Journal of Energy & Environment 3 (2004) 25 - 32

Performance and Life Cycle Cost Analysis of a Stand Alone PV Lighting System

M. Obaidullah*, M. A. R. Sarkar* & Ivo Martinac**

**Bangladesh University of Engineering & Technology, Dhaka, Bangladesh*

***Royal Institute of Technology, Stockholm, Sweden*

Email: mdobaidullah@ces.buet.ac.bd

(Received on 30 Sep 2003, revised on 24 Jan 2004)

Abstract

This paper studies the prospects of solar photovoltaic (PV) application in the remote rural areas of Bangladesh. Performance and life cycle cost analysis of a stand alone PV system in Bangladesh is done. The experimental setup is developed in a laboratory of Bangladesh University of Engineering and Technology (BUET). This system is designed and installed to supply electricity to 14 fluorescent lamps. This system consists of 180 W peak capacity PV modules, charge control unit, batteries, switching circuits, and connecting wires. The life cycle cost (LCC) of this PV lighting system has been compared with that of an isolated diesel generator. The analysis shows that life cycle cost of the PV system is lower than the diesel generator.

Introduction

Bangladesh is a developing country with small land area of 147,570 square km and 125 million populations. About 85% of the population lives in rural areas. The average family size is 5 persons per household. With a low level of literacy and a poor industrial base, the economy of the country is primarily agrarian and the rural people depend on some form of land based production system for their survival.

Bangladesh is experiencing a rapid growth in demand for energy. Per capita energy consumption is a measure of quality of life. The per capita energy consumption at subsistence level is about 200 kg OE (Oil Equivalent), while development threshold is at 800 kg OE. Per capita total energy consumption in Bangladesh has increased from 90 kg OE in 1971 to 140 kg OE in 1997 [1]. At present, limited fossil fuels and biomass sources are supplying the total energy requirement. In commercial energy mix, use of natural gas, major fossil fuel in Bangladesh, has increased from 46.5% in 1983-84 to 65.8% in 1993-94 [2]. Biomass was supplying about 60% of total energy in 1993, down from 70% in 1983 [3]. Increased consumption of fossil fuels can continue for a few more decades. Excessive use of biomass fuel is depleting the forest reserves. Forest areas are depleting at a rate of about 8000 ha per year, which has reduced the present forest reserve to about 6% of the total land [2]. Thus, this dreadful scarcity of energy made the nation conscious to harness new and renewable sources and to take measures of conservation.

This paper highlights the potentials of solar energy in the perspectives of rural Bangladesh through a study on the performance of a lab setup for PV system and its life cycle cost comparison with that of a diesel generator set having the nearest equivalent size available in the market.

Solar Energy

Solar energy utilization is being accepted gradually, but its slow progress is due to high initial cost, low daily operation time, and lower output level. Bangladesh is ideally located for tapping solar energy effectively (3-6 kWh/m^2 per day) [1,4]. BUET, BAEC, BCSIR, Dhaka University and a few other organizations are continuing their work to improve solar utilities in Bangladesh. Solar energy has been used in Bangladesh for drying crops and fishes since early days. The Rural Electrification Board (REB) has introduced solar photovoltaic electricity in Narsinghdi District. Government has waived duty and taxes on solar and other renewable energy applications to encourage both public and private sectors.

Solar radiation data that we used for photovoltaic system performance analysis have been measured in the city of Dhaka. Bangladesh being largely flat country this data may be taken as representative of the whole country. The monthly variation data in Fig. 1 shows that the period February to June gives excellent insolation over Bangladesh, followed by reasonably good sunshine during September and October. The winter months of short days during November to January on the one hand, and the peak monsoon months of July and August on the other, create some lowering of insolation, and uncertainties. But in spite of having a long rainy season, the overall solar energy research in Bangladesh is a very good one throughout the year.

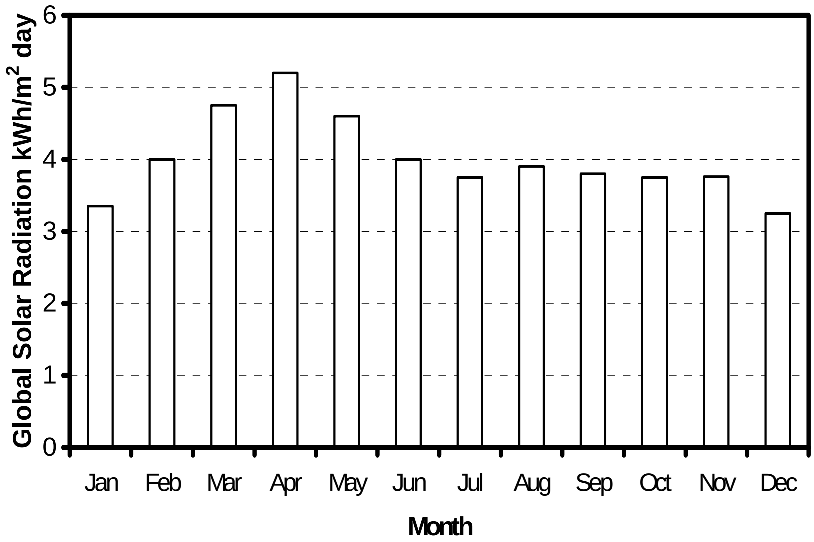

Fig. 1 Monthly average daily solar radiation for Dhaka city

System Description

A stand-alone photovoltaic power system is designed and installed to supply electricity to 14 fluorescent lamps of 12 V, 8 W at the Heat Transfer Laboratory, E.M.E building, Bangladesh University of Engineering and Technology (BUET). This system consists of 3 PV modules of each 60 W_P capacity, 1 charge control unit of 12 V, 20 A, 5 batteries of capacity 12 V, 100 Ah connected in parallel, switching circuits, and connecting wires. Experimental facility of the PV system is shown in Fig. 2. Minimum array and battery size is obtained to operate the loads for four hours per day according to the estimation methods. The array and battery is selected in such a way that these can reliably operate the loads even during the month of minimum insolation. The specifications of the various components that have been selected are given in the Appendix. The PV array is placed on the top roof of the E.M.E building and charge control units, batteries, switching circuits, and connecting wires are placed at Heat Transfer Laboratory of the same building.

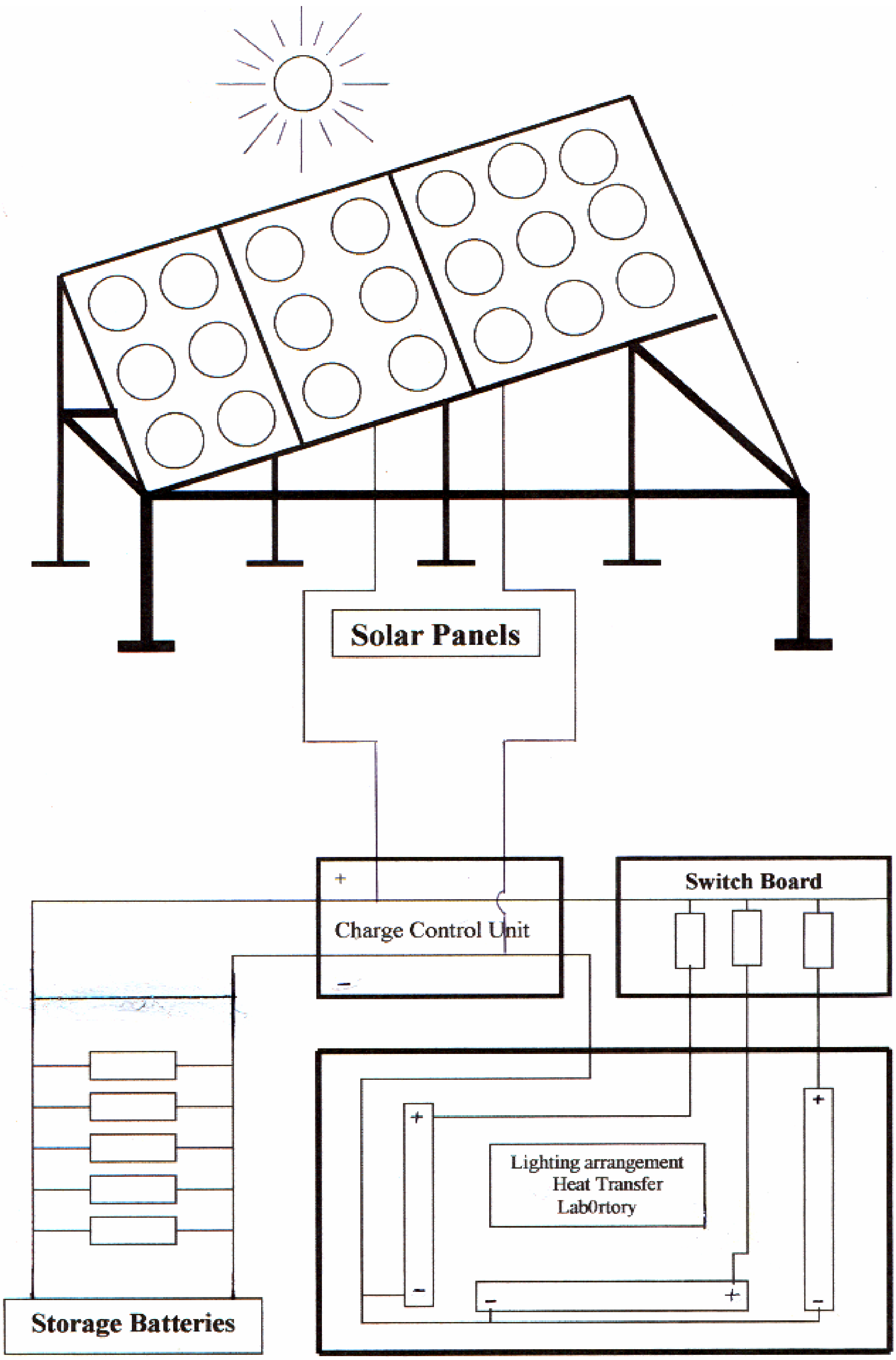

Fig. 2 Experimental facility of the PV system

I-V Characteristics

Fig. 3 is a sample curve obtained from the experimental data for the array of PV operated fluorescent tube light. In this Fig., the reading for the current versus voltage for the curve is obtained for this module using a variable load. The load currents are measured for different values of loads. In Fig. 3 the open circuit voltage is 11.1 V which is the maximum voltage corresponding to zero current. The maximum short circuit current is 7.2 ampere. It is found that the output current decreases from maximum to minimum value when the voltage drop across the load is decreased from maximum to minimum value.

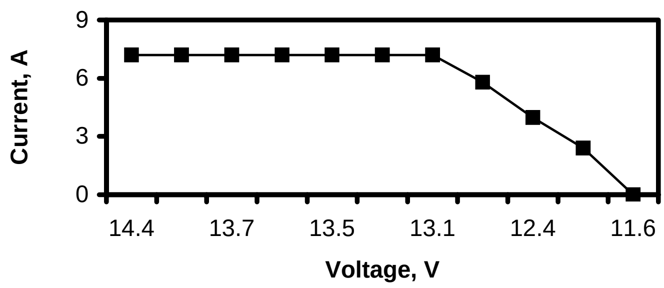

Fig. 3 I-V curve on Aug 19, 2001

P-V Characteristics

Fig. 4 is a sample curve of P-V characteristics obtained from the experimental data for the array of PV operated system. The maximum power determined from Fig. 4 is 85.21 Watt and the corresponding maximum power point voltage is recorded as 12.9V. The fill factor is found to be about 70%.

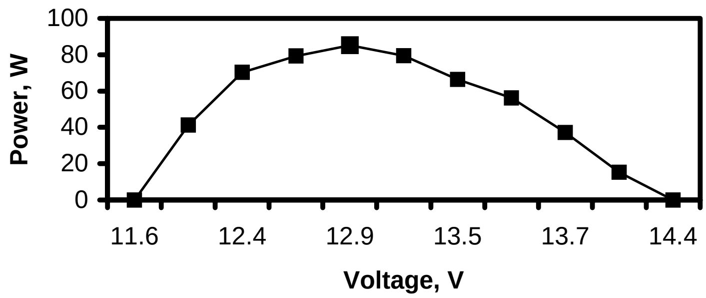

Fig. 4 P-V curve on Aug 19, 2001

Charging of the Battery

Fig. 5 shows the generated data for the month of August 2001. The reading of the battery voltage and solar insolation were taken at one hour interval. The graph shows that the maximum and minimum solar insolation are 648 w/m^2 and 236 w/m^2 respectively. From the graph it was observed that the battery starts charging at 10.23 V and ends at 14.26 V. It took two days for charging the batteries. The total charging time is found to be 16 hours.

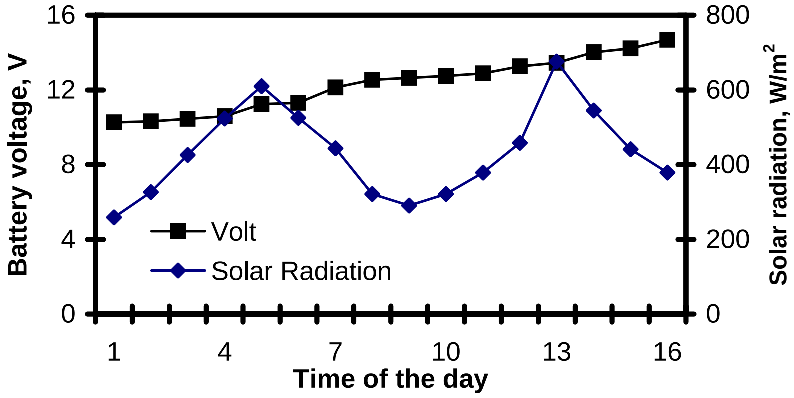

Fig. 5 Time versus battery charging and insolation curve on 26-27 August, 2001

Discharging of the battery

When the battery is being discharged the voltage of the battery is reduced. A sample curve of time versus battery discharging potential is given in Fig. 6. The graph shows that the battery voltage gradually decreased from 14.65V to 10.02 V after four hours working without charging.

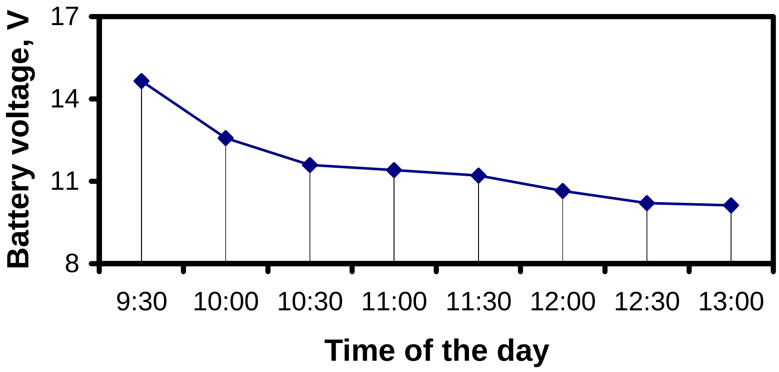

Fig. 6 Time versus battery discharging on July 6, 2001

Illumination Characteristics

The illumination produced by the solar PV lamps is measured at difference distance from the lamps with time. It may be mentioned that all tube lights has been operated during the data collection period from 7:00 pm to 9:00 pm on July 6, 2001. The variation of illumination level with time at different distance from the lamps is shown in Fig. 7. The comparison of illumination levels of solar PV lights with a hurricane lantern (low and high flame) and a candle is also presented in Fig. 8. From Fig. 8 it is clearly observed that solar power lantern produces higher illumination at all distances than the conventional sources in remote and rural areas.

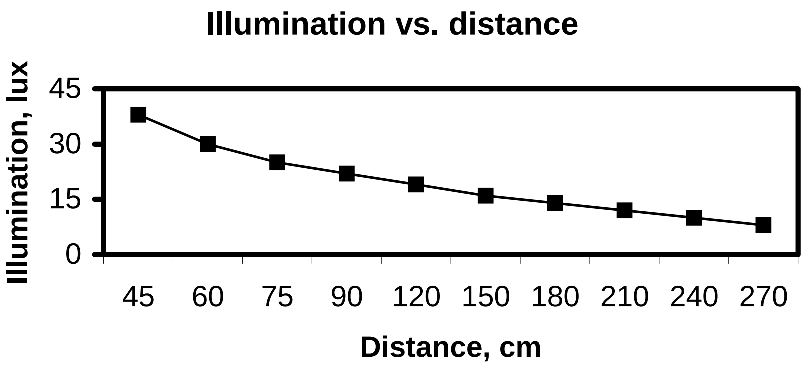

Fig. 7 Illumination vs. distance on September 04, 2001

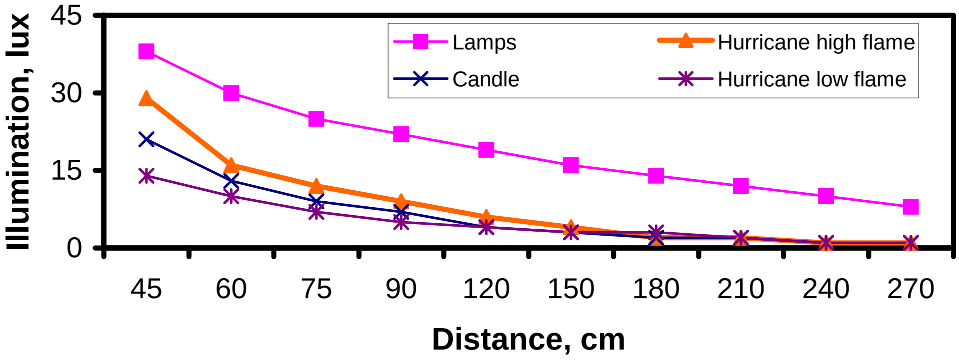

Fig. 8 Comparison of illumination levels of solar powered lamps with hurricane

Life Cycle Cost Comparison

Life cycle cost of the experimental system is analyzed and compared to a diesel generator system. This is presented in Table 1. The methodology adopted to analyze life cycle cost appears in the work [5].

Table 1 Life cycle costing comparison: PV vs diesel generation system

Period of analysis	20.00 years
Inflation rate	0.00 %
Annualisation factor	8.51
Discount rate	10.00 %

PV calculation

Battery efficiency	70.00 %
Days of battery storages	5.00 days
Design insolation	4.00 kWh/m^2/day
Array mismatch factor	0.90
Module price	4.00 \$/W$_P$
Battery price	120.00 \$/100Ah
Florescent lamp price	0.75 \$/W
Array size	180 W$_P$
Battery size	500 Ah
Florescent lamp size	114 W
Florescent lamp price	0.75 \$/W
Array cost	720.00 \$
Battery cost	600.00 \$
Florescent lamp cost	84.00 \$
Power control	250.00 \$
Support/wiring	500.00 \$
Capital cost	2154.00 \$
Installation	100.00 \$
Total installed cost	2254.00 \$
O & M costs	45.08 \$/yr
Life cycle O & M	383.61 \$
Recurring costs	
Array	0.00 \$
Battery	750.00 \$
Florescent lamp	105.00 \$
Charge control unit	97.50 \$
Support/wiring	0.00 \$
Total replacements	952.50 \$
Total life cycle cost	2998.00 \$
Total energy	3270.00 kWh
Life cycle cost	1.07 \$/kWh

Diesel calculation

Generator efficiency	30.00 %
Generator price	1.20 \$/W
Generator size	650.00 W
Generator cost	780.00 \$
Hardwire/support cost	200.00 \$
Installation cost	200.00 \$
Total installed capital cost	1180.00 \$
Fuel consumption	0.50 lt/hr
Fuel price	0.26 \$/lt
Fuel cost	189.80 \$
Life cycle diesel cost	3796.00 \$
Engine oil replacement cost	197.39 \$
Total O & M cost	3993.39 \$
Recurring costs	
Generator with installation	339.30 \$
Hardwire/support cost	93.00 \$
Total replacements	732.00 \$
Environmental cost	
CO_2/GJ diesel	70.00 kg
Tax rate/kg CO_2	0.04 \$
Total environmental	100.00 \$
Total life cycle cost	5796.00 \$
Total energy	3796.00 kWh
Life cycle cost	1.48 \$/kWh

The above analysis shows that the life cycle cost of the PV lighting system is $1.07/kWh. For diesel generator it is $ 1.48/kWh. The life cycle cost of diesel generator is higher than the PV lighting system.

Conclusions

This paper presents the use of solar PV home lighting system in the remote and rural areas of Bangladesh. It covers the performance characteristics and economic analysis of a stand alone PV lighting system installed in Bangladesh. From the experimental results of the performance study, it is found that the tested PV array can supply power to operate a small scale home lighting system for four hours per day on average. In the performance characteristics, it is found that the system is satisfactory both for clear and cloudy weather conditions. From the life cycle cost analysis of the system it is found that at the market price of the year 2001, the life cycle cost of the considered PV system is significantly lower than that of a diesel generator set having the nearest equivalent size available in the market.

References

[1] M. A. R. Sarkar and S. M. N. Islam, "Rural energy and utilization in Bangladesh," Solar energy, Vol 23, No. 9, Great Britain, 1998, pp 785-789.

[2] GOB, "National energy policy," Bangladesh gazette, Ministry of Energy and Mineral Resources, Government of the People's Republic of Bangladesh, 1996.

[3] M. Obaidullah, "Design, performance and economic analysis of a stand-alone solar PV system in Bangladesh," M. Sc. thesis, Royal institute of Technology, Sweden, 2002, pp 8-21.

[4] M. A. R. Sarkar, Z. Mahmud, M. Obaidullah and A. M. A. Huq, "Solar PV submersible water pumping for small scale in Bangladesh," in Proc., RUWATSS-2000, India, 2000, pp 1-7.

[5] T. Markvart, "Solar electricity," 2nd ed., John Wiley & Sons Ltd., UK, 2000, pp 148-155

Appendix: Specifications of different components of the PV system

1. Panel

Brand	:	TATA BP Solar
Type	:	TBP 1260
Nominal peak power (W)	:	60 W
Peak power voltage (Vmp)	:	17 V
Peak power current (Imp)	:	3.52 A
Minimum power (Pmin)	:	57 W

2. Fluorescent lamps

Brand	:	Toshiba
Capacity	:	8 W daylight, FLBD

3. Battery

Manufacturer	:	Rahimafrooz Batteries Ltd
Type	:	6BC 120T/3
Capacity	:	12 V