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EXPERIMENTAL INVESTIGATION OF SOLAR IRRADIATION IN SYLHET AND FEASIBILITY ANALYSIS OF A PHOTOVOLTAIC (PV) SYSTEM

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Abstract*- In Bangladesh, renewable energy particularly, solar energy has a great potential due to its geographical position to enhance the socio-economic infrastructure. In this research work, the first aim is to assess the solar energy potential of Sylhet by measuring solar irradiance using a widely used device called Pyranometer. The study also aims at designing of a photovoltaic (PV) power generation system for an academic building at Shahjalal University of Science and Technology (SUST) as well as studying its economic and environmental impacts. Three categories of PV solar systems have been studied considering mainly net present value (NPV), simple payback period and internal rate of return (IRR). The preferred and economically feasible category is found to be the grid-connected PV system without battery. The solar irradiance at a tilted plane (25° with the horizontal) was found to be the maximum that averaged to 5.26 kWh/m^2 in a day.*

Keywords: Solar energy, Solar irradiance, Photovoltaics (PV) module, Economic feasibility, Net present value (NPV)

1. INTRODUCTION

Bangladesh is a developing country of South-East Asia with a large population of about 170 million [1]. Bangladesh is maintaining a steady GDP growth rate over 6.5% per annum for the last five years [2]. The economy of the country is growing at a faster rate. Industrialization is also growing with a steeper pace. Different export processing zones are on the way to be developed. So, there is a growing demand for sustainable energy supply, as economic and energy demand goes parallel. Also, the standard of living is improving day by day with rapid urbanization. The better lifestyle demands more use of energy. The entire scenario as a whole indicates that there is prime concern how to manage and maintain a sustainable energy supply.

Throughout the world, fossil fuel is the main source of energy with a contribution of 79.68% of total energy consumed whereas Bangladesh consumes 73.8% of total energy [3]. The electricity produced also dominantly depends on fossil fuels. The largest share is from natural gas about 46.96% of total energy and the share of electricity from heavy fuel oil (HFO), captive power plants, high speed diesel (HSD), imported electricity, coal and renewable energy are 22.43%, 10.71%, 10.61%, 5.64% and 2.16%, respectively [4]. However, the fossil fuels are exhaustible and depleting rapidly. The lifetime for the world reserves of oil, natural gas and coal are estimated to be 50, 51 and 132 years, respectively [5]. Moreover, these sources of energy are not free from harmful emissions. Sustainable development without compromising the eco-friendly environment is a burning issue in Bangladesh as well.

Having a limited fossil fuels and the socio-economic development of Bangladesh, it is a great challenge to the scientists and researchers to deal with the increasing demand of electricity as well as reducing harmful emissions and maintaining eco-friendly environment. Renewable energy sources such as solar, wind, biomass and hydro power can be the probable alternatives to offset the energy crisis not only for Bangladesh but also for the world. In Bangladesh the present share of renewable energy to the total energy generation is only 1.49% where the major portion of total renewable energy (61.1%) is from solar energy [6]. The least amount of electricity is seen to be produced from renewable energy.

Solar energy is the most abundant sources of renewable energy. It is one of the most potential renewable energy attracting significant drive to be harvested across the world. Due to the geographical location of Bangladesh, between 20.30-26.380 north latitude and between 88.04-92.440 east longitudes, it has a great potential to harvest solar energy [6]. Energy obtained from sunlight striking the earth in one hour is more than the energy consumed by human in one year [7]. In fact, the solar energy resources dominate over all other renewable and fossil-based energy resources. Generating electricity by harvesting solar energy directly through photovoltaic panels is considered one of the most promising and growing market in the field of renewable energy [8]. Moreover, the cost of Si-based solar panel have declined so rapidly that panel costs now make up <30% of the cost of a fully installed solar electricity system [9]. Sustainable solution using solar energy have been explored for a variety of application such as solar boat, solar-powered wheel chair, solar powered base station of mobile networks, solar pumps, etc. [9-12].

With an increasing attention towards carbon-neutral energy production, solar electricity using photovoltaic (PV) technology is receiving heightened attention as a promising approach towards sustainable energy production. Energy requirement for a university sourced from renewable energy will obviously play a vital role for reducing fossil fuels consumption. Shahjalal University of Science and Technology (SUST) located at a city of Sylhet in Bangladesh is a green campus having a green panorama and hills with a number of tourist attractions. Average global solar insolation in Sylhet during 1988-98 considering the whole year was reported as 4.54 kW/m^2/day [13]. However, the data of solar irradiance in this research is not reported as experimental data.

To the best of our knowledge, no research work is found to report experimental solar irradiance data collected in Sylhet division. Limited research [14-15] has been published worldwide on designing of a PV system for University Campuses towards their energy independence. It is worth investigating the technological and economic feasibility of replacing the existing fossil fuel based energy system (grid-electricity) with solar energy for Shahjalal University of Science and Technology, Sylhet, Bangladesh.

2. RESEARCH METHODS

The local solar irradiation level is crucial for a successful PV installation design. This has been achieved by collecting experimental data using a solar irradiation measuring device (PYRANOMETER) for a reasonable period of days varying the time of a day. Data was logged in every 1 minute using a Mooshimeter (USA) wirelessly connected (Bluetooth) with a cellphone. Therefore, the solar irradiance for a whole day was mapped with a better precision reflecting any transition from sunny to cloudy atmosphere. The value of irradiance (E) in W/m^2 is determined using the equation below:

$$\boldsymbol{E = \frac{U_{emf}}{S}}$$

Where, U_{emf} (µV) is the output voltage and S is the sensitivity of the Pyranometer (73.4 µV/W/m²).

In the present research, a four-storied academic building at Shahjalal University of Science and Technology, Sylhet has been selected for this study. The building has total floor area of about 1800 m^2 being used as lecture rooms, seminar rooms, different laboratory, library space, office rooms. Data has been collected visiting different area of the selected building to determine the total energy consumption for a variety of electrical appliances. In this research, air-conditioners and other heavy-duty machines have been excluded to lower down the total energy consumption of the selected building. Total number of existing electrical appliances (Fan, Light, Projector, Printer, and PC) for academic building 'C' of SUST has been manually counted. Several rational assumptions have been made to calculate the total amount of energy consumed daily in the selected academic building.

The assumptions considered are:

- A calendar year has been divided into one cold and warm weather where November to February is assumed as the cold weather period and March to October is considered the moderately hot or hot weather period. All fans are assumed to remain unused during the cold weather.
- Total number of holidays including the weekends has been calculated.
- AC and other heavy-duty machines including laboratory equipment has been excluded for lowering down the power consumption requirement.
- Average durations of lectures, laboratory demonstrations and office opening have been considered as 6 hours, 3 hours and 9 hours, respectively.

The Microsoft Excel Software has been used for technical analysis along with system sizing of the studied PV systems and RET Screen Expert (viewer mode) was used for the financial feasibility of the PV systems in terms of cost analysis, financial analysis and emission analysis. Present value(PV) for existing energy system and PV systems during the Project Life Cycle has calculated by using the equation given below:

$$PV\ of\ cashflow = Annual\ cost\left(\frac{1+e}{(1+d)(1+i)}\right)^{n}$$

where, for the project life of 25 years, n is the number of years, fuel escalation rate, e=5.7%, inflation rate, i= 5.5% and discount rate d = 10%.

Finally, the net present value(NPV) for different systems are calculated using the following relation.

NPV= Sum of PV for whole project life – Initial Investment

3. RESULTS AND DISCUSSION

The ongoing issue of energy independence in government offices raises the importance for research to be carried out in planning, designing and implementation of solar PV installation in the University campuses of Bangladesh. So, this research tries to highlight how a feasible and sustainable alternative which also be renewable option can be found towards meeting the self-generation target.

3.1 Solar irradiance at SUST campus

The diurnal variation of solar irradiance is common for all solar PV installations. So, a calibration of irradiation on a sample space (per square meter) must be carried on an hourly basis. The standardized data for a monthly average insolation for different tilting angles is also necessary. The daily data collection is carried out for the last six months and averaged for monthly solar insolation. These results are summarized in Table 1 and Figure 1 given below. The usual standard measuring unit (System International-SI) is used for conversion of radiation data which is generally measured in induced voltage with a current rating. The conversion of induced voltage (micro-volt) to energy unit is carried out using the mentioned software. The standard unit of insolation is kWh/m^2/day.

Table 1: Monthly average solar insolation at Sylhet during November 2018 to April 2019.

Month	Insolation kWh/m^2/day		Average Insolation (kWh/m^2/day)	
	Horizontal	Tilted at 25^0	Horizontal	Tilted at 25^0
November	4.07	5.20		
December	3.73	4.76		
January	4.01	5.24	4.30	5.26
February	4.48	5.72		
March	5.08	5.71		
April	4.43	4.91		

From the above table and Figure 1, it is clearly observed that solar irradiance is much higher on a tilted plane at 25° during the selected months. The average solar irradiance is found to be 5.26 kWh/m^2 in a day which implies that Sylhet has high potential for solar energy applications.

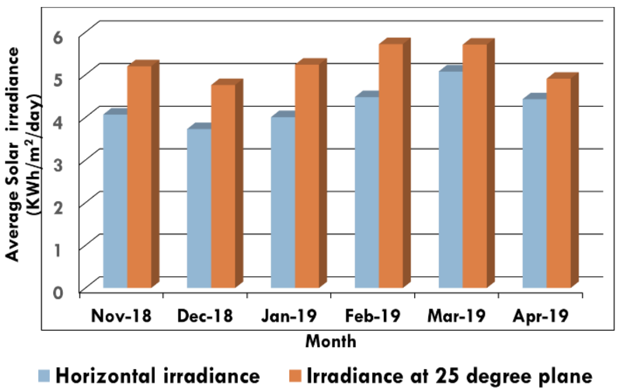

Figure 1: Month wise comparison of average solar insolation at Sylhet.

Solar irradiance data collected by the Pyranometer and logged at every minutes for five consecutive days on a number of tilted planes (0 to 30 degree) was considered for a straightforward comparison as shown in Figure 2. The fluctuation observed in the figure is due to the cloud cover over the sun periodically during the selected month of October 2019. Solar irradiance is found to increase with the increase of tilted angle with a maximum at 25°. It is also seen that the solar irradiance decreases at 30°, however, it is higher than the irradiance at other studied angles. From this comparison, it can be concluded that the maximum power is expected to be produced from a solar module tilted at 25° planes. The tilted angle is equal to the latitude of Sylhet. It was reported that the maximum power was supposed to be extracted from a solar panel while installed at a fixed angle that is close to the value of latitude for a geographical location [16]. The findings in the present research support the argument.

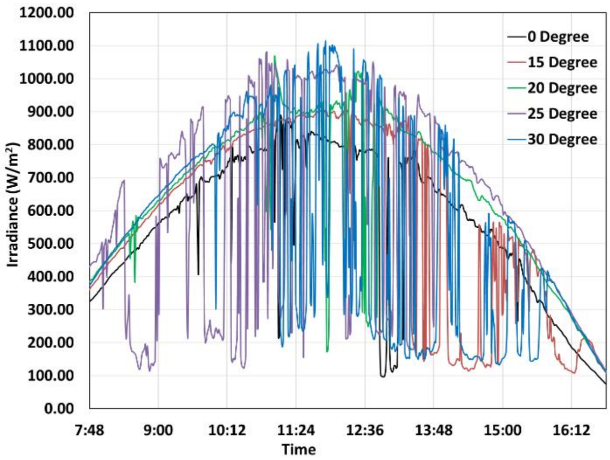

Figure 2: Solar irradiance at different tilted planes in October 2019 at SUST.

3.2 Design of the PV systems

The total number of existing electrical appliances such as lights, fans, personal computers (PCs), printers, projectors, and photocopiers and their corresponding energy consumption has been assessed in this research. The total power consumption capacity using all electrical appliances with their individual power ratings is found to be 105.830 kW. The total energy consumption is expected to be 557.108 kWh per day which is considered as a peak energy demand for the off-grid system. The off-grid system ideally does not get energy from the grid. On the other hand, for the grid-connected PV systems, average energy demand calculated for duration of a year is considered as the system can use electric energy from the electric grid when it is necessary. Neglecting the minimal energy consumption during the holidays and weekends, the total energy consumption per year is found be 100.27 MWh. Consequently, the average energy consumption per day is estimated to be 274.72 kW for the grid-connected PV system.

Using a number of equations reported by Hasan et. al. [17] for sizing a PV system, the off-grid standalone PV system were evaluated in the present work. It is estimated to have 720 panels with a peak power of 280 W at standard testing conditions (STC), 228 batteries with a capacity of 250 Ah each, 35 charge controller (120 Ah) and 4 inverters (50 kW). On the other hand, both of the grid-connected PV systems require 368 panels and 2 inverters of same specifications. The different components selected for the PV system are shown in Table 2 with their model, capacity and price.

Table 2: Different components of the PV systems with their specifications [18].

Components	Model	Capacity	Price/unit (BDT)
Charge controller	VarioString VS-120 (MPPT)	5.76 kW	91,300
PV module	PLM-280M-60 (Mono)	280 W	6,275
Battery	NP12_250 (AG, Lead)	250 Ah	22,410
Inverter	Solectria PVI 85 kW (String)	85 kW	2,075,000

3.3 Financial analysis

The development costs of the off-grid PV system, the grid-connected PV systems with battery and without battery are calculated to be BDT 15,174,980, BDT 7,728,160 and BDT 3,485,200, respectively. Replacement costs for replacing batteries are considered as periodic cost at a five-year interval. It is found to be about BDT 2,076,245 for the off-grid PV system and for the grid-connected PV system with battery is BDT 1,060,740. Whereas this replacement cost is not required in case of the grid-connected PV system without battery. Due to de-rating it is required to add 19 new PV panels with the estimated panels every year of project life for the off-grid PV system which requires a replacement cost BDT 119,225. The grid-connected PV system with & without battery requires 16 panels every two years that costs BDT 100,400.

The cost of 1 kWh grid electricity for an educational institution is found to be 6.0012 BDT [19]. Considering 5% VAT and demand charge BDT 50 on peak load, the total cost of energy for a year is calculated to be about BDT 694,863.43. This cost of energy is mainly considered as annual savings or annual income for the considered 25-year project of the PV systems. In addition, greenhouse gas (GHG) reduction income through CDM (clean development mechanism under Kyoto Protocol) and electricity export income for the grid-connected PV systems are also taken into account.

Financial viability has been performed using RET Screen and Microsoft Excel to see which scenario of the PV systems will be viable to implement. If the net present value(NPV) is greater than zero, it means that the project will add value to the farm or investor and create wealth for shareholders [20]. If the internal rate of return (IRR) is greater than the Minimum Attractive Rate of Return (MARR) which is considered 10%, the PV project is considered as the acceptable and viable project. Financial viability analysis requires some factors to be consider such as inflation rate is 5.5%, the discount rate or minimum interest rate is 5% [21] and fuel cost escalation rate is 8.3% [3].

The input of those factors to RET Screen provides the output that has been shown in Table 3. The table indicates that the off-grid PV system is not acceptable in any way, but the other two systems are viable, profitable and thus acceptable. The cumulative cash flow for the grid-connected (without battery) PV system is evaluated and plotted in Figure 3. The figure and Table 3 shows that the payback period for the grid-connected (without battery) PV system is found to be about 3.47 years.

Table 3: Financial viability analysis for the PV systems.

Particulars	PV Systems		
	Off-grid	Grid-connected	
		with battery	without battery
After-tax IRR (%)	Negative	11.32%	32.9%
Simple payback (year)	>25	8.78	3.47
Net present value (BDT)	-23,930,957	5,652,567	16,584,800
Annual life cycle savings (BDT/year)	-1,333,977	475,134	1,706,426

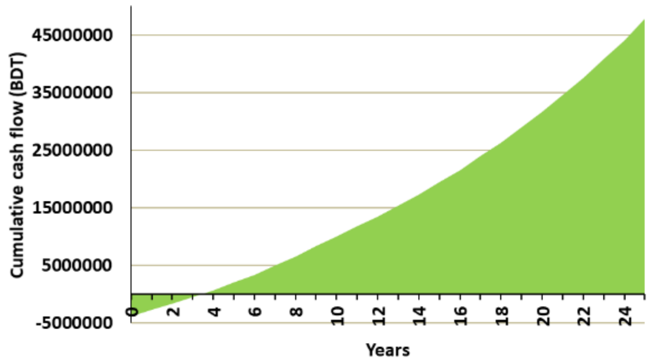

Figure 3: Cumulative cash flows for the grid-connected PV system without battery.

3.4 Emission analysis

The contribution of natural gas, petroleum, coal and hydropower for total electricity generation is 52.83%, 36.94%, 8.84% and 1.21%, respectively [22]. Therefore, to produce 1 kWh electricity, total gas emission is 608.74 gCO_2 equivalent (eq.). On the other hand, a solar PV system using Si-based PV modules releases 45 gCO_2eq. to produce 1 kWh electricity [23]. As a result, total reduction of CO_2 gas emission by installing a PV system to generate 1 kWh electricity is 563.74 gCO_2eq. The off-gird system necessary for generating electric energy for the selected academic building with a production capacity of 100 MWh yearly is going to save the emission of 56.37 ton CO_2 eq. Whereas, the grid-connected PV systems with a capacity of 161 MWh yearly is capable of saving the emission of 90.76 ton CO_2 eq.

4. CONCLUSIONS

This study aimed at investigating the potential of harvesting solar energy in Sylhet and hence designing of a photovoltaic (PV) power generation system for a typical academic building of a public university of Bangladesh in order to study its economic and environmental feasibility. The solar irradiance at a tilted plane (25° with the horizontal) for six months averaged to 5.26 kWh/m^2 in a day which implies that Sylhet has high potential for solar energy applications. The daily energy requirement for the academic building to design the off-grid PV system and the grid-connected PV system (with or without battery) were considered 547.108 kW (peak) and 274.720 kW (average), respectively. The net present value (NPV) of the grid-connected PV system with battery and without battery are found to be BDT 5,652,567 and BDT 475,134, respectively. Their respective annual life cycle savings are BDT 16,584,800 and BDT 1,706,426. Both the grid-connected PV systems can save greater emission with 81.51 tons of CO_2 per year than the off-grid system with 50.63 tons. Though both the grid-connected PV systems are feasible, considering the net present value (NPV), emission savings and annual life cycle savings, equity payback period and internal rate of return (IRR), the most preferable option is the grid-connected PV system without battery.

5. ACKOWLEDGEMENT

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