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A Case Study of Grid Connected Solar PV Irrigation System in Semi-Arid Region of Bangladesh

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Abstract

The semi-arid region of Bangladesh is called the Barind tract lies roughly between latitudes 24°20´N and 25°35´N and longitudes 88°20´E and 89°30´E and covered an area of 7728 km^2. This region has already been designated as drought prone. So this region experiences extremes that are clearly in contrast to the climatic condition of the rest of the country. To combat the extreme conditions of climate for sustainable agricultural development a special authority has been formed named 'Barind Multipurpose Development Authority' (BMDA). Under the BMDA activities an irrigation project has been launched since decades. Under this project irrigation facilities are provided for agricultural cultivation at this semi arid region. The total number of deep tube well installed so far under the BMDA irrigation project is 11,967 and the total demand of electricity is 277 MW. The project experiences frequent grid power outage, including low-voltage problems and load shedding, and encourages off-peak hour irrigation (after 11:00 pm). To overcome this problem a grid connected solar PV system is proposed in the Barind tract. A techno-economic feasibility analysis is done for 500 kW grid connected solar photovoltaic (PV) system for this location. HOMER and RETScreen computer tools and monthly average solar radiation data from NASA is used in this study. The unit electricity production cost is found to be 14.51 BDT (Bangladeshi Taka) based on project lifetime 20 years and 10% discount rate. Considering the selling price of electricity 10 BDT/kWh with 5% escalation rate annually to the grid, the IRR, equity payback and benefit-cost ratio are found to be around 5.6%, 13.1 years and 0.68 respectively without considering any clean energy facilities. The total annual greenhouse gas reduction is estimated to be 658 tons for 500 kW grid system.

Keywords: *Irrigation for semi-arid region, Solar PV, Grid electricity.*

1. Introduction

World Bank reported that 2.4 billion people rely on traditional energy sources, whereas 1.6 billion people do not have access to electricity [1]. With an estimated world average growth rate of 2.8%, the electricity demand is expected to be doubled in 2020. During this period, the electricity demand in developing countries is projected to increase by 4.6% annually [2]. Bangladesh lacks a sufficient electricity generation capacity and there are always a huge gap between demand and supply. Fig. 1 presents power system master plan 1995 base case power demand forecast for the years 1995-2006 and the actual demand served and power load shedding done the said years [3]. The country has been facing a severe power crisis for a decade. Power generation in the country is almost entirely dependent on natural gas, which accounts for 81.4% of the electricity generation of total installed capacity 5248 MW [3].

The greater northern part of Bangladesh (Rajshahi, Dinajpur, Rangpur and Bogra District) and the Indian territorial Maldah District of West Bengal is geographically identified as Barind Tract. The hard red soil of these areas is very significant in comparison to that of the other parts of the country. The Rajshahi Barind Tract lies roughly between latitudes 24°20´N and 25°35´N and longitudes 88°20´E and 89°30´E (Fig. 2) and covered an area of 7728 km^2.

The climate of this area is typically dry climate with comparatively high temperature except for the wet season beginning from mid June to October. The annual rainfall in the area varies from about 1500 mm to 2000 mm. Temperature ranges from 8°C to 44°C. The total cultivable area being 0.583 million hectares, out of which 34% is loamy, 10% Sandy, 49% is clayed and 7% others. Out of the total cultivable land, 84% are single cropped, 13% are double cropped and the rest are triple cropped. The cropping intensity was 117% [15].

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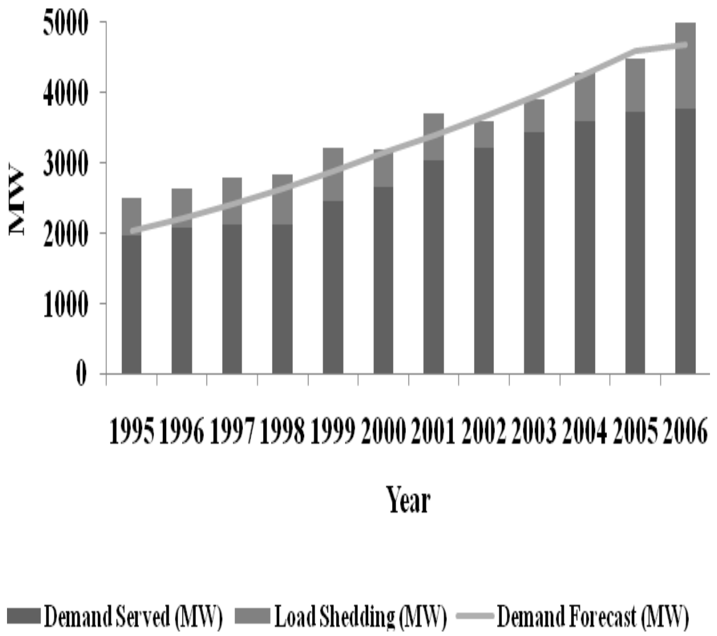

Fig. 1. Power Demand and Supply Gap (1995-2006)

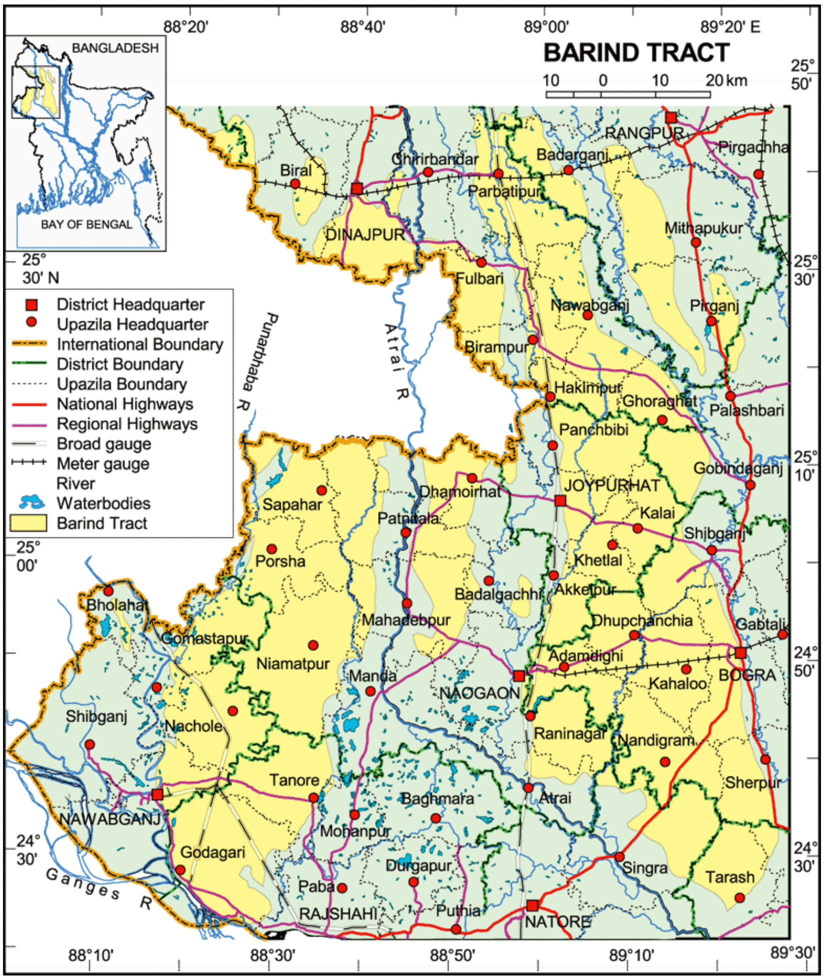

Fig. 2. Location of study area (Barind Tract) [16]

In 1985 the Government approved a project named Barind Integrated Area Development Project under the Bangladesh Agricultural Development Corporation. Later on to speed up the development project implementation of the Barind area a separate authority was created named Barind Multipurpose Development Authority (BMDA) on 15th January 1992 under the ministry of Agriculture. The main task of this authority is to enhance the irrigation services in this semi arid region. The irrigation capacity of this authority is shown in Table 1.

The total number of deep tube well installed so far under the BMDA irrigation project is 11,967 and the total demand of electricity is 277 MW. The project experiences frequent grid power outage, including low-voltage problems and load shedding, and encourages off-peak hour irrigation (after 11:00 pm). To overcome this problem a grid connected solar PV system is proposed in the Barind tract.

Table 1. Irrigation activities at Barind Tract, Bangladesh[15]

Activities	Achievement
Installation of deep tube well (DTW)	12001
Electrification of DTW (Nos.)	11967
Irrigation Water Distribution System (Nos.)	9629
Drinking water supply from deep tube well (Nos.)	461
Deep tube well utilization in 2008-2009 (No)	11663
Irrigated area in 2008-2009 (hectare)	471463

At the current rate of increase in consumption (10% annually), the national proven reserve of natural gas may not last more than 15-20 years [4]. Only limited amount of coal resource is available to generate electricity, although it has adverse environmental impact. On the other hand, the government of Bangladesh has declared that it aims to provide electricity for all by the year 2020, although at present there is a high unsatisfied demand for energy, which is growing by more than 8% annually [5]. The Rural Electrification Board (REB) in its master plan of 2000 noted that it had supplied electricity services to about 31% of the total rural population. It aims to reach 97 million rural populations by 2020, which is about 84% of the total rural population [5]. In order to address this target only fossil fuel based power plant would not be able to satisfy the demand. It needs to look for the alternative sources of energy for power generation. Renewable energy technologies would be one of the important emerging options.
Bangladesh is situated between 20.30 and 26.38°N latitude and 88.04 and 92.44°E longitude, which is an ideal location for solar energy utilization. Daily solar radiation varies between 4 and 6.5 kWh/m^2. Solar PV technology is an important emerging option for electricity generation. So, densely populated tropical country like Bangladesh could be electrified by PV grid system using the inexhaustible and pollution free solar energy without using any novel technologies. Compensation of electricity shortage and reduction CO_2 emission would be done by introducing solar energy sources for electricity generation in mass scale.

In this paper, a techno-economic feasibility analysis is carried out for 500 kW PV grid system to deliver electricity at Barind Tract (Rajshahi). To find the optimum size of inverter and for technical analysis, Hybrid Optimization Model for Electric Renewables (HOMER) is used. Another simulation software Renewable Energy Technologies screen (RETScreen) is used to find the financial viability of the system based on HOMER's technical optimization data.

2. Baseline Data of Solar Radiation

NASA Surface meteorology and Solar Energy (SSE) data set for the study site is used for RETScreen analysis. The NASA SSE data set is formulated from data gathering for the 10 years period from July 1983 to June 1993. These data is used to get baseline data of 8760 hours. The baseline data is the set of 8760 values representing the average global solar radiation on the horizontal surface in kWh/m^2, for each hour of the year. To synthesize data by HOMER, it needs to enter twelve average monthly values of either solar radiation or clearness index. Where, clearness index is a dimensionless number between 0 and 1 indicating the fraction of the solar radiation striking the top of the atmosphere to strike the earth surface. After entering the values in the table, HOMER builds a set of 8760 solar radiation values. It creates the synthesized values using the Graham algorithm [6]. Table 2 shows the solar radiation at Rajshahi by NASA SSE, recorded data [7] and clearness index by HOMER using the monthly average solar radiation data from NASA SSE.

Table 2. Solar Radiation and Clearness Index at Rajshahi

Month	Daily Solar Radiation (kWh/m2)		Clearness Index
	NASA	Recorded[7]	
Jan	4.32	3.96	0.654
Feb	5.25	4.47	0.678
Mar	5.95	5.88	0.649
Apr	6.33	6.24	0.609
May	5.74	6.17	0.519
Jun	5.04	5.25	0.447
Jul	4.41	4.79	0.396
Aug	4.36	5.16	0.412
Sep	4.03	4.96	0.422
Oct	4.42	4.88	0.543
Nov	4.46	4.42	0.651
Dec	4.21	3.82	0.675

3. RETScreen and HOMER Tools

RETScreen software developed by the Ministry of Natural Resources, Canada, is the leading tool aimed at facilitating feasibility analysis of clean energy technologies. The core of the tool consists of standardized and integrated project analysis software which can be used to evaluate the energy production costs, life cycle costs and GHG emission reduction for various types of proposed energy efficient and RETs [8]. HOMER is an optimization computer tool that simplifies the task of evaluating design option for both grid and off-grid connected power systems. HOMER's optimization analysis algorithms allow evaluation of the economic and technical feasibility of a large number of technology options and account for variation in technology costs and energy resource potentials. This model identifies the least cost system that meets the electricity demand by performing hourly simulations from thousands of potential power systems [9]. Block diagram of proposed on grid PV system is shown in Fig.3.

4. Technical and Economic Parameters

The solar modules are placed at the south facing with 0^0 angle of azimuth. The modules are tilted with an angle of 25^0, same as the latitude angle of the site. For this study, solar panel model mono-Si-BP4175, capacity per unit 175 W, efficiency 13.9% and 2857 units for total capacity 499.98 kW are considered. Solar PV array- technical parameters and cost assumptions are given in Tables 3 and 4.

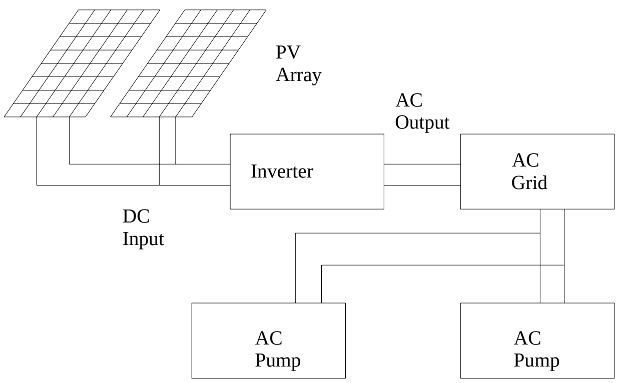

Fig. 3. Block Diagram of proposed on grid PV system

Table 3. Solar PV Array- Technical Parameters and Cost Assumptions

Parameter	Unit	Value
Capital cost [10]	BDT*/Wp	274
Replacement cost	BDT/Wp	206
Operation & maintenance cost	BDT/kW/yr	50
Lifetime	Year	20
Derating factor	Percent	90
Ground reflection	Percent	20
Tracking system	No tracking system	

*Bangladeshi Taka (1USD = 68.5 BDT)

Table 4. Inverter Technical Parameters and System Evaluation

Parameter	Unit	Value
Inverter:		
Capital cost [11]	BDT/kW_{rated}	15000
Replacement cost	BDT/kW_{rated}	10000
O & M cost	BDT/yr	6500
Lifetime	Year	10
Efficiency	Percent	90
Rectifier capacity	Percent	95
Rectifier efficiency	Percent	85
System Evaluation:		
Annual interest rate	Percent	10
Inflation rate	Percent	4
System other O & M cost	BDT/kW/yr	1125
Project lifetime	Year	20

5. Results

The optimum sizes of the technologies that meet the maximum grid demand of 500 kW for the selected site under the given condition of solar resources are simulated by HOMER and RETScreen. HOMER analysis yields that 450 kW inverter is the least cost optimization size for the proposed 500 kW PV grid system. Technical outputs for this analysis by HOMER are given in Table 5. Maximum energy generated in March is 89.94 MWh and minimum energy generated in September is 55.36 MWh and annual total production is 894.55 MWh. Per unit energy production cost found for the proposed project is 14.51 BDT, which is competitive with diesel based grid power generation. By using average monthly highest and lowest solar radiation at different parts of the country with same parameters, the production cost per unit of electricity is found to be 15.25 to 14.10 BDT.

Sensitivity analysis results of electricity generation cost for changing PV cost and discount rate are given in Fig. 4 and Fig. 5 respectively. It is found that the electricity production cost 8.5 BDT and 18.2 BDT when the PV panel costs are 150 BDT/Wp and 350 BDT/Wp respectively. Fig. 6 shows the production cost of electricity for different project lifetime ranging from 12-30 year.

Table 6 presents the IRR, equity payback period and benefit-cost ratio for the proposed project based on different rental power plants electricity selling rates of 7BDT/kWh, 10 BDT/kWh, 13 BDT/kWh, 15 BDT/kWh [12, 13] and 18 BDT/kWh with 5% escalation rate annually. Net annual greenhouse gas emission reduction is about 658 tons.

Table 5. Technical Outputs for the Analysis

Parameter	Unit	Value
PV array area	m^2	3597
Electricity export	MWh/yr	894.55
Average output	kWh/day	2449
Excess electricity	kWh/yr	3082
Maximum output	kW	559
Capacity factor	percent	20.4
Hours of operation	hour/year	4378

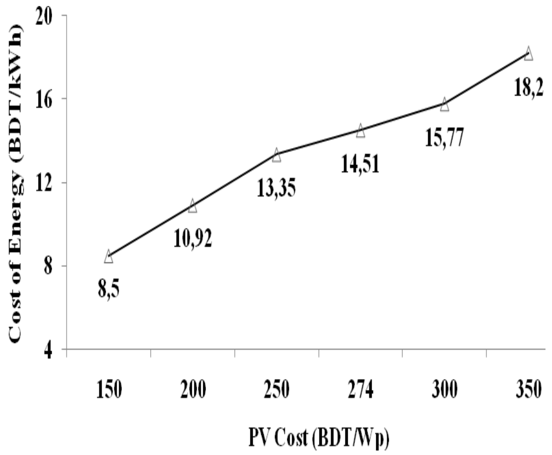

Fig. 4. Sensitivity Analysis due to Change of PV Cost

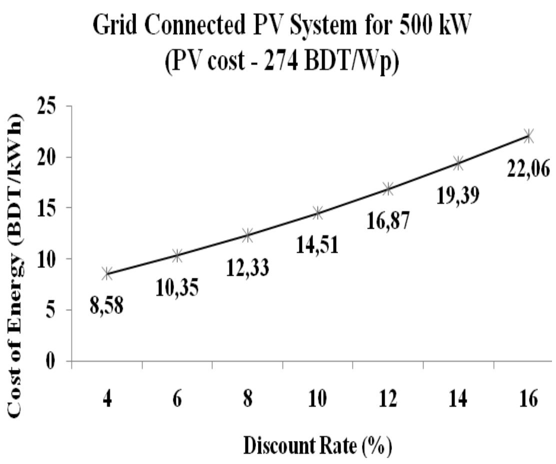

Fig. 5. Sensitivity Analysis due to Change of Discount Rate

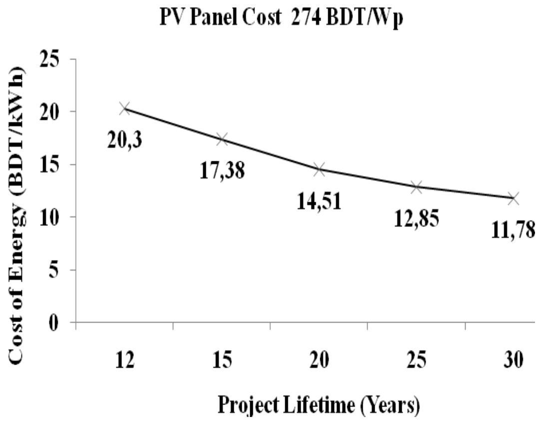

Fig. 6. Production Cost for Different Project Lifetimes

Table 6. IRR, Equity Payback and Benefit-cost Ratio for Different Rates of Electricity Selling Price

Electricity Selling Rate (BDT/kWh)	IRR (%)	Equity Payback (Year)	Benefit-cost Ratio
7	2	17.2	0.46
10	5.6	13.1	0.68
13	7.7	11.3	0.82
15	10.4	9.4	1.04
18	12.9	8.1	1.25

6. Conclusion

Grid electrification is essential for economic development in Bangladesh. The country has very limited fossil fuel reserve for electricity generation. PV grid electricity generation system could be effective to extend the grid connection and available power for all. This study examines the feasibility of PV grid system for 500 kW generation plant for irrigation purposes at a semi-arid region, Barind Tract, Rajsahi. It is found that the per unit electricity production cost from the studied system is cost-competitive with grid-connected diesel power generation which is around 15-18 BDT. If clean development mechanisms, carbon tax, and oil price increase are considered, the unit cost would be lower than the grid-connected diesel power generation.

Due to the high initial investment cost of PV grid system, there should be favorable policies for this sector. These should first set a target for renewable energy deployment and use instruments to achieve such target. The instruments that can be applied to encourage renewable energy technologies promotion are incentives, consumer credit schemes, capacity building and to establish a renewable energy service company for semi-arid region to deliver irrigation and water supply services.

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