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Development of a Roof-Top Grid-Connected PV-System for Unstable Grid Supply in Bangladesh

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Abstract

A 1k-W roof-top grid-connected PV system has been developed for unstable grid supply of developing countries like Bangladesh. The grid-connected inverters available worldwide do not work properly in unstable grid supply. To overcome this problem a compensating circuit has been developed using a variac. The performance of the system has been studied for a long time in different weather conditions. A preliminary economic analysis of the system has also been done. It is found that the system works satisfactorily in unstable grid system with the help of the compensating circuit. The practically obtained efficiency of the system is around 80% and the cost of electricity produced by the system is about 11Tk/kWh.

Keywords: Grid-Connected Systems, Net-metering, Photovoltaic Power Systems.

I. INTRODUCTION

The growing energy crisis looms over us both locally and globally. Non-renewable resources i.e. oil, coal, natural gas and Uranium are being rapidly depleted, compounded by consequent irreversible ecological as well as economic damages. Although, energy is a key factor for development, many of the people of poor countries have little access to grid electricity. About 70% of the people of Bangladesh [1] have not yet been provided with electricity.

Study of the solar and wind energy assessment data by SWERA project under UNEP shows that Bangladesh is richly endowed with solar energy [2]. Therefore, photovoltaic system can play a significant role in the energy sector for the overall development of Bangladesh.

Although solar home systems are gradually becoming popular in Bangladesh and have good dimensions, the grid-connected PV-system can also be good power sources in cities and in remote areas where power generation in the existing grid is needed to be increased. Gradually decreasing rate of the price of grid-connected PV-systems and their increasing rate [3] of use suggest that this system will be very prominent alternative power source as the primary fuel source of conventional electricity is rapidly being exhausted.

To study the performance and feasibility of home PV system and grid-connected systems quite a number of researches have been done and the reports are readily available [4]-[23]. However, none of them have reported about the performance of a grid-connected PV system for poor grid management in developing countries.

With a view to study the applicability of grid-connected PV-system in Bangladesh and to adapt the technology, the first ever system has been successfully installed at the roof-top of Renewable Energy Research Centre (RERC), Dhaka University. The system is now running quite successfully in the weather condition of Bangladesh under an unstable grid management system.

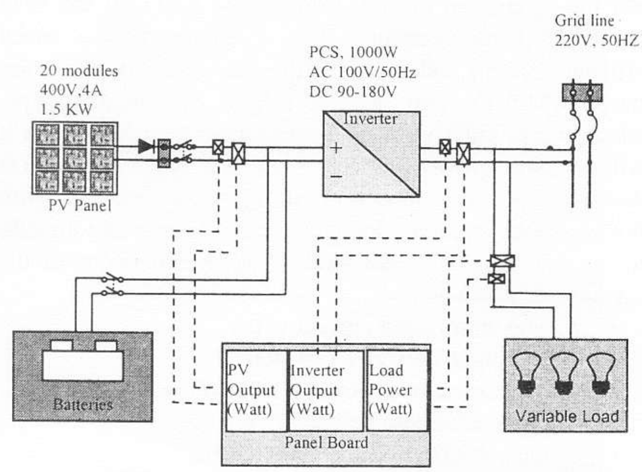

Fig. 1: Block diagram of the developed system.

II. DESCRIPTION OF THE SYSTEM

Realizing the significant potential of this technology a model of 1kW (actually 1.1kW) rooftop grid-connected photovoltaic system has been designed, developed and successfully commissioned at the rooftop of RERC, University of Dhaka. As the target of the system is to meet the demand of a small house, its capacity was considered to be 1k-Watt.

A. PV Array

For the grid-connected system the sizing of the panel is not so critical. As in the most projects, the total amount of PV purchased for the system was based on the available funds and the system size. The PV array has been installed on the rooftop of the RERC building using steel frame structure. Each module was placed with an inclination of 27°, due South. As the capacity of the system is considered to be 1kWp, the peak output of the panel is selected to be 1.5kWp. To construct a PV string of such capacity, 20 modules has been connected in series. The capacity of each module is 75W, 20V, 4A. Since the inverter's input DC-voltage range is 139–400V, the modules are connected in series to make the maximum DC output voltage 400V. The modules are constructed using poly-crystalline solar cells and manufactured by BP Solar, India.

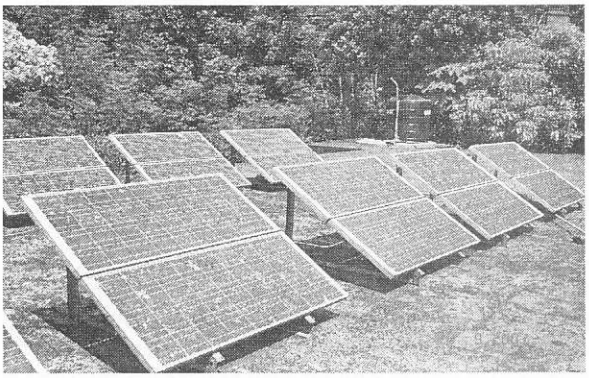

Fig. 2: Photograph of the PV string of the system.

B. Inverter

The main unit of a grid-conned PV system is the inverter. For the system, an inverter (Sunny Boy SB1100) has been purchased from Germany. It is a microprocessor based efficient system and includes the maximum power point tracker (MPPT). This inverter is grid commutating type, which works only when the grid voltage is available. So it will not cause any islanding problem. Sunny Boy SB1100 is designed for the connection of up to two strings with homogeneous structure. Its output can be connected directly to the grid line and local loads. The specifications of the inverter are given below.

- Maximum input current : 10A
- DC input Voltage : 139–400V
- Maximum input power : 1.21kW
- Nominal output power : 1kW
- Output AC voltages: 220V, 50Hz

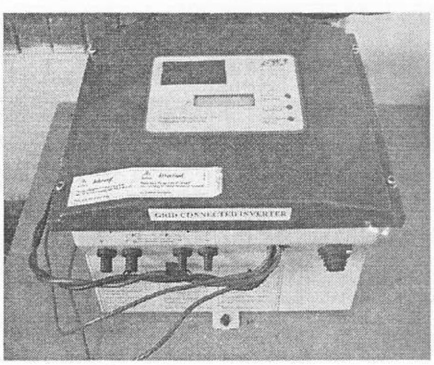

Fig. 3: Photograph of the grid-connected inverter.

C. Variable Load

To simulate local load of different sizes, a variable load was constructed using incandescent lamps. The size of the load can be made 30W to 1.5kW.

D. Panel Board

A panel board is constructed using ammeters, voltmeters and wattmeters to measure powers of different units of the system. A voltmeter and an ammeter give the readings of the output current and voltage of the PV array (i.e. the DC input to the inverter). Another pair of voltmeter and ammeter is used to measure the output of the inverter. A bidirectional wattmeter has been used to measure the grid power. Bidirectional wattmeter is not available in the local market. To serve the purpose a locally

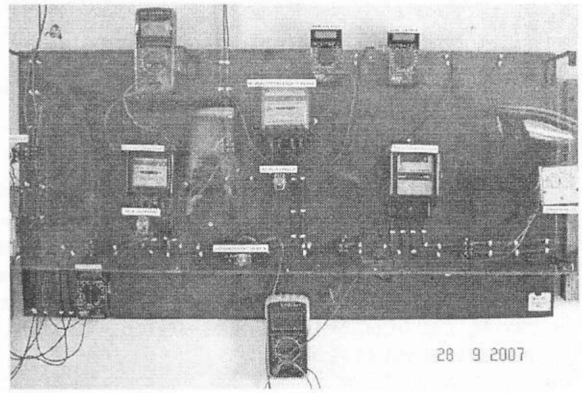

Fig. 4: Photograph of the panel board.

available wattmeter has been converted into a bidirectional one. Using all of these meters the DC output of the PV array, DC input to the inverter, AC output of the inverter, power consumed by the local loads and power sold to or bought from the grid line have been measured.

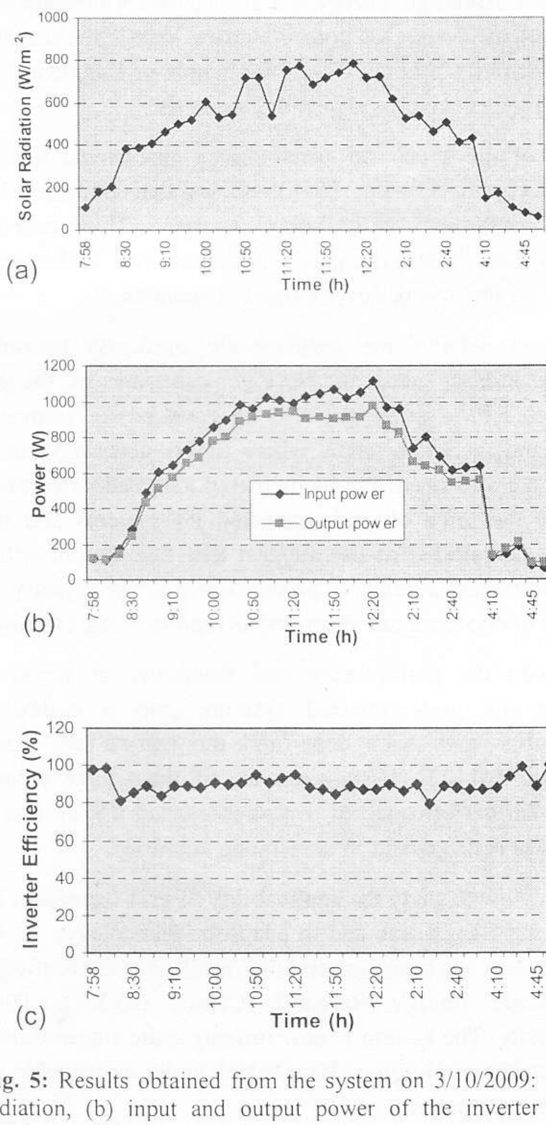

Fig. 5: Results obtained from the system on 3/10/2009: (a) solar radiation, (b) input and output power of the inverter and (c) efficiency of the inverter.

III. Performance Study of the System

Although different meters have been permanently connected in the system to measure various power level of the system, but the reading of these meters have to be taken manually with an effort to obtain complete information about the continuous performance of the system for the whole day. The performance of the system has been studied in different days.

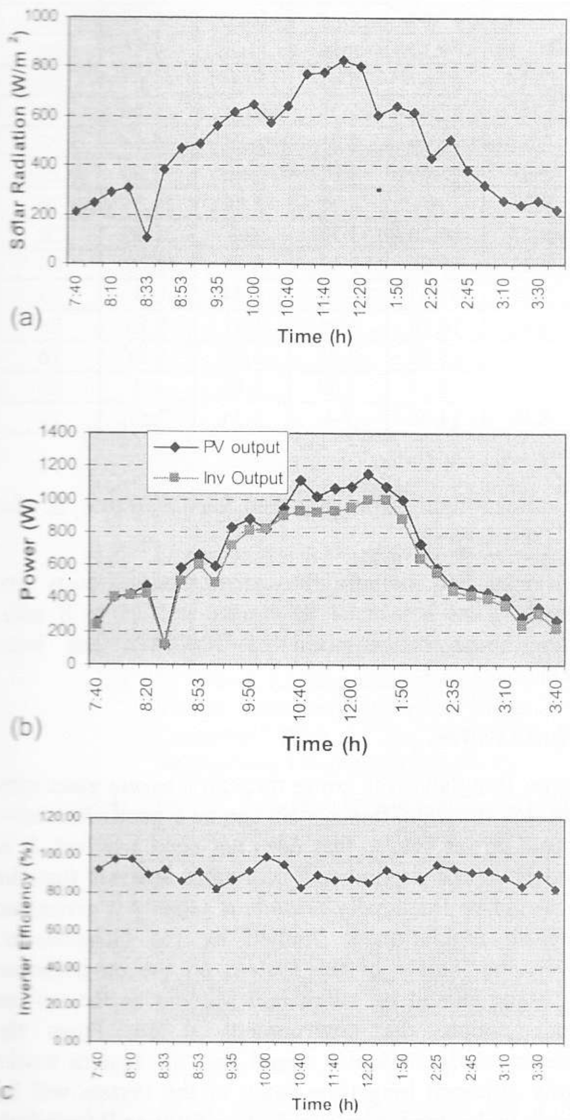

Fig. 6: Results obtained from the system on 3/13/2009: (a) solar radiation, (b) input and output power of the inverter and (c) efficiency of the inverter.

The solar radiation, output voltage and current of PV array, output voltage and current of the inverter, and power taken or supplied to the grid have been measured in various weather conditions. Fig. 5 and 6 show the results of performance of the system for two representative days.

From Figs. 5(a) and 5(b), and Figs. 6(a) and 6(b), it is found that the output of the PV array and that of the inverter almost follows the radiation patterns. At few points the output of the PV panel and the output of the inverter do not match with the solar radiation. This may be due to the errors in manual data recording.

Table :I Performance Data

Parameters	Measured Values
Average Efficiency of the PV array	12%
Average Efficiency of the Inverter	90%
Over all Efficiency of the System	81%
Total Energy Taken form Grid	0.5 kWh
Total Energy Sold to Grid	2.7 kWh
Net Energy Sold to Grid	2.2 kWh

The graphs of the input power and output power of the inverter (Fig. 5(b) and Fig. 6(b)) have also the same shape. The inverter output power is a little less than its input power. From the efficiency curves, it is found that the efficiency fluctuates between 100% and 80% and its average value is 90%.

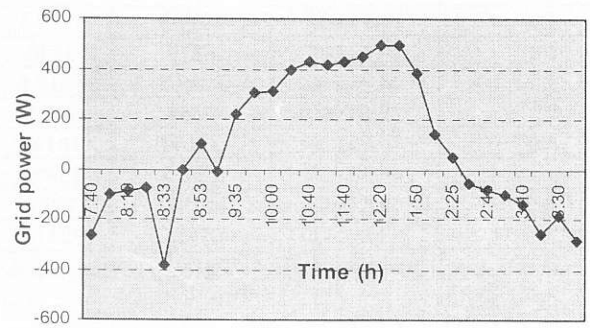

Fig. 7: Grid power on 3/10/2009.

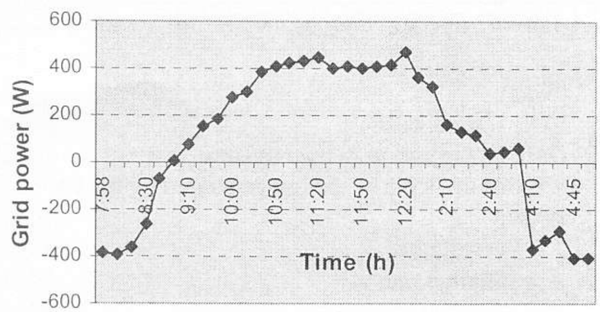

Fig. 8: Grid power on 3/13/2008.

During the performance study, a local load of 500W was used. Power sold to or taken form grid line is shown graphically in Fig. 7 and Fig. 8. In the morning and afternoon when the generation of the system was low, power was taken form the grid line, which is represented by the negative power level in the graph. During the rest of the day power was sold to the grid line.

For these two representative days the efficiencies of the PV array, over all system, total energy taken form the grid and total energy sold to the grid have also been calculated. These are given in the table I.

A. Preliminary Economic Analysis of grid-connected PV systems

A preliminary economic analysis of the system (1.1kW) as well as systems of different sizes of roof-top grid-connected PV has been done using standard method of economics taking into account the various factors, viz., capital cost, life-cycle of the system, interest rate, inflation rate, operation and maintenance cost with and without net-metering benefit. In the analysis 3000kWh of energy has been considered as the minimum requirement of consumption per urban household. Cost of one unit of energy (1 kWh) is given by the following equation [24]:

Table :II Data of Economic Analysis

System Size (kW)	System Price (Taka**) [3]	Annual Energy Generated Q (kWh)	Rest of 3000 kWh (Q-3000) kWh	Cost of 1 kW-h of Energy (p) without net-metering			Cost of 1 kW-h of Energy (p) without net-metering			Life Cycle (Yrs)
				i=0 e=10%	i=5% e=10%	i=10.% e=10%	i=0% e=10%	i=5% e=10%	i=10.% e=10%	
0.7	3,84,000	1149.75	*	5.65	10.22	17.67	5.65	10.22	17.67	20
1.1	6,60,000	1806.75	*	6.18	11.18	19.32	6.18	11.18	19.32	20
1.4	7,63,000	2299.5	*	5.61	10.15	17.67	5.61	10.15	17.67	20
1.6	8,68,000	2629	*	5.59	10.10	17.46	5.59	10.10	17.46	20
2.0	10,22,000	3285	285	5.27	9.52	16.46	4.85	8.76	15.14	20
2.4	11,69,000	3942	942	5.02	9.07	15.69	4.05	7.32	12.66	20
3.0	14,91,000	4927.5	1927.5	5.12	9.25	16	3.68	6.66	11.51	20
4.0	20,23,000	6570	3570	5.21	9.42	16.29	3.38	6.1	10.55	20
5.0	24,78,000	8212.5	5212.5	5.11	9.23	15.96	3.12	5.65	9.76	20
6.0	29,68,000	9855	6855	5.09	9.21	15.93	3	5.44	9.4	20
8.0	40,46,000	13140	10140	5.21	9.42	16.28	2.94	5.31	9.19	20
10	49,56,000	16425	13425	5.11	9.23	15.96	2.81	5.08	8.78	20
12.2	58,85,260	20038.5	17038.5	4.97	8.99	15.53	2.69	4.86	8.4	20
24.5	1,10,00000	40241.25	37241.25	4.62	8.36	14.46	2.4	4.34	7.51	20

*generation is less than 3000kWh **taka = currency of Bangladesh; 1$ = 70taka

$$p = \frac{(CC)\times\left[\frac{e-i}{1+e}\times\left\{\frac{(1+i)^y}{(1+e)^y-(1+i)^y}\right\}\right]+(OMC)}{(Annual\ Energy\ Output\ from\ the\ System)}$$

Where

CC = Capital cost

OMC = Operation & maintenance cost

p = cost of 1kWh of energy generated by the PV system

i = Interest rate

e = Inflation rate

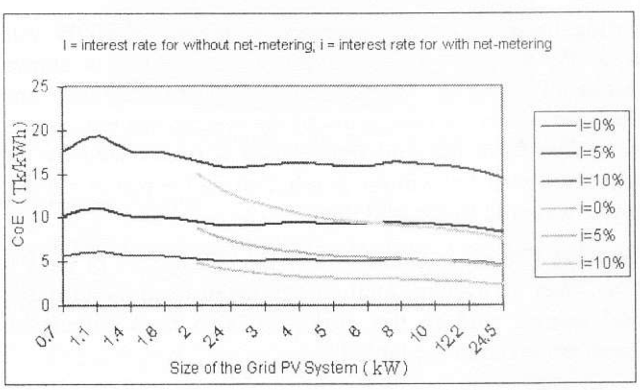

Fig. 9: System size vs. cost per unit of electricity.

Fig. 9 shows the variation of the cost of unit of energy for various sizes of systems for interest rates of 0%, 5% and 10% and flat inflation rates of 10%.

For interest rates of 0%, 5% & 10% with flat inflation rate of 10% the cost of unit of energy without net-metering benefit varies roughly from taka 6 to 5, taka 10 to 8, & taka 18 to 15, respectively.

With net-metering benefit the corresponding costs are respectively 5 to 3 taka, 9 to 4 taka and 15 to 8 taka. Minimum home consumption of 3000kWh has been considered.

IV. Conclusion

At present, Bangladesh is going through a severe electricity crisis. In this situation, this system can be a good alternative small scale power source that does not need any fuel. It is observed from the preliminary economic analysis that the system would be financially feasible if subsidy is given and net-metering regulation is framed by the Government. Moreover, the impact of the system on the environment friendly issue should be taken into account as the system does not pollute the environment at all. From the performance study it is also found that the system works efficiently although long time study of the system will be required to understand its complete feasibility in Bangladesh under poor grid management. The system can be used in urban area to reduce the load on grid line.

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