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Original article

Techno-economic analysis and challenges of solar powered pumps dissemination in Bangladesh

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ABSTRACT

In this paper, the optimal conditions for solar photovoltaic (PV) irrigation have been identified by doing a technical and economic feasibility study for Bangladesh. The optimum system is found to be a lone PV system for irrigation load below 4 kWh/Day, and a hybrid system of PV-Generator-Battery for loads greater than 4 kWh/Day with storage tank having capacity lower than 20 kWh. Excess electricity fraction can rise up to 83.2% of the total production without adequate storage capability. Alternative use of this excess electricity has to be identified. The levelized COE can be as low as $0.182 with PV in operation only. Replacing a single 1 kW diesel pump with solar PV pump has an Internal Rate of Return (IRR) of 12.95%, simple payback period of 9.33 years, equity payback of 8.26 years, and benefit to cost ratio of 1.08. Net annual GHG reduction of the project is 0.9 tCO2. The present policy issues, and challenges for implementation of solar irrigation pump projects in Bangladesh are also discussed in this paper. Finally, positive outcomes and challenges are identified and recommendations are given to mitigate these challenges.

1. Introduction

Bangladesh is a developing country with agriculture as the vital component of the economy in terms of GDP and lifestyle. The rural economy contributes 60% of the GDP which mostly comes from the agricultural sector [1]. Around 45% of Bangladesh's work force is employed in agriculture [2]. Irrigation is an essential component of this agriculture. Proper irrigation at proper time increases the yield of crop significantly. Due to climate change and intensive agricultural practices of changing crops and cropping patterns the demand for irrigation water increased a lot [1]. Besides this, expansion of High Yielding Variety (HYV) rice cultivation increased the need for groundwater irrigation which is 73% of the total irrigation need [3]. Farmers spend a lot of money to ensure adequate and consistent water supply for their crops. A developing country like Bangladesh spends around $900 million per year for 1 million tons of diesel to power its irrigation systems [2]. To lower this huge cost of energy, associated carbon emission and to increase the renewable energy fraction in the energy basket renewable solutions like solar PV energy, wind energy or other type of renewable energy should be used. On the other hand, Solar PV powered pumps are a reliable and sustainable alternative to diesel powered pumps for farmers in a developing country like Bangladesh. Solar PV powered pumps help reduce costs, protect the environment, and also lower expensive diesel fuel imports.

Application of PV arrays for water pumping as an alternative to diesel engines were investigated by various researchers of the world [4–10]. Various technical works have been done by researchers to replace diesel powered pumps with solar PV pumps in Bangladesh [11–13]. However, most of these works are for demonstration and research purposes only.

The objective of this paper is to find the optimal condition for solar PV irrigation by doing a technical and economic feasibility study along with the present policy issues, challenges, and recommendations for Bangladesh. For this purpose a pre-feasibility study was done in HOMER to see the optimal condition to replace the diesel powered irrigation pumps with solar PV powered motor-pumps in Bangladesh. Than a detailed economic analysis is done with RETScreen software. The impact of government policy issues and involvement of various national and international organizations are also discussed. Finally, the challenges to implement solar irrigation pumps are analyzed along with their possible solutions.

2. Present irrigation scenario of Bangladesh

2.1. Pump types

There are three types of pumps used for irrigation purposes in Bangladesh. These are: Deep Tube Well (DTW), Shallow Tube Well

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(STW), and Low Lift Pump (LLP). Presently, in 2014–15 there were around 1,753,452 unit of irrigation pumps in operation among which 88.38% are STW and 2.09% DTW and 9.53% LLP [15]. The average elevation of Bangladesh from sea level is very low and static head of surface water is less than 20–30 m in most of the places [15]. This is the reason why STWs are most popular for irrigation in Bangladesh. Fig. 1 shows the present ground water depth in different areas of Bangladesh.

From the available data from Bangladesh Agricultural Development Corporation (BADC), Fig. 2 shows the number of irrigation pump units in 2012–13, 2013–14 and 2014–15 and their fuel mix. We can see that a huge portion of pumps are being run in diesel. From the official survey of BADC around 11,061,212 farmers are using irrigation water from a diesel run pump, whereas 6,647,045 are using water from an electricity run pump which is 40% lower than that of diesel run pumps [15]. This is a significant issue for the environment as well as economy of Bangladesh. Besides this, there is an increasing trend of irrigation water need which will increase significantly in the next upcoming years and satisfying this stepper demand with grid electricity will be quite impossible.

2.2. Energy scenario

Among fossil fuels, Bangladesh has only natural gas that is used in power generation in the country [16]. As on March 2016, according to Bangladesh Power Development Board (BPDB), Bangladesh has a total installed capacity of 12,229 MW and among which 62.76% of the total generation comes from natural gas [17]. Fig. 3, shows the total installed power capacity by fuel type for Bangladesh. A large amount of imported furnace oil is burnt to produce 21% of total power which emits a huge amount of CO_2 and other toxic gases. Besides this, the estimated reserve of natural gas which is around 3.89×10^{11} m^3, would meet the country's demand till 2015. After that there will be a shortage of gas supply which would rise to 1.252×10^8 m^3/day by 2025. Therefore an additional 2.36×10^{11} m^3 supply of gas is to be met by some other means [16]. Geographically, Bangladesh is a low-lying delta and has insignificant amount of hills and high water reservoirs. There is only a single hilly area situated in the southern part of the country and the only hydro power plant is situated there [17]. This plant gives only 230 MW which is only 1.99% of the total capacity and there is no other suitable location for anymore large hydro power plants. Every year Bangladesh is also providing a substantial amount of subsidies to power sector as shown in Table 1 [18]. The trend was also increasing from fiscal year (FY) 2010–2012. However, the Government kept the tariff of electricity for irrigation purposes as low as 3.82 Tk./unit which is equivalent to $0.05 approximately [17]. Even with this low tariff plan for irrigation, use of diesel powered pumps are 40% higher that that of electricity powered pumps.

2.3. Renewable resource availability

The requirement of irrigation for crops depends on mostly two factors- amount of rainfall and solar insolation. Bangladesh receives most of its rainfall (around 90%) in the monsoon from June to September as shown in Fig. 4. In the other months due to lack of rainfall crop production is hampered. So, the crops need to be irrigated from surface water in those months.

The effectiveness of solar powered irrigation pump mostly depends on the solar radiation received. Average insolation level for Bangladesh is pretty high which ranges from 4–5 kWh/day around the year. This ensures the potential of solar power harvesting for irrigation in Bangladesh [19]. Fig. 5 shows the 22 years average of monthly averaged daily solar insolation and clearness index of Dhaka city. On the other hand, wind energy is not feasible because the wind speed is not attractive in Bangladesh between December to May when around 70% of the irrigation is required [20].

3. Design optimization and feasibility studies

3.1. Optimization using HOMER

HOMER is a micropower optimization and simulation software developed by National Renewable Energy Laboratory (NREL), USA. The word HOMER came from the abbreviation of "Home Energy". It simulates the operation of a system by calculating energy balance equations for 8760 h in a year and compares the solutions with different possible configuration and finds the best possible and economically suitable solution [21].

3.1.1. Modeling the irrigation pump system in HOMER

Most of the diesel run pumps which have to be replaced are STWs. Usually, in Bangladesh the static head of ground water is not higher than 20–30 feet. Therefore the irrigation pump modeling is done for the case of STWs only. Irrigation water requirement is not a primary load which has to be met immediately, rather it can be deferred for a later time. Therefore, this load can be modeled as a deferrable load in HOMER. The load can either be DC or AC according to the type of the motor. Here, the deferrable load, PV arrays and a battery element is connected in the DC bus, and a diesel powered AC generator was added in the AC bus coupled with a converter to power the DC bus. The schematic diagram is shown in Fig. 6. Now we have to model the load and appropriate parameters of other system elements and run the simulation to find the optimum system.

3.1.2. Modeling the deferrable load

Irrigation for crops can be delayed for 1–3 days without any disturbance in the production process [14]. Therefore the load is assumed to be a deferrable load. The definition of a deferrable load is given in HOMER help index as "an electrical load that must be met within some time period, but the exact timing is not important" [22]. Loads are normally classified as deferrable because they have some storage associated with them. In irrigation system we can use a storage tank, pond or canals as the storage system for the deferrable load.

The average water requirement per hectare land for prime crops of Bangladesh are given Table 2 [23]. We can see from the table that most of the crops require irrigation in the dry winter season when there is ample sunlight.

A typical 1.1 kW solar STW pump has a flow rate of 55 LPM with 20 m water head [24]. So, at rated power the solar pump can lift 3300 lit/hour. One hectare of sample land were taken to irrigate. Therefore, taking these values and incorporating the amount of precipitation the monthly averaged daily water pumping load can be calculated as:

$$L_D = \frac{W_c - W_p}{30(F_p \times 60)} \quad (1)$$

where, L_D is the deferrable monthly averaged daily water pumping load (kWh/day), W_c is the monthly water need for crops (lit/month), W_p is the monthly averaged precipitation (lit/month), and F_p is the flow rate of the pump (lit/min or LPM).

As the time of rainfall over the year is uncertain so 0.5 kWh/day load was added for supplementary irrigation need during May – September. Fig. 7 shows the monthly averaged daily load profile of our deferrable load as used in this study. As the irrigation need