The changes in output power of the loads during the charging of the battery is tested for different months. Fig.5 shows time versus load power for the month of December 1997. In this graph it is seen that the voltages of the fluorescent tube, incandescent light and ceiling fan decreases by 3.1%, 2.7% and 3.1% respectively from the starting initial voltage. For the month of January 1998 the output power decreases by 3.0%, 3.1% and 3.2% respectively.

For the month of February 1998 the output power is decreased by 3.1%, 3.2% and 2.9% respectively. For the month of March, the output power is decreased by 2.9%, 3.1% and 2.6% respectively. For the month of April the output is decreased by 2.5%, 2.7% and 2.6%. For the month of May the decrease in output power is by 2.5%, 2.6% and 2.7% respectively. Moreover, available experimental data show that for a number of consecutive days if the battery is in charging condition then for four hours of operation per day of these loads the battery voltage decreases slowly. It is found that the decrease in battery voltage is negligible.

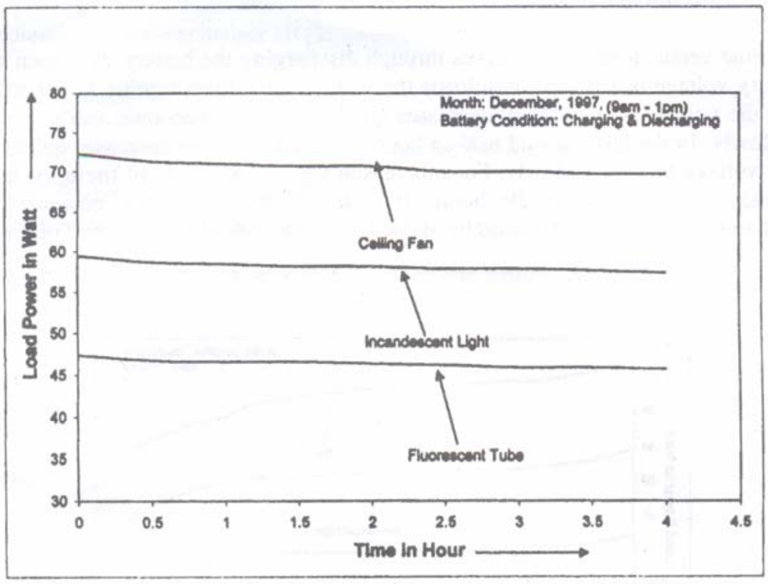

Fig. 5. Time versus load power curves through battery charging and discharging

This is due to the fact that the amount of charge from the battery, which is consumed by the load, is the same as received by the battery from the PV array. As a result, the battery voltage does not decrease significantly. Thus, it is seen that the performance of the system is in agreement with the theoretical design and satisfactory. The performance of this system is tested for worst weather conditions. For the month of June 1998, corresponds to the worst weather it is found that the load power is decreased by 4.3%, 4.1% and 4.5% for the Fluorescent tube, Ceiling fan and Incandescent light respectively for a cloudy day. Moreover, available data for worst weather condition showed that the battery supplies the extra power in this condition.

Conclusion

The output of the PV system is dependent on the tilt and azimuth angles and as also on the insolation depending on the geographical location and season. It is therefore important to find the optimum parameters for each locality experimentally. The theoretical design [8] are based on data published by M. Hussain etal in their papers [9,10.]. The theoretical design used in this experiment is found to be in agreement with the practical performance of the system. It is observed that the PV array can supply power to operate the ac appliances for four hours per day. In the experimental performance, the battery autonomy is found to be of the order of two days. It is observed that when the azimuth angle is changed by $\pm 45^0$ the charging time is reduced by about 12% compared to the azimuth angle of 0^0. It is found that the performance of this system is satisfactory both for clear and worst weather conditions. The use of battery can be neglected by connecting PV system to the grid. Thus, PV power system can contribute towards meeting the demand of electricity in the rural and remote areas of Bangladesh.

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