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Design of a 100 MW Solar Power Plant on Wetland in Bangladesh

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Abstract. World-wide a small-scale solar photovoltaic (PV) system is increasingly becoming a popular power source for domestic application. In contrast, large-scale solar power plants are of growing interest for commercial, industrial and community users as an alternative to fossil fuel-driven power plants. Despite the growing interest, scant information on large-scale solar power generation especially in rural and inaccessible locations is available in the public domain. Hence, the primary objective of this study is to design a large-scale (100 MW) solar power plant for wetland areas in Bangladesh. For the 100 MW power plant, a total of 166,670 solar modules (each of which is 2,070mm long, 1,390 mm wide and 45mm thick with 600 W power capacity) have been used. To generate 100 MW electricity (power), around 303 acres (approximately 123 hectares) of the wetland is required keeping the distance of 2.35 m between every two adjacent solar panel mounting rows. A total of six hundred and seventy (670) three-phase grid-tie inverters (GTI) and 40 transformers have been connected to the solar panel. Along with the renewable electricity production, the required wetland (123 hectares) located under the solar panels has been considered for permanent sanctuary to conserve the indigenous fish species. The challenges and risk factors of the 100 MW plant have also been elaborated.

INTRODUCTION

Energy is one of the vital global strategic resources for national and international security, economic development, and prosperity. Emerging and developing nations have progressively been increasing power generation capacity to drive their industrialization and economic development. The global total power generation capacity has increased by 192% in 2015 compared to 1974 [1]. Till today most power generation is achieved by fossil fuel which creates a large amount of greenhouse gas emissions and other environmental and health hazards. Most of the modern-day power sources create pollution, and among the genre, eco-friendly photovoltaic energy is a reliable source to elevate the greenhouse gas (GHG) emission and the present energy crisis [2]. Small scale power sources such as standalone solar home systems (SHS) as well as grid-tied systems are considered as worldwide popular green power sources [3]. Besides these small-scale power sources, the large solar power plant is becoming popular in commercial and industrial applications [4]. To date, there are different types of megawatt solar power plants that have been installed in the plane land, desert, or into the sea as floating fashion [5-7]. Being one of the highest densely populated countries (1,265 people per square kilometer), Bangladesh with over its 160 million populace faces severe scarcity of land for large-

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scale PV power plant installation. It has no desert or barren lands, though there are thousands of wetlands throughout the county [8].

Implementation of a large-scale power plant is always challenging in Bangladesh where each and every portion of fertile land is utilised for food production [9]. The main drawbacks of installing this kind of massive power project are the huge amount of inhabited and/or prime agricultural firming land, and associated rehabilitation and re-settlement cost. Because of huge land demand, these mega projects are generally implemented into deserts, large barren lands, dry or salty lands where cultivation is not possible [10, 11]. In recent years, it has been seen that, there is a tendency to implement massive solar power plants in unused lands. For example, in 2014, a 550 MW Topaz Solar Farm was installed in the central coastal area, and an another 550 MW PV power plant, known as Desert Sunlight Solar Farm, was commissioned in the far eastern desert region of California, USA [12, 13]. The areas of these power plants are 16 km^2 and 19 km^2 respectively. In 2020, India installed its largest solar power plant, called Bhadla Solar Park, into the dry barren land in Phalodi Tehsil of Jodhpur district, Rajasthan [14, 15]. The 2,245 MW capacity power plant occupies a total 57 km^2 of land in Phalodi. Dubai commissioned Mohammed bin Rashid Al Maktoum Solar Park with 1,013 MW capacity in Saih Al-Dahal desert area in 2020, and the plant spread over a total area of 77 km^2 [16]. China officially connected her first large-scale 500 MW grid connected solar power plant (PV front-runner) with the grid in Golmud, Qinghai, in December 2018 [9]. The country also operates another 1,547 MW photovoltaic power plant known as Tengger Desert Solar Park. This large plant has been installed in Zhongwei, Ningxia and its plant area is 43 km^2 [17].

In recent years, due to the steep decrease of the solar panel prices, the government and private investments are increasing for mega-watts scale PV power plant installation. The design and techno-economic evaluation of large-scale solar power plants located in plane lands and deserts are reported in open literature [18-20]. However, no information is available for large solar power plants on low-lying marsh areas in densely populated country such as Bangladesh. Thus, the main objective of study is to investigate the design and techno-economical aspects of a 100 MW solar power plant in low lying marsh area. Bangladesh, a part of Ganges delta, is a small country, and most of her land is fertile for cultivation [18, 19]. The country has no desert, salty barren lands, or valleys for large-scale solar farm implementation. But it has many freshwater floodplain wetlands throughout the country. According to the Department of Bangladesh Haor and Wetlands Development, the country is a blessing with 373 Haors and 6300 Beels [8]. These wetlands are inhabited by hundreds of indigenous species of freshwater fishes, and many of these are in threatening condition. Bangladesh is committed to boosting the proportion of renewable electricity generation in its overall energy mix to reduce the economic reliance on fossil fuels. The government and the regulatory bodies of the country are inclined to implement a list of solar parks to fulfill their targets to increase the green energy proportion in multi-sectoral integrated power generation. As mentioned earlier, Bangladesh has no suitable unused land for large-scale PV power plant installation, so wetlands would be better options for the implementation of the clean energy generation as well as for preserving the indigenous fish species. Moreover, Bangladesh is blessing with sufficient solar insolation that is very much potential for large power plant implementation [4]. So, in this research work, a 100 MW grid-connected solar power plant is to be designed at Chalan Beel wetland, located at the North-Western region of the country. The pioneering design would assist in fulfilling the government target to implement the large-scale PV plants and to form a permanent sanctuary for preserving the indigenous fish species. To the best of our knowledge, there is no such work found in the literature that is conducted for PV power plants on wetlands in Bangladesh.

METHODOLOGY

Site Selection

In order to design a 100 MW solar power plant, we have selected Chalan Beel area having coordinates as 24.309ºN 89.266ºE and average depth of 2 m [20]. The Beel stresses over four adjoining districts of Bangladesh, namely Rajshahi, Pabna, Sirajganj, and Natore, though the significant part of the marshland consists of the large areas of Sirajganj and Pabna districts [21]. It is one of the largest fresh water wetland in Bangladesh possessing enriched flora and fauna [22]. In the past, Chalan Beel covered a large area, though, at present, the total surface area has shrunk to around 26 square kilometres [23]. Tarash point of Chalan Beel is deep enough where farmers cannot cultivate the regular crops. Moreover, as water is available throughout the year, the mentioned point is very much suitable for breeding different indigenous species of fish by simply converting the fish belt to breeding belt. Furthermore, there is a huge amount of government owned land at Tarash point in Chalan Beel that has currently been given to the local farmers as temporary leasing. Hence, the land acquisition challenge is relatively easy here compared to other wetlands in Bangladesh. A list of metrological data collected from [20, 24] of Chalan Beel is given in Table 1.

TABLE 1. Meteorological data of Chalan Beel

Sl. No.	Particulars	Descriptions
1.	Project site	Chalan Beel
2.	Name of the division	Rajshahi
3.	District name	Rajshahi, Pabna, Sirajganj, and Natore
4.	Geographical coordinates	24.309ºN 89.266ºE
5.	Daily global solar irradiance	4.55 kWh/m^2
6.	Daily diffuse solar irradiance	1.81 kWh/m^2
7.	Annual global solar irradiance	1663 kWh/m^2
8.	Annual diffuse solar irradiance	661 kWh/m^2
9.	Total surface area	26 km^2
10.	Average depth	2 m
11.	Maximum depth	4 m

The proposed site location of the 100 MW solar power plant at Chalan Beel is shown in Fig. 1.

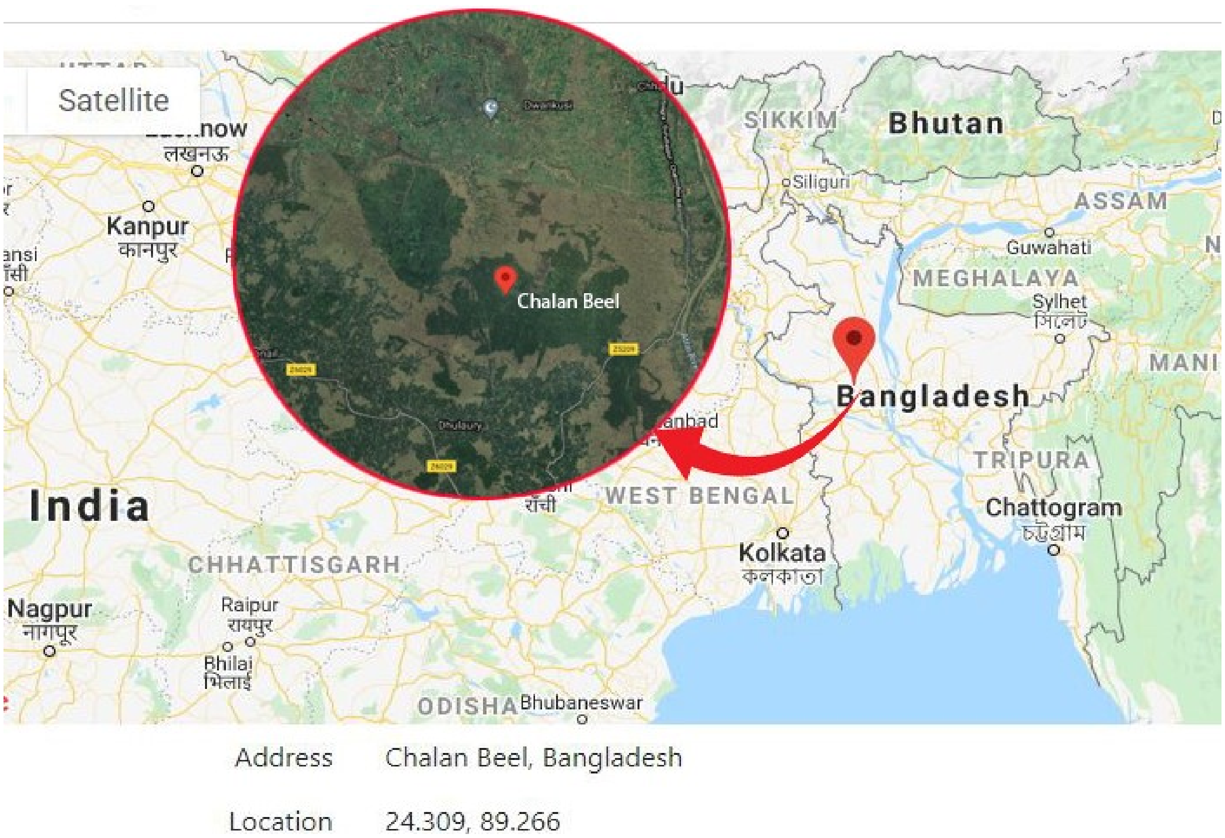

FIGURE 1. Proposed solar power plant layout of Chalan Beel

Solar Potential in Chalan Beel

The annual average global solar irradiance of the project site is 1,663 kWh/m^2 [24]. Figure 2 shows the variation of monthly average solar radiation throughout a year for the site 'Chalan Beel' a wetland in Bangladesh. The average daily radiation at Chalan Beel is estimated to be 4.75 kWh/m^2/d using HOMER tool.

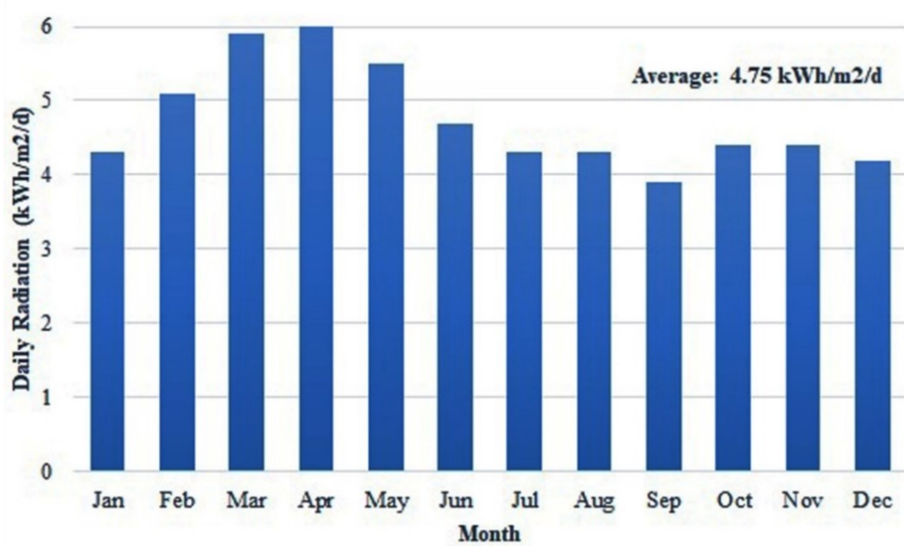

FIGURE 2. Variation of daily solar radiation of Chalan Beel.

Details of Proposed 100 MW Solar Power Plant

In this study, Changzhou Sunday Energy (China) made monocrystalline 600 W solar panel (Model: SDM-600) has been considered for electricity generating device. The dimension of this panel is 2070 mm x 1390 mm x 45 mm, and the number of solar cell is 96 in each solar panel or module [25]. Each panel occupies an average of 2.8773 m^2 of area and has the power generation rating of 600 watts at peak hour. In order to generate 100 MW electricity, a total of 303 acres (approximately 123 hectares) of wetland is required for maintaining a decent 2.35 m distance in between every two adjacent panel bearing rows. The detailed electrical specifications of the solar panel are shown in Table 2.

TABLE 2. Technical specification of the solar module

S/N	Parameter	Specification
1	Maximum Power (P_{max})	600 W
2	Open Circuit Voltage (V_{oc})	61.73 V
3	Voltage at Maximum Power (V_{max})	51.51 V
4	Short Circuit Current (I_{sc})	12.5 A
5	Current at Maximum Power (I_{max})	11.65 A
6	Panel Efficiency	20.85%
7	Dimension	2070 mm x 1390 mm x 45 mm
8	Capital Cost Per Watt	$ 0.18 / W
9	Warranty	25 Years
10	Operating Temperature	-40 ~ +85°C
11	Power Tolerance	1%

Three-phase GTI converts the unstable DC current generated from the rows of solar panels into a stable AC current, and in this design 670 GTI inverters have been considered. Moreover, the system requires two types of watt-hour meters: a) sell back meter that measures the total amount of AC current generated from the plant, and b) net meter which indicates the actual power utilized by the load. The rigid mounting system, where solar panels are placed along with the connecting wires, is also the mandatory part for constructing the large-scale solar plant. The transportation, security, and maintenance are also other essential criteria for successfully operating the plant. To design a large-scale solar plant, it is important to find out the accurate amount of the design components along with the electrical circuit knowhow. The calculation of the proposed design is presented in Table 3.

TABLE 3. Design parameters of different components of the 100 MW solar power plant

S/N	Component	Specification	Quantity	Price is USD
1	Solar Module	Changzhou Sunday Energy 96 cells, 600 W panel Crystallinity: monocrystalline Efficiency: 20.85%	1,66,670	$ 40,697,675
2	Inverter	SMA PEAK3 150kW inverter, Max Input Voltage: 1500 V DC Rated power at nominal voltage 150 kW Output Voltage: 300 V AC AC grid frequency/range: 50 Hz/44 Hz to 55 Hz Rated grid frequency: 50 Hz Max. output current: 151 A Max. efficiency: 99.1%	670	$ 15,581,400
3	Transformer	2.82 MVA, 33 V/0.315 kV, Dy11	40	$ 8,000,000
4	Mounting system and its components	Number of Strings	238	$ 1,200,000
		String Combiner Box (SCB) having 12 inputs	476	
		Number of Inverter Container having 2.52 MW capacity	40	
		Stainless Steel (SS) Rod	5,00,000 m	
5	Column	24 feet height	2,25,000	$ 29,069,800
6	Connecting Wire	Different diameters connecting wire	6,50,000 m	$ 410,000
7	Other components	Meter, Y-connector, Switch	As per requirement	$ 400,000
8	Transport		---	$10,00,000
			Total	$ 96,358,875

Calculation of Required Area for Solar Power Plant

Solar modules need substantial space due to their low power generation capability. The physical dimensions of the solar panel selected for this study are 2.07 m (length), and 1.39 m (width). Hence the area of each panel becomes 2.8773 m^2. It needs a one-inch separation between two adjacent panels for placing the solar modules on the mounting system properly. So, for placing 350 solar modules, a total of 495 m length is required for each module string. In this design, a 10 m empty space has been kept between two strings in a line, and another 20 m long empty space has been kept beside each portion of the string. So, for placing 700 modules on the two adjacent strings, it needs a total length of 1040 m that can be considered as the width of the solar power plant. Besides, for avoiding the shadow effect of the solar panels, a decent 2.35 m empty space, considering the tilt angle of the project site, is required between two adjoining rows. After taking into account the length of the panel and the inter-row spacing, a total of 4.42 m length has to be ensured between two adjacent rows of the plant for proper incoming of the solar irradiance. Hence for housing 166,670 solar modules, an amount of 238 rows is required where each row supports 700 panels. Besides, a 90 m × 1040 m area is required for sub-stations, office, and residential buildings. Therefore, the total estimated surface area of the 100 MW plant is 1,227,200 m^2 that is equivalent to 303 acres or approximately 123 hectares of land.

The schematic diagram of the power plant is presented in Fig. 3 that elucidates its required components.

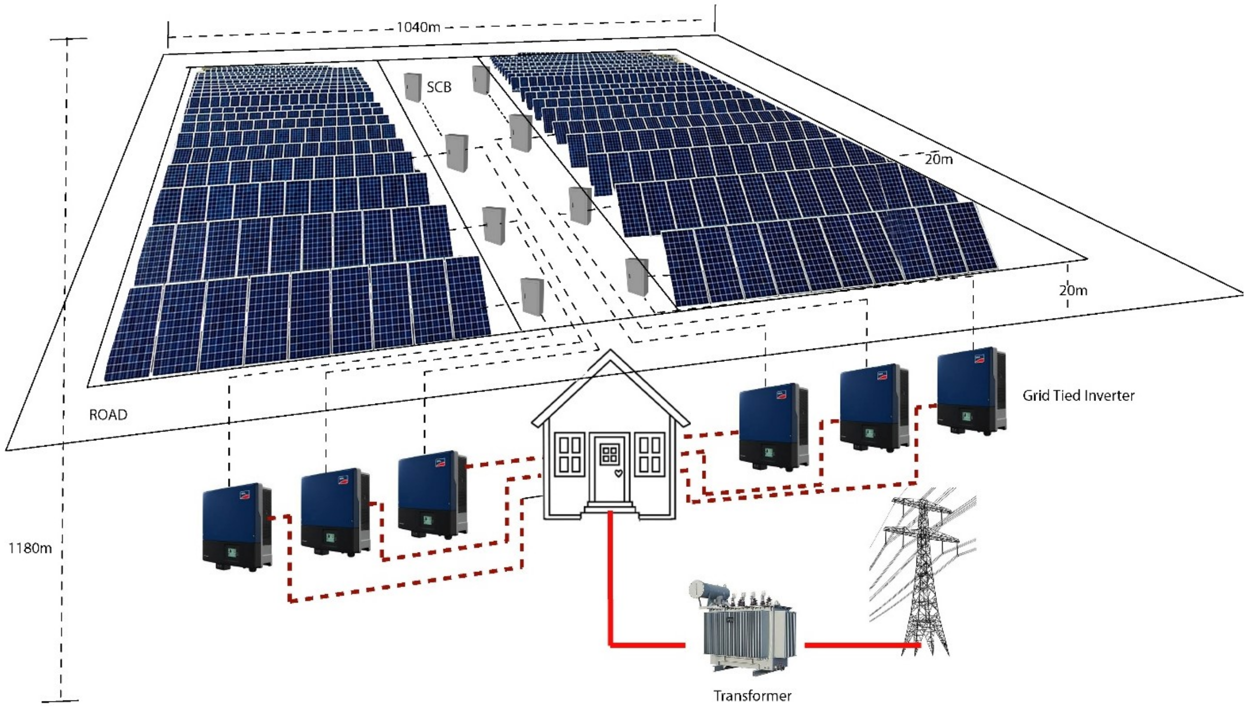

FIGURE 3. Schematic diagram of the components and interconnections of the 100 MW power plant.

Performance and Cost Analysis

As mentioned earlier, the efficiencies of the solar panel and the inverter are 20.85% and 99.1%, respectively. The month-wise electricity generation of the designed 100 MW solar power plant is presented in Table 4.

TABLE 4. Month-wise average electricity generation of 100 MW monocrystalline photovoltaic system

S/N	Month	Average sun hours (h)	Electricity generation (MWh)
1	January	4.3	13,210
2	February	5.1	14,152
3	March	5.9	18,125
4	April	6.0	17,838
5	May	5.5	16,897
6	June	4.7	13,973
7	July	4.3	13,210
8	August	4.3	13,210
9	September	3.9	11,595
10	October	4.4	13,517
11	November	4.4	13,081
12	December	4.2	12,903
		Total electricity generation	171,711

The table shows that the total electricity (power) generation per year is 171,711 MWh. The performance ratio of the solar power plant can be considered as 78% [26]. So, the actual electric power generation is 133513.04 MWh, and the total power generation of the plant considering 25 years lifetime is 333,935 MWh. The total estimated net present cost (NPC) of the 100 MW power plant is US$ 96,358,875. The total annualized cost of the system is US$ 6,745,121 and the total annualized cost of the system lifetime is US$ 168,628,025. The total cost (installation and annualized) of the 100 MW power plant is $ 264,986,900. Hence, the per kWh cost of electricity (power) is approximately US$ 0.0794 or US 8 cent.

DISCUSSION

The land acquisition cost is not counted in this calculation since the proposed project site is government own land. The per-watt cost of the solar module in international market is US$0.18, though in the retail market of Bangladesh, the cost is nearly US$ 0.4. Thus, the total cost requires for 166,670 solar modules is US$ 40,697,675 and for 670 grid-tied inverters is US$ 15,581,400. Also, the total plant installation cost is US$ 96,358,875 and the annualized cost of the PV system is US$ 6,745,121. The total expense of the power plant for its entire lifetime is US$ 264,986,900. However, the total price can be reduced if the modules, inverters, transformers, and meters are purchased together, and the total power plant installation cost can be reduced. The number of solar panels would vary due to the panel size and power capacity, and it is also true for GTI. The designed plant will generate a full-scale 100 MW power through average 4.75 peak hours in a day, and total 333,935 MWh in every year. Although the installation cost of the power plant is huge, the simulated cost per unit of electricity is US$ 0.0794, which is significantly smaller compared to US$0.087, the latter represents the average per unit electricity generation cost from other sources such as coal or diesel engine driven power plant available in Bangladesh, whereas the present PV generated electricity per unit cost is more than US$ 0.209. However, diesel-based power plant generates electricity throughout the 24 hours in a day, though in case of solar plant, electricity generation occurs only when the sunlight is available. The lifetime of a solar power plant is rated to 25 years. Since this plant facilitates a smaller per unit cost of electricity, thus, less power generation will trade-off by the long lifetime of the solar-based power plant. Moreover, the burning of coal or diesel, which is required for driving a coal or diesel engine plant, generates greenhouse gases (GHGs) such as CO_2 CO, SO_2 and so on. It has been reported that, in case of 1 kW electricity generation, Coal-fired power plants emit 950 g CO_2, whereas the solar PV system emits between 60g and 150g CO_2 depending on where the solar panels have been manufactured, though during the operational condition of the power plant, there is no such emissions [27]. As the average daily solar irradiance of the Chalan Beel area is 4.75 kWh/m^2/d, the designed 100 MW solar power plant will reduce the total amount of 164,706 tonnes and 6,0681 tonnes of CO_2 emission compared to coal-fired and gas-fired power plants, respectively. These GHGs have a detrimental effect on the environment and are responsible for climate change. The major benefit of the solar power plant is that it is eco-friendly, sustainable, and offsets $CO_{2,}$ SO_2 NO_x emission compared to power generation by fossil fuel.

Bangladesh is a cyclone-prone country, and it faces mild to severe storms each year. Hence the support-structure needs to be significantly reinforced resulting in higher installation and maintenance cost. The plant will be installed in wetland (marsh area) with certain height (clearance from the water level seasonally adjusted) which will increase the support-structure cost further. Since the Chalan Beel region possesses one of the largest open surface water body inland Bangladesh, the support structure will be required to withstand high wind load and water wave load. The cost associated with these issues also needs to be factored. A well-designed support mounting system and ensuring easy access for repair and maintenance work for the proposed 100 MW solar power plant at Chalan Beel is vital for reliable power generation. The hailstorm can damage the solar panel also if hailstorm's diameter is larger than 20 mm. Past weather data indicates that Chalan Beel area rarely faces such hailstorms.

The design of the proposed power plant permits sufficient sunlight to enter the wetland through every two adjacent panel rows. Hence the phytoplankton and zooplankton can grow naturally and easily. The wetland of Bangladesh is very much suitable for fish cultivation due to the availability of natural food ingredients for different fish species. The power plant will not create any obstruction or hinderance to local fish habitat and other fauna. Furthermore, the power plant will provide natural sanctuary to endangered fish species and conservation of extinct fish at Chalan Beel area of Bangladesh.

CONCLUSIONS

The design and techno-economic feasibility of a new type of large-scale solar power plant have been demonstrated. The study reveals that the 100 MW solar power plant can potentially generate 333,935 MWh renewable power per year. The total NPC of the 100 MW power plant has been estimated as US$ 96,358,875, the annualized cost is US$ 6,745,121 and the per-unit electricity production cost is US$ 0.0794. This per-unit cost is decent low compared to current average per-unit electricity cost generated from coal-fired or diesel engine-driven power plants in Bangladesh. Moreover, the proposed power plant will reduce the total amount of 164,706 tonnes of CO_2 emission compared to the coal-fired power plants and 60,681 tonnes of CO_2 emission compared to the gas-fired power plants. Moreover, the environmentally benign nature, the plant can be used as the permanent sanctuary for indigenous fish species that are in extinction list in Bangladesh. The plant will facilitate a new dimension of biodiversity conservation and environmental protection. For cost-effectiveness, eco-friendly nature, and biodiversity conservation perspectives, the proposed 100 MW solar power plant would be a beneficial for Bangladesh where the energy and plain land crisis is extreme.

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