Original Research Article

A techno-economic viability analysis on grid integration of solar irrigation pumps in Bangladesh: prospects and challenges

A B S T R A C T

Irrigation is an important area of Bangladesh where most cases it depends on fossil fuels either diesel-powered irrigation systems or grid electricity-operated irrigation systems. Solar irrigation is an alternative way to promote clean energy in the irrigation sector which is in line to achieve the Sustainable Development Goals (SDG). Techno-economic viability of solar irrigation is an important issue to make acceptable to the farmers or end users. The government of Bangladesh published a dedicated grid integration guideline for solar irrigation pumps (SIP) as an alternative option to make the business viable of solar irrigation pumps. Interested solar irrigation pump operators can take this facility by adding grid integration-related connections and additional equipment to their projects to supply surplus electricity into the distribution grid after irrigation uses. This paper analyzes the grid integration-related integration costing and surplus electricity pricing to understand the techno-economic viability of grid integration of solar irrigation pumps. According to the analysis result, higher-capacity solar irrigation pumps are financially viable for grid integration up to a certain distance. Also, this study gives a financial viability analysis of the combined grid integration of multiple SIPs.

Highlights:

- Grid integration of solar irrigation pumps in Bangladesh
- Techno-economic viability analysis of SIP grid integration
- Opportunity and challenges of SIP grid integration
- Promotion of clean energy for irrigation purposes

Keywords: Solar Irrigation, Grid Integration, Techno-economic viability, Alternative use of solar irrigation pumps

1. Introduction

Electricity is essential for socioeconomic progress and the improvement of people's living standards [1]. The government of Bangladesh is committed to bringing all the citizens of the country under the power facility and it was achieved in the year 2022. The Ministry of Power, Energy and Mineral Resources has adopted energy diversification as one of the strategies aimed at providing universal access to electricity and ensuring energy security [2]. Under energy diversification, steps have been taken to generate environmentally-friendly electricity from conventional fossil fuels as well as renewable energy [3]. A significant increase in the use of renewable energy is one of the goals of the United Nations Sustainable Development Goals (SDG-6) [4]. The Bangladesh Renewable Energy Policy’2008 has set a target of generating 10% of the total electricity from renewable sources [5].

Agriculture is an important sector of Bangladesh's economy and it is one of the driving forces of economic growth in Bangladesh [6]. The contribution of agriculture to GDP is 13.47% in the FY 2020-21 [7]. The government promotes various technologies as a priority to meet the growing demand for food and agricultural products [8]. Irrigation plays an important role in the agriculture of Bangladesh as it is located in the tropical region. Irrigation accounts for approximately 43% of agricultural expenditure [9]. Solar-based alternative energy sources will ensure food security and reduce carbon-dioxide emissions from inefficient diesel-based irrigation systems. Solar-powered irrigation is an Economical and eco-friendly solution for farmers [10].

At present, there are about 3.75 lakh electric-powered irrigation pumps in the country which require about 2000 MW of electricity in the summer season. In addition, about 13.4 lakh diesel-powered irrigation pumps (DTW-3000, STW-12 lakh, LLP-1.4 lakh) are being used for irrigation in 34 lakh hectares of land in the country [11]. The government aims to replace diesel-powered pumps with solar pumps, which would significantly reduce the use of fossil fuels in the irrigation sector [10], [11]. Solar-powered irrigation pumps have higher initial costs (the retail price of technology) compared to diesel pumps, but lower O&M costs in the long run, offering higher reliability than diesel generators [12], [13]. Combined planning and policy incentives for water, energy and food can bring the success of solar irrigation but the sector still depends on the subsidy [12], [14]. On the other hand, considering the electrically operated pumps, expansion of the electricity line has a cost and it depends on the distance between the electricity source and the project site, assessed for Iran compared with the life cycle cost of solar-powered irrigation pumps [15]. But in Bangladesh, the access to electricity scenario is different than in Iran. Overall, solar irrigation pumps are more popular in diesel irrigation-based areas rather than in grid electricity-powered irrigation areas as grid electricity is highly subsidized for irrigation. Most of the SIPs are installed in the Rangpur division, Rajshahi division and northern part of the Khulna division of Bangladesh [16]. Still, there are some practical challenges to implement solar irrigation pumps like over degradation of solar modules, operation and maintenance on due time, etc. that need to be addressed as well [17], [18].

Installed solar irrigation systems remain unused for more than half of the year after the irrigation period. Alternative use of water and electricity can make the projects more profitable after fulfilling the primary objective of the project. 14 factors have been identified in the paper [19], which together determine, whether the use of SIPs in any given context would be economically, socially, and environmentally sustainable. The use of a larger water storage tank and alternative use of electricity especially for other agricultural energy needs have been recommended in the papers [20], [21]. Grid integration of solar irrigation is one of the alternative use that was facilitated by the government through policy incentives. It could be done in Bangladesh by following the “Guidelines for the grid integration of solar irrigation pumps-2020” or “Net metering guideline-2018” [11], [22].

This paper analyzes the techno-economic viability of grid integration of solar irrigation pumps in Bangladesh including its prospects and challenges. Such assessment is not yet done by others after publishing the grid integration guideline in Bangladesh.

2. Methodology

Techno-economic viability analysis for different aspects of SIP grid integration is the objective of this study. To do this, the policy directives and opportunities published by the government of Bangladesh have been discussed first. The present scenario of solar irrigation in Bangladesh is also discussed with it. A piloting result of a case study site has been analyzed to understand the scenario of solar energy requirement for irrigation use and the possibility of surplus electricity feeding to the distribution grid. Additional arrangements for SIP grid integration and its cost have been discussed after that. Finally, a cost-benefit analysis has been conducted for different types of grid integration (Single phase or Three phases, etc.) with different integration distances for different capacity SIP projects. A combined SIP grid integration analysis has been conducted for the case study site and its nearest SIPs. Electricity tariff order 2022 and previous tariff-increasing trends have been considered for this analysis. Finally, the study gives a conclusion on it according to the objective of this study.

3. Guidelines of the Government

The solar irrigation systems installed in the country remain unused for more than half of the year (depending on the crop patterns of the area), from which it is possible to further expand the solar irrigation system by making the projects more profitable through proper use of productive electricity or water. To facilitate this, grid integration is an alternative use of electricity from solar irrigation pumps. The government of Bangladesh published some guidelines to promote the grid integration of solar irrigation that are discussed below.

3.1. Guidelines for the grid integration of solar irrigation pumps-2020

The use of solar irrigation pumps needs to be encouraged instead of grid electricity-operated pumps. Moreover, there is a risk of entrepreneurs becoming disinterested in the maintenance and repair of solar systems if import and export options are available with grid integration. As a result, solar irrigation may be discouraged. The government of Bangladesh published separate guidelines titled *‘Guidelines for the Grid Integration of Solar Irrigation Pumps-2020’* to encourage solar irrigation considering all the issues.

Encouraging the alternative use of electricity and water in the extra time of irrigation from solar irrigation systems is important. As a part of such alternative uses, the government of Bangladesh is providing opportunities to export electricity to the distribution grid by following the mentioned guidelines. The salient features of these guidelines are as follows:

a) An irrigation entrepreneur does not have to be a consumer of the power distribution utility, he/she will be considered a Small IPP producer;

b) SIP operator does not have to pay any demand charge every month;

c) If there is no three-phase power supply line within the specified distance of the irrigation pump area, the SIP operator will be able to do single-phase grid integration;

d) SIP operator cannot import electricity for use in load, he/she can only export electricity;

e) SIP operators can only receive a maximum of 1 kWh of electricity per month for each kilowatt AC-approved system capacity, just to keep the system running;

f) There are fines and line cuts for using more electricity per month than the permitted limit;

g) Determine the capacity of the solar irrigation system in such a way that it is enabled even during peak irrigation;

h) The entrepreneur will get the price of exported electricity at the 33 kV bulk rate of the respective electricity distribution utility, which he/she can get every month.

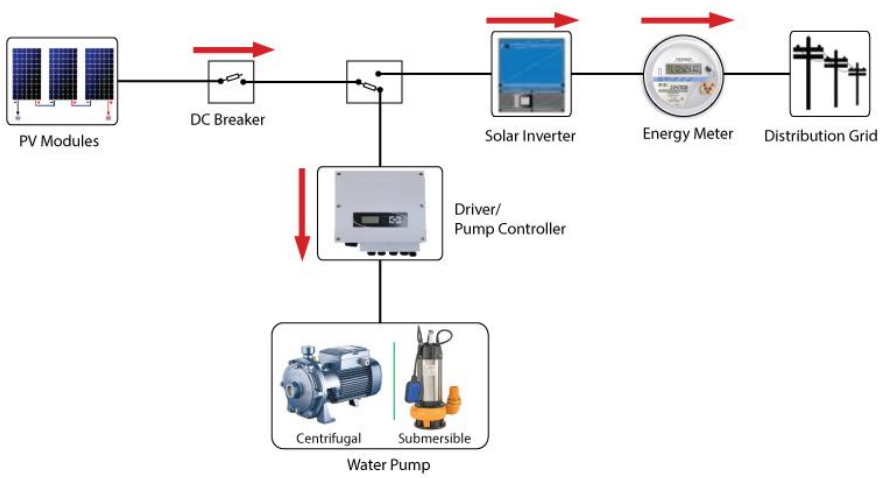

Figure 1: Connection diagram according to the SIP grid integration guidelines

Figure 1 represents a connection diagram according to the mentioned policy “Guidelines for the grid integration of solar irrigation pumps-2020”. The series combination of PV modules creates a string and a parallel combination of strings creates an array. The number of arrays will depend on the capacity of the pump, pump controller and their configurations which may be single or multiple. According to the connection diagram, any array of a SIP will be either connected with a pump controller or grid-tied inverter. It is the operator's choice with having the necessary configuration so that they can forward some arrays to the pump controller and some arrays to the grid-tied inverter. In that case, partly electricity will be used for water lifting with reduced capacity and the rest of the array's electricity will be exported to the grid. If they did not have such array wise changeover system then they can use their PV module either for water lifting or for exporting electricity to the grid at a time. Grid-tied inverters and other grid-connected equipment have some negligible self consumptions from the grid that will be adjusted every month with the exported electricity. A bi-directional energy meter will be used with this grid integration connection. The only export sign is provided on the energy meter in **Figure 1** as import is negligible and not focused on this purpose.

3.2. Net metering guidelines-2018

Through the first amendment of '*Net Metering Guidelines-2018*', the category of irrigation electricity consumers has also been included in the Net Metering facility. As a result, net metering can be done by installing a solar system on the roof of the existing grid electricity-driven irrigation pump house and surroundings if desired. Similarly, in the case of the arrival of grid electricity in the solar irrigation area, the solar irrigation entrepreneur will be able to do net metering by adopting a three-phase connection. As a result, in addition to solar irrigation during the day, they will be able to irrigate with electricity from the grid at night if required. They will earn credit by exporting the electricity generated during the remaining days except for irrigation time which will be adjusted later during irrigation or at the end of the settlement period. Pump controllers available in the market are capable of receiving both AC and DC inputs and generally operate the pumps through Variable Frequency Drive (VFD) technology. The salient features of this guideline are as follows:

a) There should be a three-phase power connection in the area of the irrigation pump;

b) They must be a three-phase power consumer of the respective power distribution utility;

c) Demand charges have to be paid every month to the distribution utility against its sanctioned load;

d) They can both export and import electricity;

e) They will be able to manage irrigation with electricity from the grid at night during peak irrigation time. Therefore, no need to oversize the solar irrigation system for the peak irrigation period.

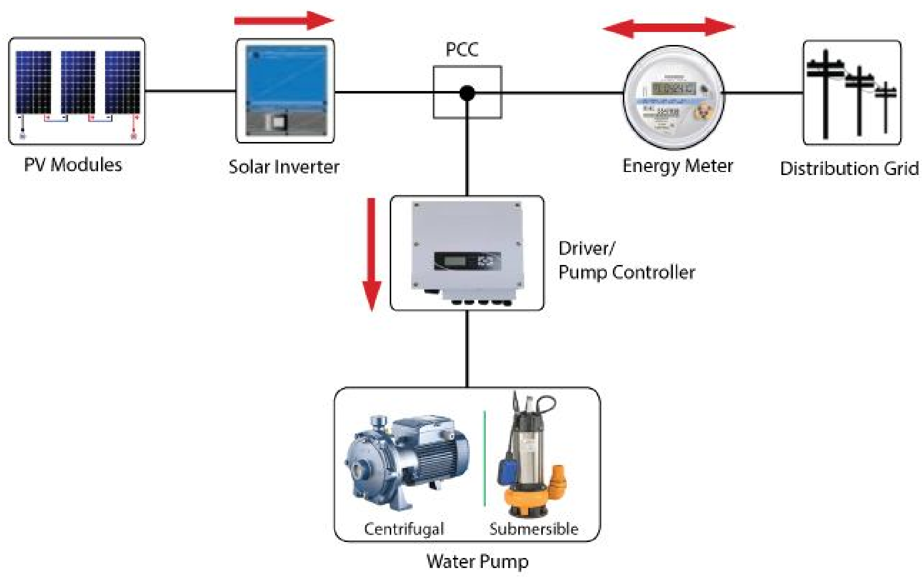

Figure 2: Connection diagram according to the Net Metering Guidelines

Figure 2 represents a connection diagram according to the mentioned policy *"Net metering guidelines-2018"*. In this figure, the output of the solar inverter, grid electricity connection and input of the pump controller are merged in a point represented by the Point of Common Coupling (PCC). Electricity export or import will be occurred automatically based on the demand of the pump controller and the supply of solar power at the PCC. But one major challenge, the system can not able to operate for irrigation in absence of the grid electricity. Technically it can be solved by a bypass connection if their pump controller has a DC input option to connect PV arrays directly, where grid absence time is huge.

3.3. Related policy and targets of the government

The government of Bangladesh published Power System Master Plan 2016 in which domestic renewable energy power generation (cumulative) has been projected as 2,470 MW by 2021, and 3,864 MW by 2041 *[PSMP 2016, Page 1-61]*[23]. In 2015, the United Nations adopted the Sustainable Development Goals (SDGs) as a new development target up to 2030. Goal 7 of SDGs is "*Affordable and clean energy. Ensure access to affordable, reliable, sustainable and modern energy for all*". The 8th FiveYear Plan of Bangladesh also focuses on inline SDGs Goal 7 by maximizing the use of renewable energy and energy trade. The target will be achieved by an efficient least-cost production, in the long run with a transmission and distribution system. A total of 2014 MW of Solar power has been targeted in the 8th five-year plan period from the year 2021 to 2025, on which solar irrigation is one of the components [24]. The Nationally Determined Contribution (NDC) mitigation actions will help to limit the country's GHG emissions and play its role in global efforts. In the unconditional scenario, GHG emissions would be reduced by 27.56 Mt CO_2e (6.73%) below Business As Usual (BAU) in 2030 in the respective sectors in which 26.3 Mt CO_2e (95.4%) emission reduction will be from the Energy sector. In the conditional scenario, GHG emissions would be reduced by 61.9 Mt CO_2e (15.12%) below BAU in 2030 on which 59.7 Mt CO_2e (96.46%) emission reduction will be from the Energy sector [25]. Although Solar irrigation can play an important role to achieve the energy sector's NDC target, a good business case is essential for the wider promotion of SIP.

4. Present Scenario of Solar Irrigation in Bangladesh

Bangladesh Rural Electrification Board (BREB), has introduced the first solar project in Bangladesh through their Solar Home System (SHS) pilot project in 1993. The project was funded by France. After that BREB installed 40 SIPs in Bangladesh on a pilot basis which was very much early stage [26]. Recently BREB has taken initiative to implement the 2000 SIP project in a commercial model including a grid integration facility as an alternative use of additional electricity. The Infrastructure Development Company Limited (IDCOL), a state-owned financing institution in Bangladesh, has taken initiative to install SIP in Bangladesh by involving private sector entrepreneurs. Their first SIP project achieved commercial operation in 2010 which is located at Sapahar Upazila, Naogaon district of the country. Bangladesh Agricultural Research Institute (BARI), a research organization under the ministry of agriculture of Bangladesh, initiated a SIP research project in 2010 with the support of the World Bank. Similar to another research SIP project has been initiated by the Rural Development Academy (RDA) in 2013. The Bangladesh Rice Research Institute (BRRI) initiated its activities in 2018 and Bangladesh Academy for Rural Development (BARD) initiated its activities in 2021 [27].

The 'Bangladesh Agricultural Development Corporation (BADC)', 'Barind Multipurpose Development Authority (BMDA)' and 'Department of Agricultural Extension (DAE)' are responsible organizations in Bangladesh for irrigation and have taken initiative to implement solar irrigation projects in Bangladesh. They use a community-based model where SIP systems are subsidized by the government and the farmer community pays a significant amount to be used for the operation and maintenance of the SIP in the project life. The commercial model of IDCOL is operated by private sector entrepreneurs with 50% grant support from government and international development partners. Under this model, the SIP installation progress is the maximum in terms of cumulative capacity in MWp. The model was initiated by comparing it with the existing diesel-based irrigation system and the model was lucrative for the farmers. Now access to electricity in Bangladesh has officially been declared 100% and the irrigation electricity consumer class is highly subsidised. Therefore, SIP is not lucrative to the farmers compared with the subsidized grid electricity-operated irrigation pumps and the growth rate of SIP installation decreases significantly [28]. The organization-wise SIP installation progress in Bangladesh is shown in **Table 1**, given below.

Table 1: Organization-wise SIP installation status up to December 2022[29]

Organization	Quantity	Installed Capacity
IDCOL	1523	42.08 MWp

BMDA	792	4.37 MWp
BADC	187	2.43 MWp
DAE	40	340 kWp
BREB	150	1.2 MWp
RDA	25	292 kWp
BARD	9	99 kWp
BRRI	9	25.68 kWp
BARI	37	51 kWp
Total	**2772**	**50.89 MWp**

According to the installation statistics of SIPs in Bangladesh, it was observed that prospects for SIP were not the same all over the country [28]. The geographical area-based scenario of SIP installation in Bangladesh has been reflected in **Figure 3**. It was displayed that most of the SIPs were installed in the Rajshahi and Rangpur divisions of Bangladesh and some are in the northern part of the Khulna division. SIP installation in the rest of the area of Bangladesh was not significant till now.

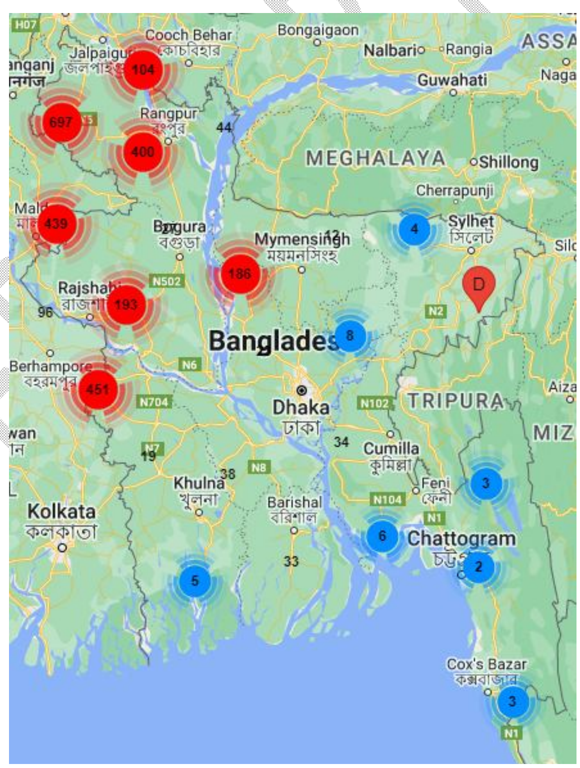

Figure 3: Area-based SIP installation scenario in Bangladesh

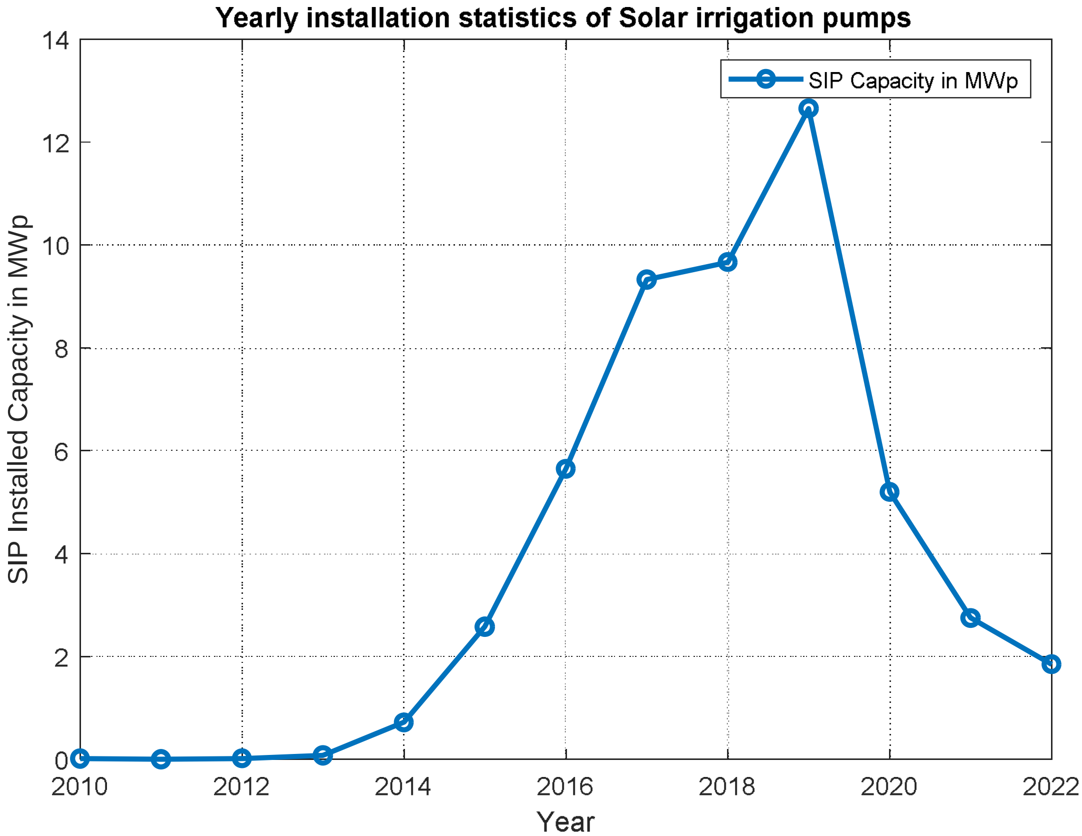

Figure 4: Yearly SIP installation scenario in Bangladesh[30]

The SIP installation scenario has been reflected in **Figure 4** on yearly basis. Before the year 2014, the SIP installation rate was very low. It can be treated as the initial and learning phase of SIPs in Bangladesh. After the year 2014, the yearly SIP installation amount increased significantly up to the year 2019. After the year 2019, the SIP installation amount was decreasing. The year 2022, the last year in **Figure 4**, is lower than the installation amount of the year 2015. The main reason is the comparative cost-benefit analysis between SIP and electricity-operated irrigation pumps where electricity-operated irrigation pumps are cheaper and preferable to the end users like farmers. It is essential to revisit the business models of SIP for Bangladesh to make it more popular than grid electricity-operated irrigation pumps where alternative use of water and electricity may play a vital role. Grid integration of solar irrigation is one of the alternative use of SIP to achieve the goal.

5. A case study for grid integration

5.1. Description of an existing solar irrigation pump

The country's first piloting of SIP grid integration was done on 4th November 2019 at Kalinathput village, Mirpur Upazila of Kushtia district, Bangladesh. The latitude and longitude of the site are 23.859384, 89.000207. The additional grid integration components and interconnection facility were developed in an existing 24.45 kWp solar irrigation project operated by Bright Green Energy Foundation (BGEF).

Figure 5: First SIP grid integration piloting site in Bangladesh

5.2. Results after grid integration

The primary use of the solar irrigation project is water lifting for irrigation purposes whose amount is dependent on the crop pattern of the project area. One year's power generation statistics have been recorded for the grid integration viability analysis. In the year 2020, the total solar energy production from the system (January 2020-December 2020) was 25,501 kWh. Out of this total solar energy production, 15,992 kWh was used for irrigation purposes and 9,509 kWh of electricity has been exported to the distribution grid via the newly introduced grid integration facility. The surplus electricity of the mentioned project for the year 2020 was around 37% of the total electricity produced from the solar irrigation project. This amount may be different in different places in the country based on the irrigation crop type, regional soil characteristics, weather conditions, etc. The monthly energy statistics of the project are shown in **Table 2** below.

Table 2: Monthly energy statistics of the SIP grid integration piloting site for the year 2020

Condition/Month	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Annual
Grid Feed (kWh)	670	612	1371	201	721	1000	1105	311	538	1640	837	503	**9509**
Self-Consumption (kWh)	11.92	10.93	10.71	12.57	10.46	7.81	10.51	12.46	11.92	10.85	10.38	11.65	**132**
Used for irrigation (kWh)	1872	1389	1481	2559	650	0	1034	1549	2000	1064	1235	1159	**15992**

According to the information in **Table 2**, the capacity-based generalized figure has been developed as follows. The grid feed rate is 389 kWh/kWp/year, the Irrigation use rate is 654 kWh/kWp/year and the Self-consumption rate from the grid is 5.4 kWh/kWp/year whereas the total power generation rate from the solar irrigation system was 1043 kWh/kWp/year. A monthly comparative statement for irrigation use and grid feed is shown in **Figure 6** below.

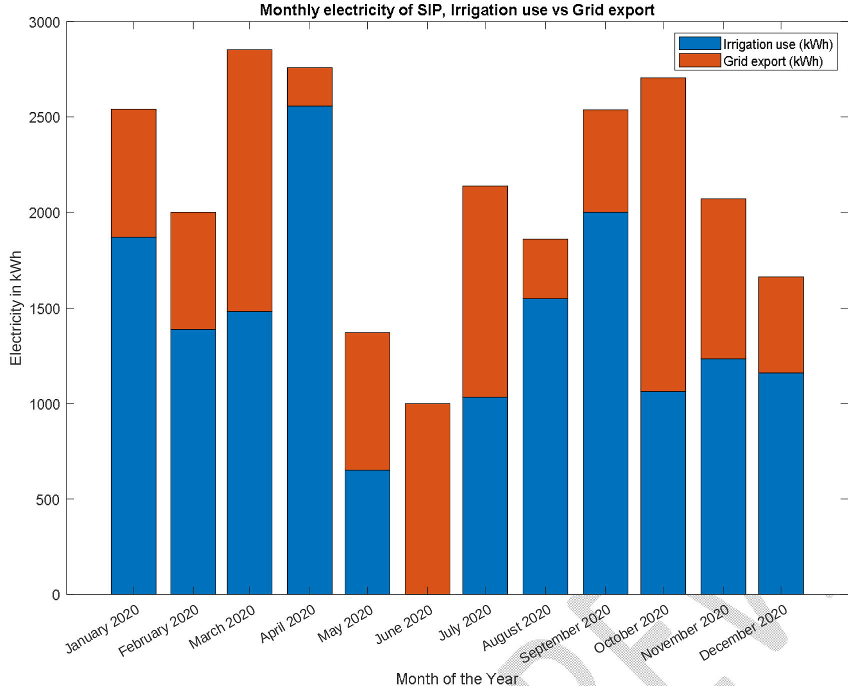

Figure 6: Comparative energy review for Irrigation use vs Grid export

5.3. Additional requirements for grid integration

The SIP entrepreneurs can take the initiatives to make grid integration for their solar irrigation project and apply for it to the nearest electricity distribution utilities under any related policy. The utility will give initial integration approval after inspecting the basic conditions. SIP entrepreneurs will arrange the necessary technical interconnection facility. Such an interconnection facility has main two parts where one is inside the SIP project area and another part is the transmission line arrangement to the nearest connection point. According to **Figure 1**, the required remarkable components inside the SIP project areas are Grid-tied inverters (single-phase or three phases based on the connection requirement), bidirectional energy meter (whole current or CT operated based on the SIP capacity), connecting wire, circuit breaker, etc. The other part is the transmission line arrangement that depends on the individual SIP or aggregated SIPs capacity, the voltage level of the available nearest utility line, and the feeding capacity of the proposed interconnection. The category-wise tentative expenditures for the said arrangements are given in **Table 3** below.

Table 3: Category-wise tentative expenditure for transmission line arrangement

Low Tension (LT) single-phase integration (230V)	**Inverter Cost:** 20 Thousand BDT/kW **Pole and supporting materials cost:** 17 thousand BDT/pole, P-P distance is 46m **Cable cost:** 71 BDT/m for 10kW, 100 BDT/m for 20kW
Low Tension (LT) three-phase integration (400V)	**Inverter Cost:** 15 Thousand BDT/kW for 10kW, 12 Thousand BDT/kW for 20kW, 10 Thousand BDT/kW for above. **Pole and supporting materials cost:** 22 thousand BDT/pole, P-P distance is 46m **Cable cost:** 147 BDT/m for 21kW, 276 BDT/m for 60kW
Medium Tension (MT) single-phase integration (6.36kV)	**Inverter Cost:** Same as LT 1φ **Pole and supporting materials cost:** 28 thousand BDT/pole, P-P distance is 70m **Cable cost:** 65 BDT/m
Medium Tension (MT) three-phase integration (11 kV)	**Inverter Cost:** Same as LT 3φ **Pole and supporting materials cost:** 38 thousand BDT/pole, P-P distance is 70m **Cable cost:** 130 BDT/m
High Tension (HT) three-phase integration (33kV)	**Inverter Cost:** Same as LT 3φ **Pole and supporting materials cost:** 38 thousand BDT/pole, P-P distance is 60m

	Cable cost: 240 BDT/m

The Cable, circuit breaker and wiring inside the project area are needed to be taken into consideration. The cost of the energy meter is approximately BDT 20000 for each site but CT-PT costing will be added for 11kV or 33kV metering which is around 2.7 Lac BDT. The transformer and its associated cost (Lightning arrester, Fuse, Pole grounding, transformer hanger, etc.) will be added for MT and HT grid integration. The current market price for single-phase transformers are 35000 BDT for 5kVA, 55000 BDT for 10kVA, 70000 BDT for 15kVA, 1.0 Lac BDT for 25kVA, 1.2 Lac BDT for 37.5kVA, 1.7 Lac BDT for 50kVA. The current market price for three-phase transformers is 2.2 Lac BDT for 75kVA, 3.25 Lac BDT for 100kVA, and 5 Lac BDT for 200kVA. Insulators, cross arm, etc. will be added with transmission line construction.

The lifetime of the transformer, pole and conductor is more than 20 years which will cover the full project period of SIP grid integration. The grid-tied inverter, energy meter, circuit breaker etc components inside the SIP project area may need to be replaced once in the project life and here it is considered in the eleventh year.

6. Results and Discussion

The three-phase grid integration will be prioritized according to the SIP grid integration guidelines of the government. However, single-phase integration will be allowed only when the 3 phase utility network is not available in the nearest locations. Therefore, five categories have been considered according to the voltage level and number of phases. Category-wise grid integration costing is reflected in the y-axis of the following figures. All SIP integration calculations have been done on 7 distances, which are 20m, 50m, 100m, 200m, 500m, 1000m and 2000m. It is represented on the x-axis in the following figures. Capacity-wise earnings from grid feed electricity are also calculated and reflected in the y-axis to understand the comparison between investment and return of the SIP grid integration. The four levels, 5 years, 10 years, 15 years and 20 years have been displayed in the figures. 20% increment of Bulk tariff after every 3 years has been considered as the tariff increment. 0.8% solar module degradation has been considered where the first year's degradation will be 2% and the rest of the year's degradation will be 0.8%. All expenditures and returns have been calculated in the present form considering the 6% discount factor and plotted accordingly. The thickness of the plotted line represents the integration voltage level where the thinnest 2 lines represent the Low Tension (LT), the medium 2 lines represent the Medium Tension (MT 11kV) and the thick one line represents the High tension (HT 33kV). The capacity-based four SIP grid integration scenarios have been calculated which are 10kWp, 20kWp, 30kWp and 40kWp. These analysis results are presented in the following **Figure 7**, **Figure 8**, **Figure 9**, and **Figure 10**.

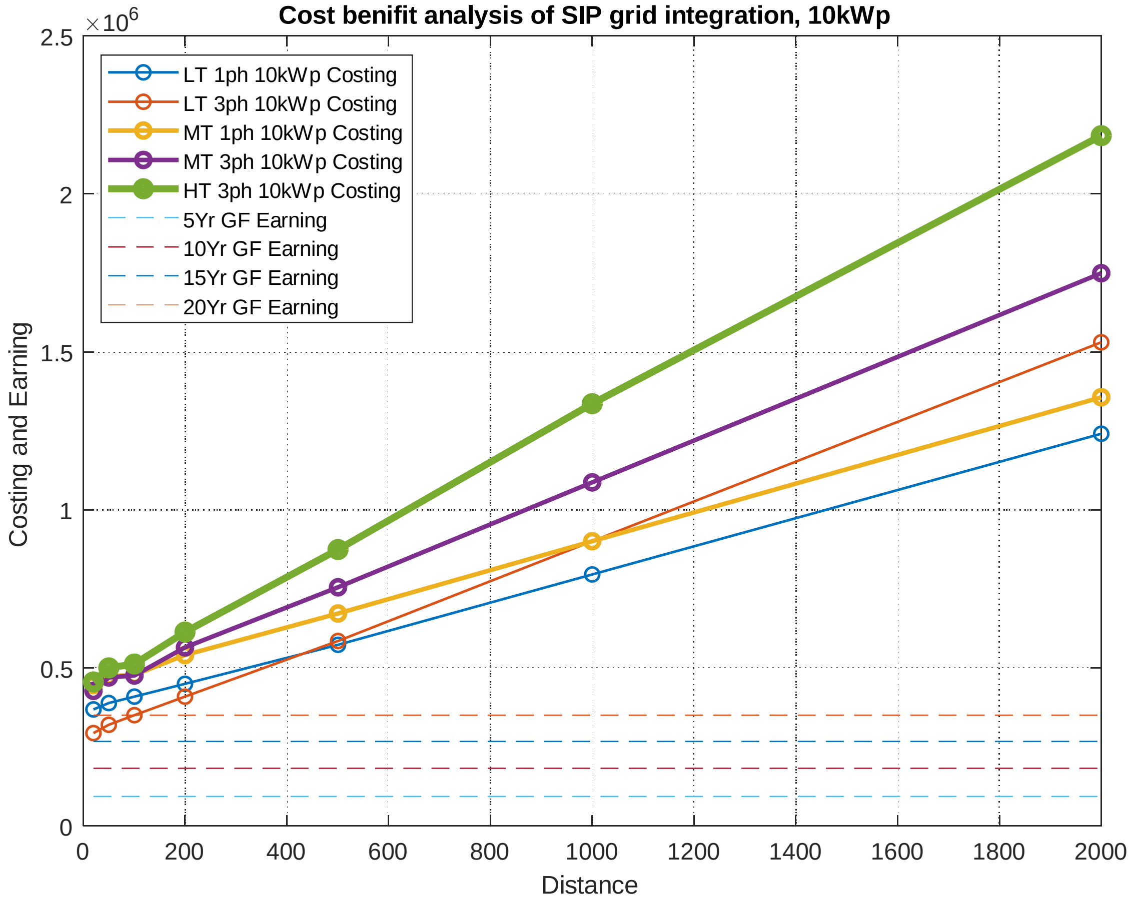

Figure 7: Cost-benefit analysis of a 10kWp SIP grid integration

Figure 7 is the representation of a 10kWp SIP grid integration at which only LT 3phase grid integration is financially viable only up to around 100m distances. The payback period of this integration is 15 – 20 years based on the integration distance. The rest of the integration criteria are not financially viable due to the high expenditures compared with the return values. Also in terms of technical suitability, LT integration is not performed well at a larger than 400m distance.

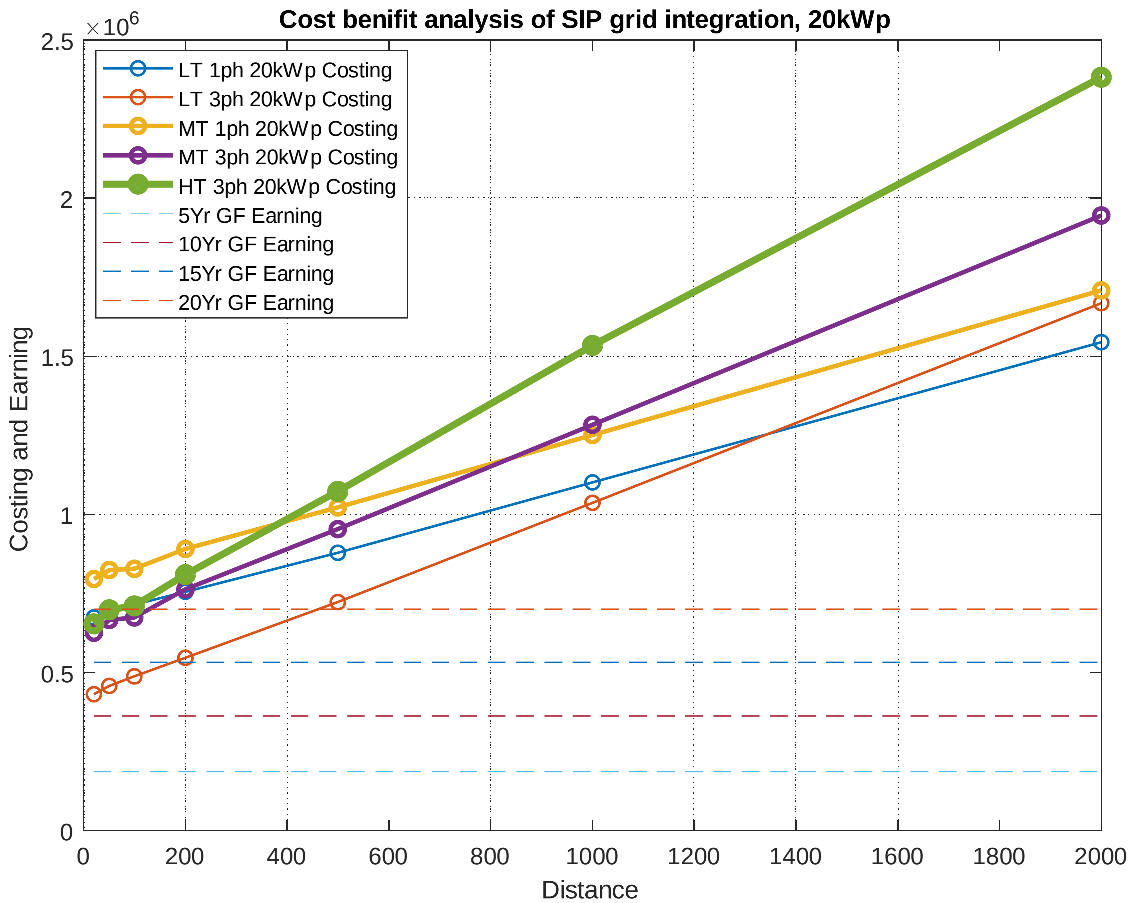

Figure 8: Cost-benefit analysis of a 20kWp SIP grid integration

Figure 8 is the representation of a 20kWp SIP grid integration where it is observed that single-phase grid integrations are not a financially viable solution. Only LT 3phase grid integrations are financially viable up to 450m and the few are financially viable only for a few meter distances. It is noted that transformer cost is not included with this LT 3phase grid integration and practically it is scarce due to the unavailability of transformers close to the irrigation areas.

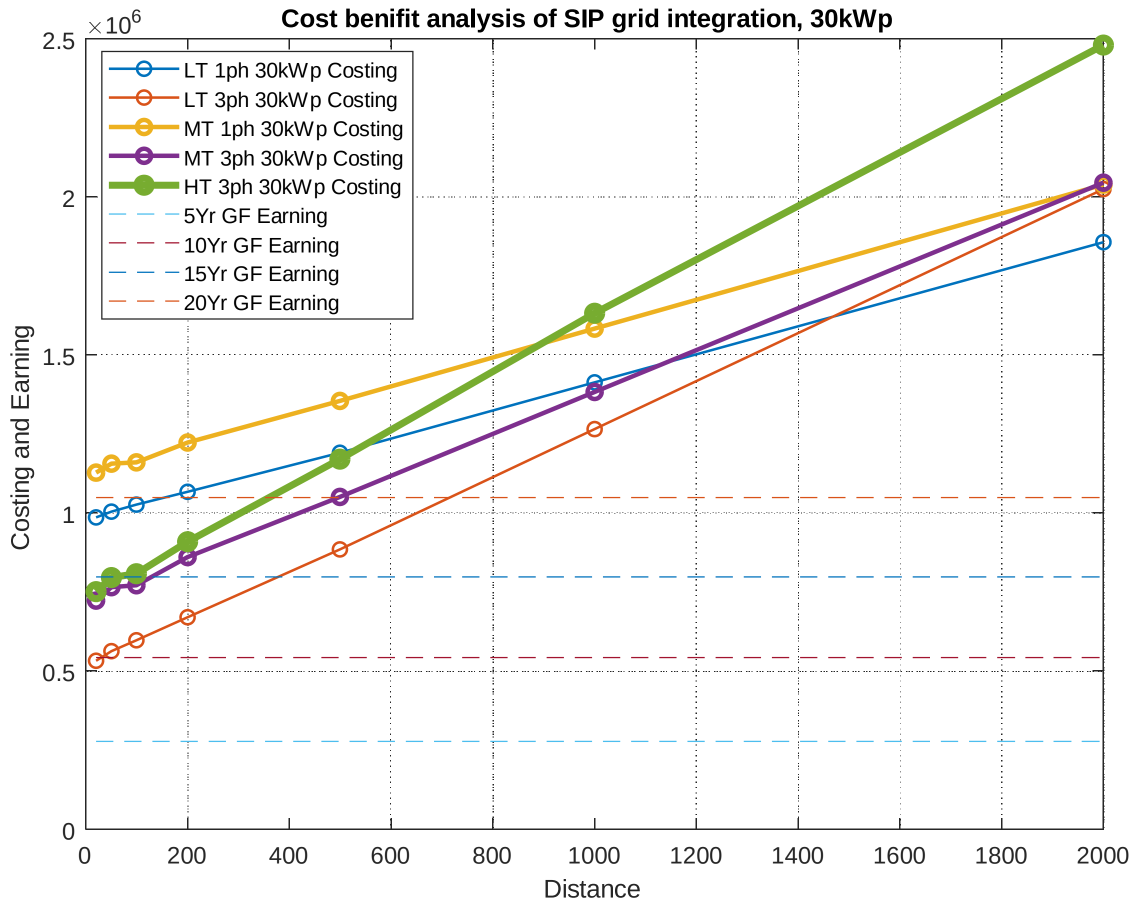

Figure 9: Cost-benefit analysis of a 30kWp SIP grid integration

Figure 9 represents the result of a 30kWp SIP grid integration. MT 3phase and HT 3phase integrations are in a good position compared with the previous figures. According to **Figure 9**, MT 3phase integration is financially viable up to the 500m distance and HT 3phase is financially viable up to the 400m distance. Payback starts after year 13.

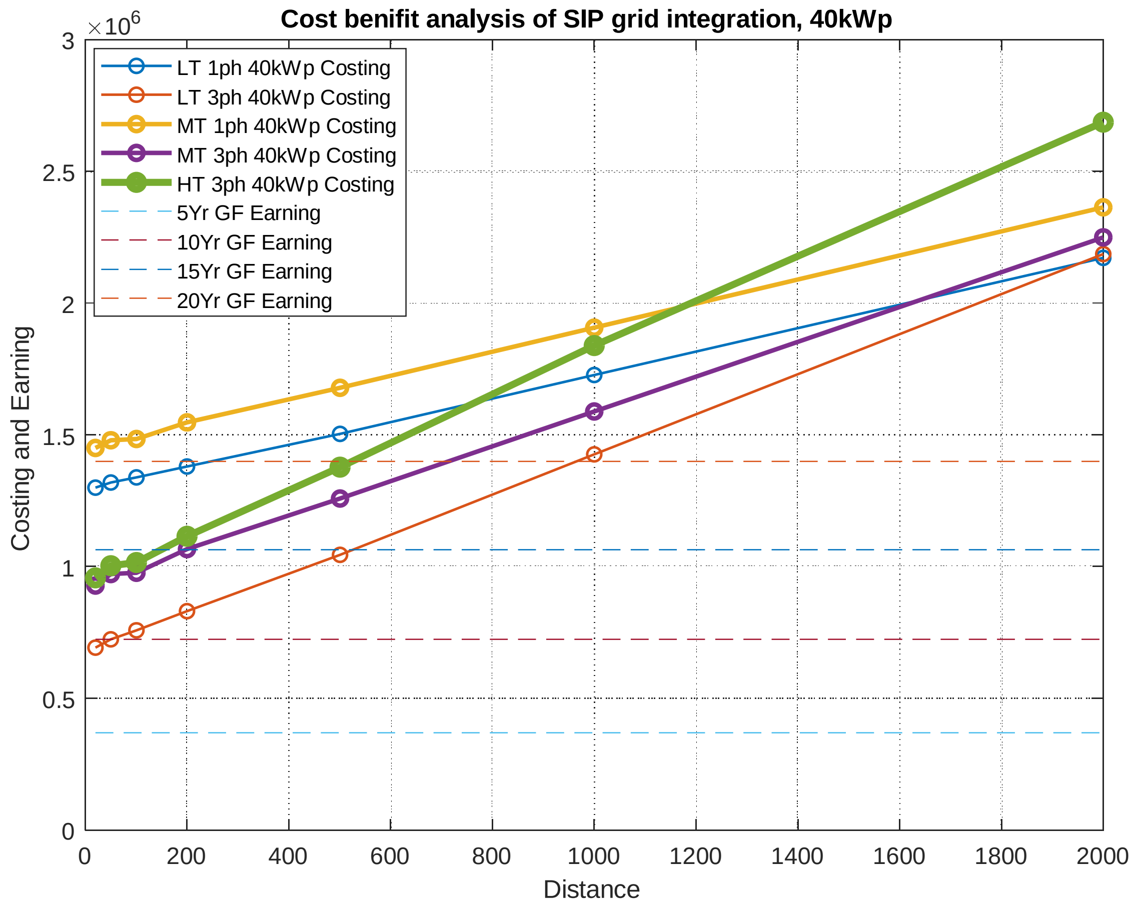

Figure 10: Cost-benefit analysis of a 40kWp SIP grid integration

Figure 10 represents the result of a 40kWp SIP grid integration. MT 3phase and HT 3phase integrations are also in a good position among all figures. According to **Figure 10**, MT 3phase integration is financially viable up to the 750m distance and HT 3phase is financially viable up to the 550m distance. Payback starts after year 13. Based on the four capacity scenarios, larger capacity systems are financially good positions for SIP grid integration. There is another scope in the policy to use combined grid integration for multiple SIP. A case study is described in **Figure 11** below.

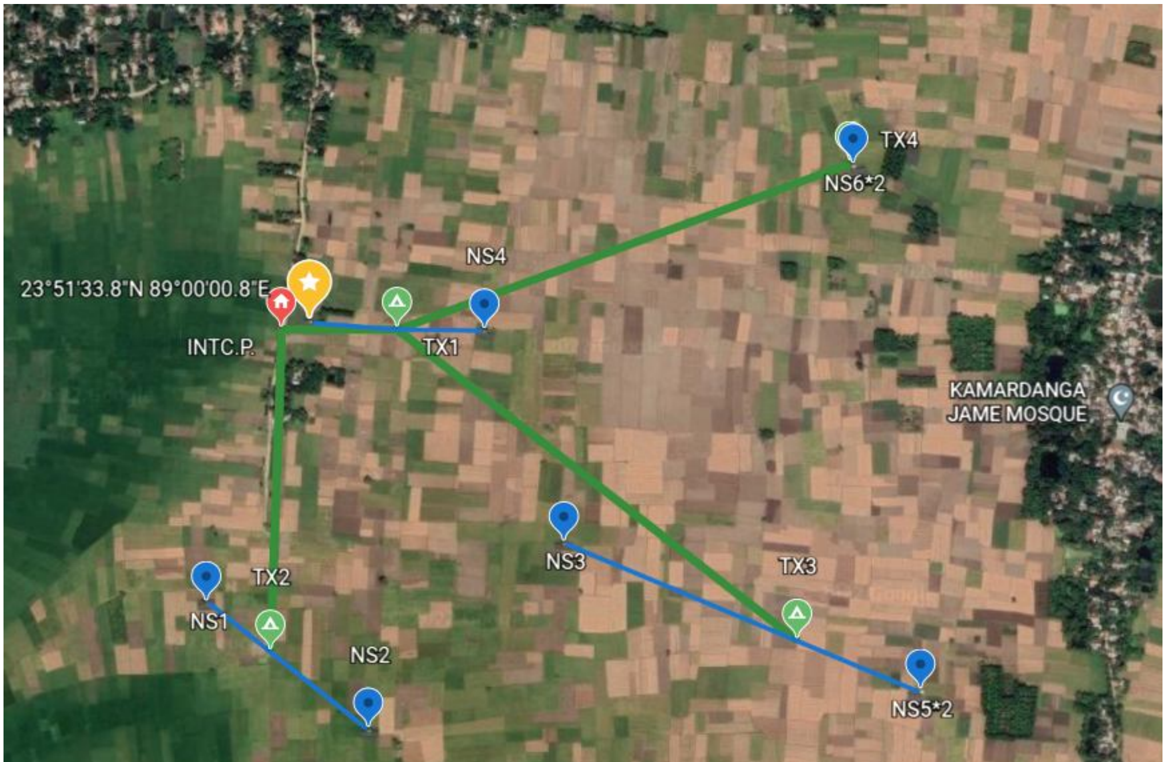

Figure 11: Prospect analysis of a combined SIP grid integration

Figure 11 is a scenario analysis for a combined SIP grid integration. The yellow marked point is the piloting SIP grid integration site mentioned in section 5. There are some other SIP sites close to the pilot site that are marked as Nearest Site (NS)-1, NS2, NS3, NS4, NS5 and NS6. The capacity of the sites NS5 and NS6 are around double that of the pilot site and the rest are similar to the pilot site. To make the combined grid integration of a total of 7 SIP sites, the 4 green points have been proposed for transformer locations. The green lines represent the MT 11kV 3phase transmission lines and the blue lines represent the MT 0.4kV 3phase transmission lines to connect the sites for grid integration. The red-marked point is the combined integration point with the utility system. Connected line distances are measured and mentioned in **Table 4** below.

Table 4: Voltage level-wise interconnection distances for combined grid integration

LT 0.4kV Interconnections			MT 11kV Interconnections		
Name	Interconnection Points	Distance (m)	Name	Interconnection Points	Distance (m)
LT1	TX1 – Pilot Site	130	MT1	INTCP – TX1	178
LT2	TX1 – NS4	130	MT2	INTCP – TX2	495
LT3	TX3 – NS5	200	MT3	TX1 – TX3	780
LT4	TX3 – NS3	385	MT4	TX1 – TX4	750
LT5	TX2 – NS1	120			
LT6	TX2 – NS2	190			
Total		1155	Total		2203

Considering the SIP capacity of NS5 and NS6 are 40kWp and the rest sites are 24kWp, the capacity of four proposed transformers TX1, TX2, TX3 and TX4 will be 48kVA, 48kVA, 64kVA and 40kVA respectively.

The analysis result of the cost-benefit scenario is given in **Figure 12** below.

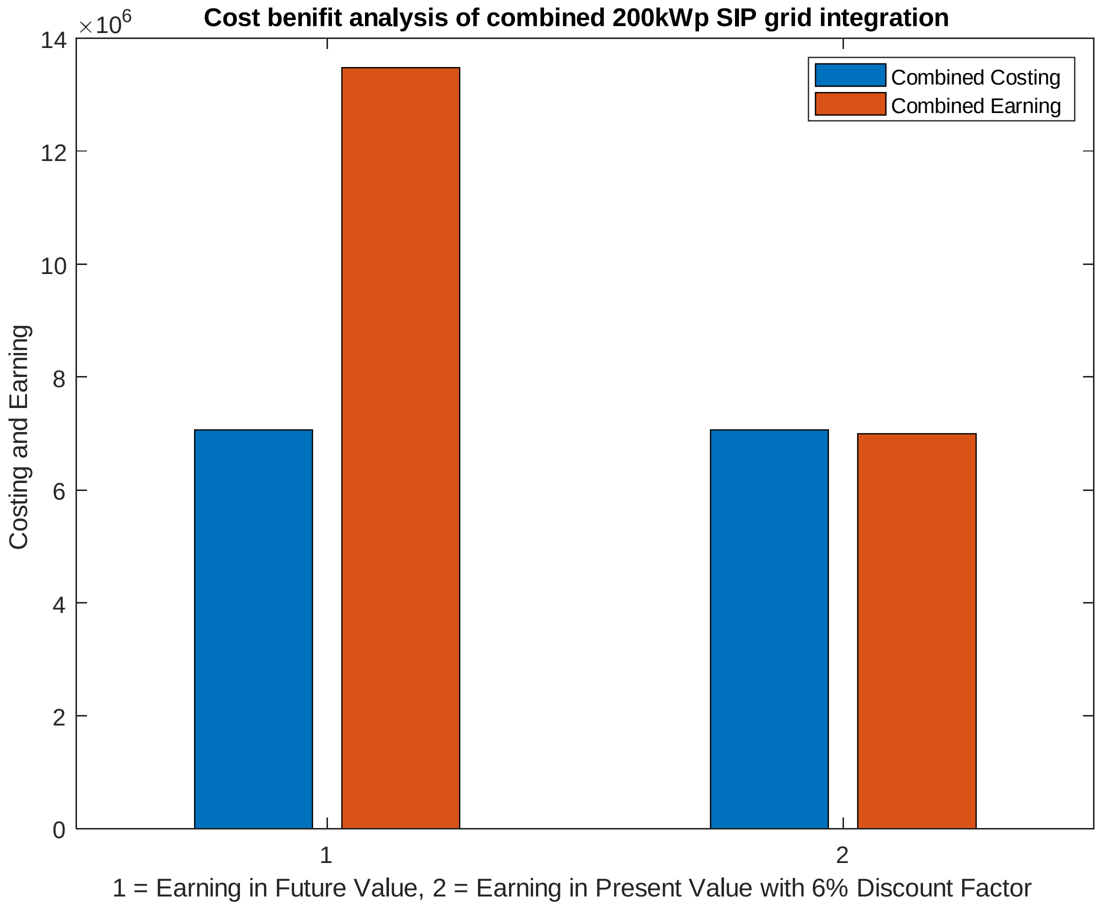

Figure 12: Cost-benefit analysis of combined SIP grid integration

In **Figure 12**, combined SIP grid integration costing versus earning from the grid feed electricity after irrigation has been displayed. Earning in future value is almost double but it looks equal to present value considering the 6% discount factor. The payback period of the mentioned combined 200kWp SIP grid integration investment is almost close to 20 years. Therefore, it is not a financially viable solution.

7. Conclusion and Policy Implications

Irrigation is an important part of agriculture and energy is essential for irrigation. Alternative use of water and electricity may play a vital role to encourage solar irrigation in Bangladesh. Grid integration of SIP is one of the alternative use of electricity after irrigation facilitated by the government. Solar irrigation mostly spreads in diesel-based irrigation areas rather than grid electricity-powered irrigation areas. Now the SIP installation rate in Bangladesh is decreasing due to the access to electricity. In this paper, the grid integration of SIP in different aspects has been analyzed including its financial viability.

According to the study result of the grid integration piloting site, the Grid feed rate was 389 kWh/kWp/year, the Irrigation use rate was 654 kWh/kWp/year and the Self-consumption rate from the grid was 5.4 kWh/kWp/year whereas the total energy generation rate from the solar irrigation system was 1043 kWh/kWp/year. 11kV 3phase grid integration is suitable in terms of technical aspects but only financially viable for above 20kWp SIP integration. Higher capacity SIP integration gives more financial benefits as well as integration distance although the best one (40kWp) has the lowest payback period which is at least

13 years. A combined 7 SIP site grid integration has been analyzed which is not a profitable solution according to the analysis. The scenarios have been calculated based on the grid feed rate obtained from the pilot site and the 20% bulk tariff increasing after every 3 years with the tariff order 2022 in Bangladesh. The result could be changed if those assumptions are changed significantly, especially the tariff-increasing rate of the grid electricity for irrigation class and bulk tariff of the distribution utilities.

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