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Study on grid-tied solar energy system at Dhaka

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Abstract

A grid connected solar energy system enables users to sell any excess power to the electric utility through a plan known as net metering. Study on a virtual power plant with $5kW_P$ solar panels shows that if the household consumption is zero, the plant can deliver 6198kWh electricity to the 220V distribution line of national grid each year. Evaluating the economic value of the plant for 20 years the energy production cost is around 23BDT/kWh while the value is 17 to 37BDT/kWh at the diesel based power plants in national grid. Moreover as the intermittent energy production from the proposed solar power system is less than 5% of the total electricity supply at the distribution lines, the grid electricity quality will not be hampered.

1. Introduction

The grid electricity production is not sufficient to meet the energy demand over the country. Only 38% of the population has getting the access to electricity[1]. Most of the power stations are old and their efficiencies deteriorated significantly[2]. Compensation of electricity shortage and reduction CO_2 emission would be done by introducing renewable energy sources for electricity production in mass scale.

Photovoltaic (PV) technology converts sunlight into electricity. Photovoltaic systems have a number of merits and unique advantages over conventional power-generating technologies. PV systems are modular, easily expandable and even transportable in some cases. Energy independence and environmental compatibility are two attractive features of PV systems. PV systems can be used for either centralized or distributed power generation. The solar energy based electricity generation plants can be connected with national electrical grid[3].

The primary component in such a grid-connected PV system is the inverter, or power conditioning unit (PCU). The PCU converts the DC power produced by the PV array into AC power consistent with the requirements of the utility grid, and automatically stops supplying power to the grid when the utility grid is not energized. This safety feature is required in all grid-connected PV systems, and ensures that the PV system will not continue to operate and feed back onto the utility grid when the grid is down for service or repair. A bi-directional interface[4] allows the AC power produced by the PV system to either supply on-site electrical loads, or to back feed the grid when the PV system output is greater than the on-site load demand. In this study analysis has been carried out on the feasibility of a solar energy based power station with $5kW_P$ modules in Dhaka.

2. Solar resource assessment at Dhaka

Renewable Energy Research Centre, University of Dhaka has been measuring global radiation since September 2002 under Solar and Wind Energy Resource Assessment program[5] at Dhaka. The organization has been collecting data at one minute intervals using an Eppley Precision Pyranometer and ICP-CON data acquisition card with a microcomputer.

The performance of a solar radiation conversion system is affected by its orientation and its tilt angle with the horizontal plane[6]. This is because both of these parameters change the amount of solar energy received by the surface of solar system. The tilt factor for the direct, diffuse and ground reflected radiation differs.

For beam radiation the tilt factor (R_b) is,

$$R_b = \frac{\cos\theta}{\cos\theta_z} \quad (1)$$

where the cosine of the incident angle, θ for direct radiation on the collector, is

$$\cos\theta = \sin\phi(\sin\delta\cos\beta + \cos\delta\cos\gamma\cos\omega\sin\beta)$$

$$+\cos\phi(\cos\delta\cos\omega\cos\beta - \sin\delta\cos\gamma\sin\beta) + \cos\delta\sin\gamma\sin\omega\sin\beta \quad (2)$$

and the cosine of the zenith angle, θ_z, is

$$\cos\theta_z = \sin\phi\sin\delta + \cos\phi\cos\delta\cos\omega \quad (3)$$

The tilt factor for ground- reflected radiation is

$$R_r = \rho(1-\cos\beta)/2 \quad (4)$$

where (1 - cosβ)/2 is the view factor from the earth to the collector and β, ρ are tilt angle and surface albedo respectively. The values of surface albedo employed for different month are NASA Satellite Data[7] and these lie between 0.12 and 0.16.

The tilt factor for diffuse radiation is

$$R_d = (1+\cos\beta)/2 \quad (5)$$

which is the same as the view factor for the sky to the collector.

The global radiation on a tilted surface is,

$$G_\beta = IR_b + DR_d + R_r G$$

$$= (G-D)R_b + DR_d + R_r G \quad (6)$$

Where, G and D are the monthly averaged daily Global and diffuse radiation on a horizontal surface in kWh/m2/day

The best way to collect maximum daily energy is to use tracking systems. The trackers are often expensive and are not always applicable. The optimum output over the years the collectors are placed at latitude angle. A recent study[7] shows the output would be more if the solar energy collectors are placed at 10^0 for Mar-Sep and 40^0 for Oct-Feb. The measured values of global and diffuse radiation for January 2003 to December 2005 are given in table 1 along with the estimated values of global radiation for tilted surfaces. The variation of solar radiation over hours[8] is shown in figures 1.

Table 1. Availability of global radiation (kWh/m^2/day)

	Tilt angles			
	0^0		**24^0**	**10^0 and 40^0**
Month	**Global**	**Diffuse**	**Global**	
Jan	3.16	1.72	3.83	4.00
Feb	4.46	1.99	5.18	3.90
Mar	4.88	2.34	5.19	5.08
Apr	5.28	2.90	5.20	5.32
May	5.46	3.12	5.09	5.38
Jun	4.22	2.83	3.90	5.09
Jul	4.42	2.76	4.10	4.40
Aug	4.18	2.79	4.03	4.11

	Tilt angles			
	0^0		24^0	10^0 and 40^0
Month	**Global**	**Diffuse**	**Global**	
Sep	3.74	2.54	3.80	3.86
Oct	3.53	1.91	3.85	3.87
Nov	3.92	1.60	4.81	5.04
Dec	3.17	1.39	3.96	4.28
Avg	4.20	2.32	4.41	4.53

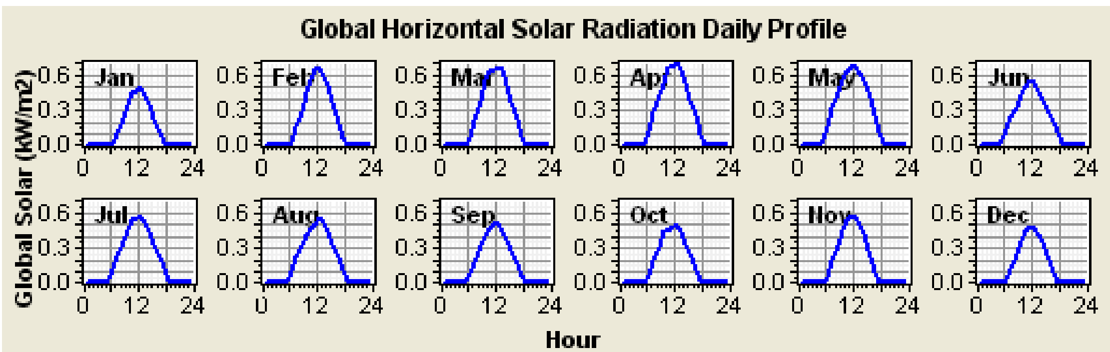

Fig. 1. Variation of global radiation with hour

3. Electrical Energy production from a 5kW solar energy system

When one designs a power system, one must make many decisions about the configuration of the system, say the components which make sense to include in the system design, the number and size of each component. The large number of technology options and the variation in technology costs and availability of energy resources make these decisions difficult. In this study, to evaluate the many possible system configurations, the optimization and sensitivity analysis algorithms of Hybrid Optimization Model for Electric Renewables[9] (HOMER) have been considered.

The solar modules were placed at south facing with azimuth angle of 0^0 and with tilt angle of 24^0, same as the latitude angle of the site. At the proposed site 20% ground reflection, derating factor due to dust of 80% and lifetime of 20 year has been considered. A grid tied special inverter is required for this system to produce AC current of 220 volts. The selected inverter has efficiency of 95% and rectifier efficiency of 85%. The connection of solar array with the distribution line of national grid is shown in Figure 2. The outputs from the plant are shown in figure 3 to figure 6 and in table 2.

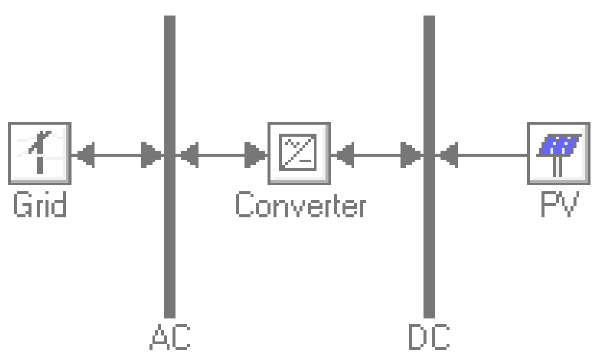

Fig. 2. Connection of solar array with the grid

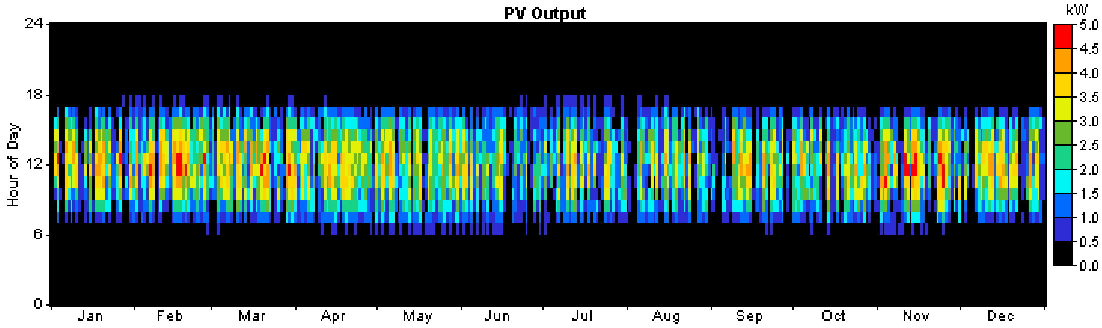

Fig. 3. Hourly PV output over the year

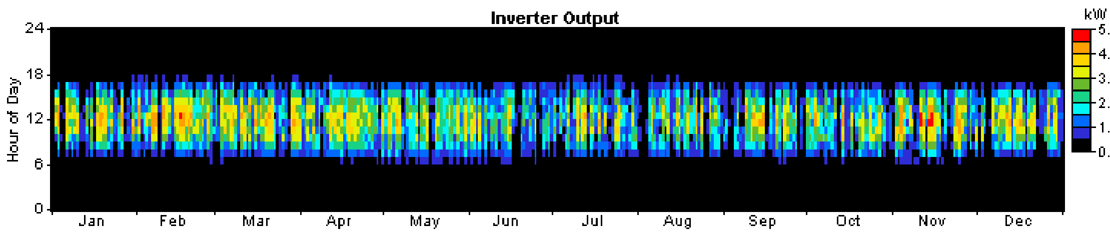

Fig. 4. Hourly Inverter output over the year

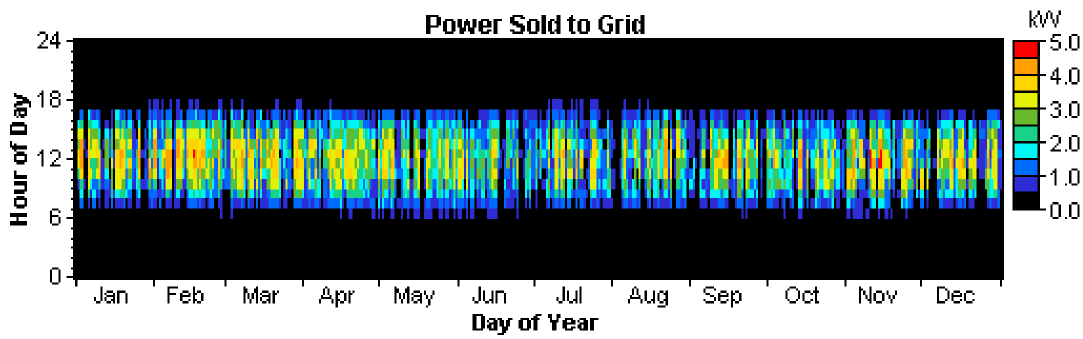

Fig. 5. Hourly power sold to the grid over the year

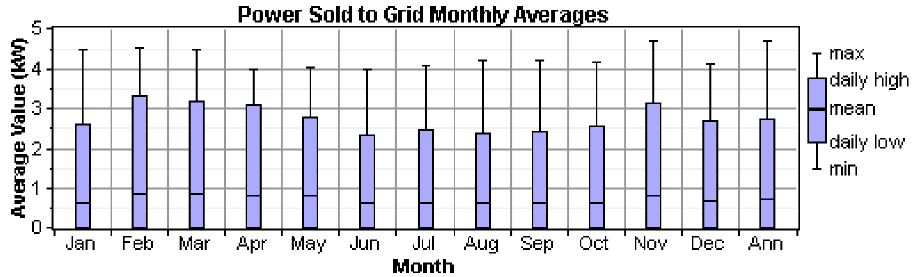

Fig. 6. Monthly average power sold to the grid over the year

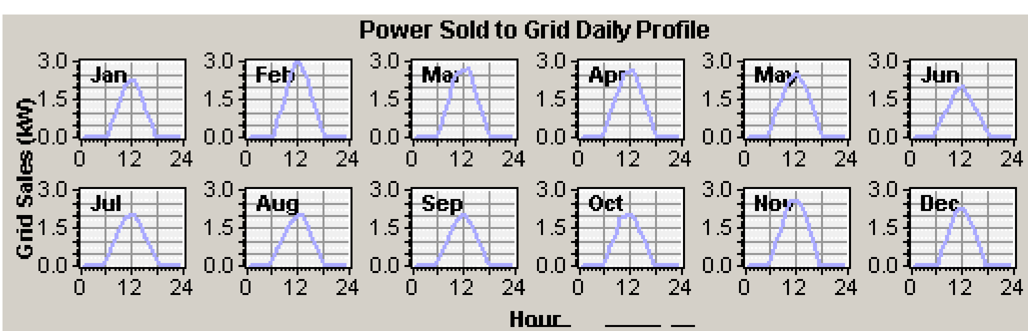

Fig. 7. Power delivered to grid (without any internal load daily profile over the year

Table 2. Summary of the outputs from the solar power plant

Variable	Value
Total rated capacity	5 kW
Minimum output	0.00 kW
Maximum output	4.95 kW
Mean output	17.9kWh/day
PV penetration	0.00%
Capacity factor	14.9%
Hours of operation	4375hr/year
Total production	6528kWh/yr
Total energy delivered to grid	6198kWh/yr

4. Economics and Constrains

Constraints are conditions which systems must satisfy. A feasible system is one that satisfies the constraints. An infeasible system is one that does not satisfy the constraints. HOMER assumes that all prices escalate at the same rate over the project lifetime. For each kW_P solar panel 175000BDT as initial and replacement cost; for each kW inverter 150000BDT as initial and replacement cost and 500BDT/yr as operation and maintenance cost are considered. The total initial cost of the 20 years solar farm project is 1625000BDT. Here at 10% nominal interest rate and 5% inflation rate or 4.76% real interest rate the operation and maintenance cost of the project is 326880BDT.

5. Results and Discussion

The Levelized cost of energy (COE) is the average cost per kWh of useful electrical energy produced by the system. To calculate the COE, HOMER divides the annualized cost of producing electricity by the total useful electric energy production. In this system, total net present cost of the 20 years project is 1832891BDT, where the annualized capital is 127754BDT, operation and maintenance cost is 2500BDT/yr, replacement cost is 29353BDT/yr and the total annualized cost is 1440982BDT. Hence the COE is 23.25BDT/kWh in this project.

The amount of power produced by a solar energy conversion system depends upon the amount of sunlight it is exposed to. More light means more power. If the solar modules are placed at 10^0 for Mar-Sep and 40^0 for Oct-Feb the total production of energy is 6604kWh/yr and the production cost becomes 22.96BDT/kWh.

The initial capital cost of the grid extension is 850,000 Tk/km., the annual cost of maintaining the grid extension is 20,000 Tk/yr/km[10]. The proposed site is connected with the distribution lines of the national grid and hence no grid extension cost is required.

Considering only the cost of fuel the electrical energy generation cost is around 2.36BDT/kWh in the national grid[11]. The fuel mixture in the grid is hydro, subsidized gas, diesel, coal and others. Energy production costs from diesel based power plants are 17BDT to 37BDT per kWh, whereas in this proposed system the energy production cost is around 23BDT.

Conclusion

A 5kW grid tied solar energy farm at Dhaka can deliver 6198kWh electrical energy per year to the national grid. Considering the current prices of components, installation costs and other economic parameters the energy production cost is around 23BDT/kWh, which is compatible with the energy production cost in the national grid from diesel based generators. Moreover the site is connected with national grid. For all these reasons, the site emerges as one of the most suitable areas for grid connected solar energy farm in Bangladesh.

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