Final Report

Grid Integration of Solar Irrigation Pumps

Technical and Financial Solutions

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Abbreviations

AC	Alternating Current
ADB	Asian Development Bank
BADC	Bangladesh Agricultural Development Corporation
BCCRF	Bangladesh Climate Change Resilience Funds
BERC	Bangladesh Energy Regulatory Commission
BMDA	Barind Multipurpose Development Authority
DC	Direct Current
GPOBA	Global Partnership for Output Based Aid
GHG	Greenhouse Gas
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
IDA	International Development Association
IDCOL	Infrastructure Development Company Limited
JICA	Japan International Cooperation Agency
JNNSM	Jawaharlal Nehru National Solar Mission (India)
KfW	Kreditanstalt für Wiederaufbau
KUSUM	Kisan Urja Suraksha Evam Utthan Mahaabhiyan (India)
MNRE	Ministry of New and Renewable Energy (India)
MPEMR	Ministry of Power, Energy and Mineral Resources
MPPT	Maximum Power Point Tracker
NEM	Net Energy Metering
PO	Partner Organizations
PV	Photovoltaic
RE	Renewable Energy
REB	Rural Electrification Board (Bangladesh)
RERED II	Second Rural Electrification and Renewable Energy Development Project
SDG	Sustainable Development Goals
SIP	Solar Irrigation Pump
SPDT	Single Pole, Double Throw
SREDA	Sustainable and Renewable Energy Development Authority (Bangladesh)

SREPGen	Development of Sustainable Renewable Energy Power Generation
USAID	United States Agency for International Development
VFD	Variable Frequency Drive

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Preface

In the remote off-grid areas of Bangladesh, the number of irrigation pumps powered by diesel is quite high. The price volatility and difficult transportation of diesel undoubtedly put heavy burden on the farmers. The Government of Bangladesh has been trying to address the issue recently by showing sincere inclination towards sustainable agriculture via promoting the use of solar powered irrigation pumps. IDCOL has already started implementing solar irrigation pump projects in many areas and aims to install 50,000 such systems by 2025. However, solar irrigation pump systems tend to remain under-utilized over a significant portion of a year, especially during lengthy monsoon season. If arrangements can be made to supply electricity from these systems into the national grid during off-season, path will open up to exploit the untapped potential. Simultaneously, the Government envisions providing access to clean, affordable and grid-quality electricity to all its citizens by 2021, which is manifested by the effort invested in expanding the national grid. Thus it is very likely that both technical and financial challenges of integrating this huge number of off-grid solar irrigation pump systems will emerge in recent future.

The present study aims to support the Ministry of Power, Energy and Mineral Resources (MPEMR)/SREDA in finding technically sound and financially feasible solution of grid integration of solar irrigation pumps. It suggests technical modality for both the grid integration of existing systems and installation of entirely new systems within the reach of national grid, as well as recommends suitable tariff structure and arrangements.

1 Introduction

1.1 Background

Successful and widespread utilization of renewable energy in agriculture has the potential to simultaneously address two of the seventeen United Nations (UN) Sustainable Development Goals (SDG) – SDG 2 (zero hunger) and SDG 7 (affordable and clean energy). While the target of SDG2 is to end hunger, achieve food security and improve nutrition and promote sustainable agriculture, SDG7 is aimed at ensuring access to affordable, reliable, sustainable and modern energy to all (United Nations, 2015). The deployment of solar irrigation pumps (SIPs) in agricultural fields is seen as one of the most promising use of renewable energy that simultaneously provide access to energy and contribute to food production. Recent advances in the design and operation of SIPs and the declining price of photovoltaic (PV) modules have contributed to the recent global surge in their use, especially in the off-grid areas in developing countries. The agriculture sector is responsible for 14.8% gross domestic product (GDP) (World Bank, 2016) and the livelihood of millions of farmers in Bangladesh, making it imperative for a reliable irrigation system.

Approximately 1.6 million units of irrigation systems were in operation in 2016 in Bangladesh, as shown in Table1 below (BADC, 2017). Around 1.31 million or 81% of the total irrigation units are powered by diesel, resulting in annual consumption of 1 million tons of diesel costing nearly 770 million US$ (GlobalPetrolPrices.com, 2018).

Table1: Summary of Irrigation Facility Used in Bangladesh, BADC 2015-16.

Type of equipment	Operated by electricity	Operated by diesel	Total		
			Units	Irrigated area	Benefitted farmers
Deep Tube wells	34,647	2,332	36,979	1194,177	2888,353
Shallow tube wells	269,847	1147,161	1417,008	2954,949	11418,979
Low lift pumps	9,415	163,764	173,179	1164,603	3083,178
Manual & Artesian well	0	0	0	29,178	27,394
Traditional method	0	0	0	18336	26,000
Gravity flow	0	0	0	128564	109,735
Country total	**313,909**	**1313,257**	**1627,166**	**5490,347**	**17553,639**

Recent statistics from the Sustainable and Renewable Energy Development Authority (SREDA) suggests that the number of diesel-run irrigation pumps has risen even higher and has reached 1.34 million (SREDA, 2017). The difficulty in transporting diesel to the fields and the inconsistency of supply at times make the farmers dependent on intermediaries, which then results in the increased price of diesel and the overall cost of irrigation and food production. 19% of the remaining irrigation units are powered by electricity from the national grid, which adds additional strain on the electricity infrastructure. The country is still faced with acute power shortages on a daily basis and the additional demand for electricity from the national grid exacerbates the situation. Most of these electricity-run irrigation pumps have to be operated at night. Regardless of the fuel used for irrigation; i.e., diesel and electricity, the existing pumps are responsible for a sizeable contribution in the country's fossil fuel consumption and total greenhouse gas (GHG) emissions. This scenario demonstrates the significant potential for utilizing renewable energy technologies, especially solar photovoltaic powered irrigation pumps in the agricultural sector of Bangladesh.

Following the global trend of increasing utilization of solar energy to power irrigation pumps, the Government of Bangladesh has initiated various projects to promote the use of SIPs across the country. Government organizations such as Bangladesh Agricultural Development Corporation (BADC), Rural Electrification Board (REB), Barind Multipurpose Development Authority (BMDA) and Infrastructure Development Company Limited (IDCOL) have acted as implementing agencies in realizing SIP projects. Among these organizations, IDCOL has the highest share of SIP project implementation with 923 SIP systems already in operation. IDCOL aims to install 50,000 solar powered irrigation pumps by the year 2025 (IDCOL, 2018). One of the challenges that requires consideration is the future scenario when this huge number of off-grid SIPs will come within the reach of the national grid or when new grid connected SIPs will be considered for installation. The integration challenges will be particularly significant during off-seasons when the pumps are not in use, but the solar panels will continue to produce and export electricity to the grid.

The subtropical monsoon climatic condition of Bangladesh is characterized by wide seasonal variation in temperature, rainfall and humidity. A hot and humid summer with intermittent rainfall from March to June is followed by a long rainy season lasting from June to October. Heavy monsoon throughout these long months often results in floods submerging vast cultivatable agricultural lands across the country. It is only reasonable to assume that majority of SIP systems will not be in operation during this long off-season. But once connected to the grid, the solar photovoltaic units will produce electricity and feed into the grid. This scenario is likely to offer significant challenges in terms of stable and reliable operation of the national grid. Moreover, the Government will have to devise tariff structures to incentivize the farmers owning SIP units without putting any extra burden on the utilities. Therefore, technically reliable and financially feasible solutions in terms of interconnection requirements, safety and protection schemes, metering arrangements, and tariff structure should be developed to meet the future challenges.

This report on the technical and financial solutions of integrating solar irrigation pumps to the national grid during off-season is prepared to address this very situation. It is developed as a part of the GEF funded "Development of Sustainable Renewable Energy

Power Generation (SREPGen)” project, which is implemented by the Power Division operating under the Ministry of Power, Energy and Mineral Resources of Bangladesh Government.

1.2 Objectives of the work

The broader aim of the SREPGen project is to reduce the yearly growth rate of GHG emissions from fossil fuel-based electricity generation system by utilizing Bangladesh’s renewable energy resource for electricity. Through this project support will be provided to the Sustainable and Renewable Energy Development Authority (SREDA) to achieve a considerable portion of renewable energy in the country’s energy mix by promoting its widespread use. In doing so, this report is prepared with the specific objective of assisting SREDA to develop technical and financial solutions for national grid integration of solar irrigation pumps during off-season.

1.3 Scope of the work

The scope of this work encompasses the following:

a. Gain an understanding of the principles of solar irrigation pumping systems;
b. Review the state-of-the-art;
c. Devise possible grid connection modes;
d. Prepare interconnection requirements, protection schemes and safety guidelines; and
e. Propose suitable tariff structures.

1.4 Working principle of typical SIP systems

Solar irrigation pumps are based on solar photovoltaic technology that converts sunlight into electricity to operate the pump and transport water from sources to the irrigation fields. The system usually consists of solar photovoltaic arrays, control circuits (required electronics), a DC/AC motor pump-set, and piping arrangement. Depending on the requirement there can be water storage tank and battery as well. The motor converts electric energy supplied by the PV into mechanical energy, which is then further converted into hydraulic energy by the pump. The capacity of a SIP system is a function of three variables that are pressure, flow and power to the pump (Chandel, N, & C., 2015).

Following are the block diagrams of typical *isolated* solar powered water pumping systems:

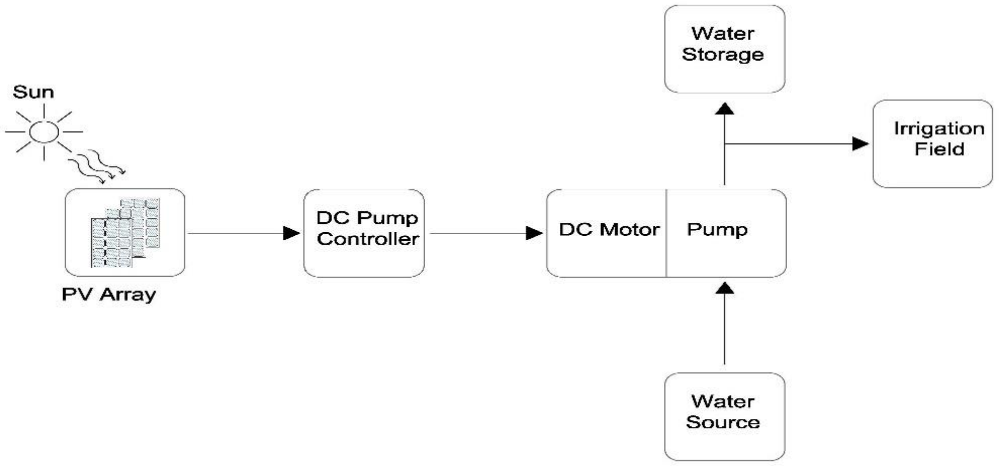

Figure 1: Block diagram of direct coupled DC SIP.

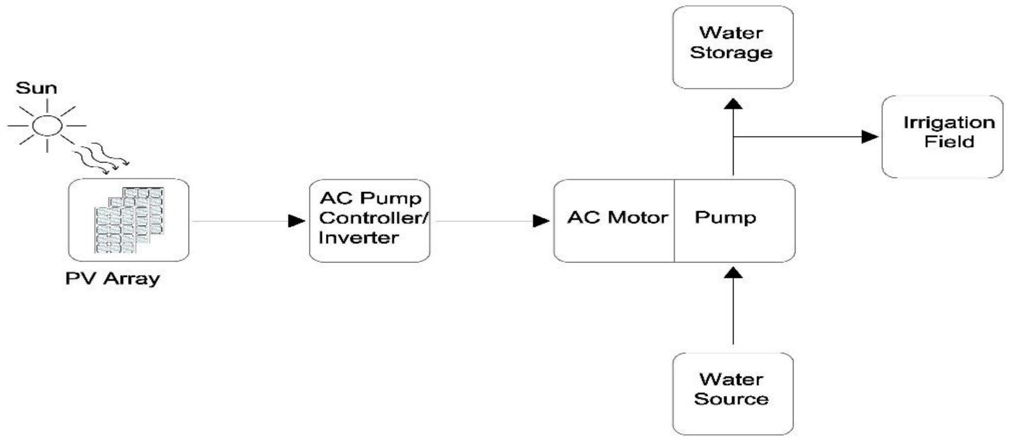

Figure 2: Block diagram of AC SIP.

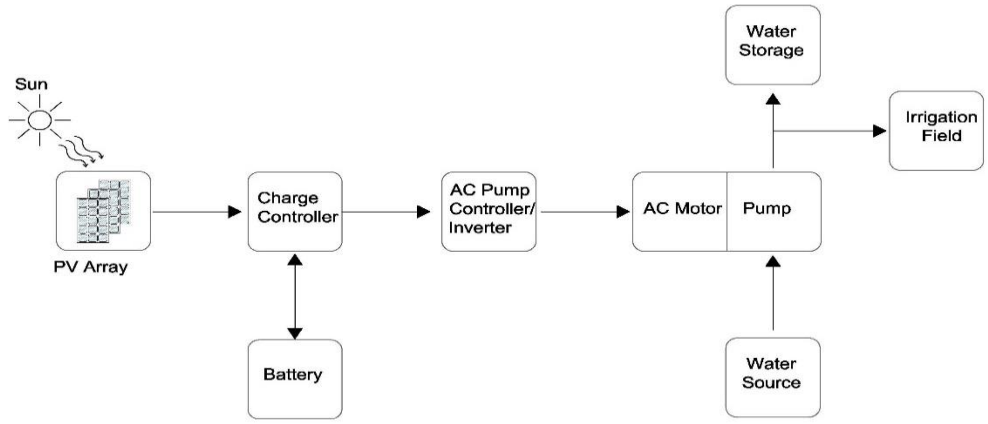

Figure 3: Block diagram of AC SIP with battery storage.

2 State-of-the-art

This section of the report aims to present the outcomes of a review of published literature and policy documents related to SIP–grid integration.

Numerous academic articles are available offering comprehensive reviews of the research and development of SIP systems across the world. Apart from the review articles, there is a considerable published literature on the successful implementation of SIPs in developing countries. An examination of these documents reveals that the majority of the reported SIPs are *off-grid* systems — deployed either in allocations in dry regions (especially the African countries) or at places where seasonal rainfall does not submerge the land.

On the other hand, many private manufacturing companies from various countries offer wide ranging technical solutions for grid integration of SIPs. Quite expectedly, financial aspects associated with such solutions (e.g., electricity export tariff structure) fall beyond the scope of private companies. It has been mentioned before that developing nations in recent decades have taken significant measures to promote SIP systems in their respective countries. Since most of these programs are based on off-grid SIP systems, there is insufficient documentation on government approved technical, financial or policy guidelines regarding the grid integration of SIP systems. The insufficient availability of such documents becomes apparent when solutions for off-seasons are considered, which is an important challenge to tackle for Bangladesh in future.

Nevertheless, there are only a few exceptions. Indian Government has launched countrywide programs on SIPs. The utilization of SIPs in India dates back to 1992 when the Ministry of New and Renewable Energy (MNRE) started deploying SIPs. By 2014 there were a total of 13,964 systems installed across the country. The drive was renewed in 2010 with the launch of Jawaharlal Nehru National Solar Mission (JNNSM) (Chandel, N, & C., 2015). On 15 March 2018, MNRE released a press note indicating the possibility to approve 480 billion INR(₹)[1] scheme titled, Kisan Urja Suraksha Evam Utthan Mahaabhiyan (KUSUM), to promote the use of solar power among farmers (MNRE (Government of India), 2018; The Economic Times, 2018). Under the KUSUM scheme, 220 billion INR will be allocated for installing 1.75 million SIPs and 157.5 billion INR for the solarization of existing grid-connected irrigation pumps, amounting to 7.25 GW. The scheme will also provide incentives to distribution companies for buying power from farmers and up to 60% financial assistance to farmers for buying SIPs. However, the scheme is yet to be launched; hence, the details on the technical modalities and financial aspects are still unavailable.

The state government of Karnataka, India adopted solar pump promotion policy titled ‘Surya Raith’ that offers guaranteed buy-back of solar power from SIP owners at an

[1] ₹ = Indian Rupees (INR). 480 billion = 48,000 crores.

attractive feed-in-tariff rate (Shah, Verma, & Durga, 2014). Under this scheme, farmers who set up SIP in their farmland without subsidy from the government are eligible to receive INR 9.56 per unit of exported electricity. This program is envisaged for SIP sets on the dedicated IP feeders (Khajane, 2014).

With financial aid from GIZ, the Ministry of Water and Irrigation of Jordan has launched a pilot project titled 'Solar Energy Farming' under the 'Azraq Groundwater Management Action Plan' (Halaby & Qoaider, 2015). Under this project, farmers were provided price incentives for the electricity generated and exported to the national grid. Unfortunately, development of this scheme faced problems as the government was not eager to provide solar energy to farmers in fear that they might over-extract groundwater (Closas & Rap, 2017).

2.1 SIP status and policy scenario in Bangladesh

Like many other developing nations, the Government of Bangladesh has been very active in promoting renewable energy across the country. The activity has been extended to the agricultural sector as well. SREDA has developed 'Guidelines for the Implementation of Solar Power Development Program' in 2013, which promotes the use of solar energy for irrigation. According to this guideline, various partner organizations (POs) will be responsible for financing the SIP projects (Power Division, 2013). In order to keep the price of delivered irrigation water within tolerable limits, IDCOL will support in securing up to 85% of the total project finance from various funds and grants.

At present, IDCOL is using two types of business models to finance *off-grid* solar irrigation projects, which are *Fee for Service* Model and the *Ownership* Model (Rahman, 2015; IDCOL, 2018). The models are similar except for the nature of exchange between the PO and the farmers. Both models are illustrated using block diagrams in Figures 4 and 5.

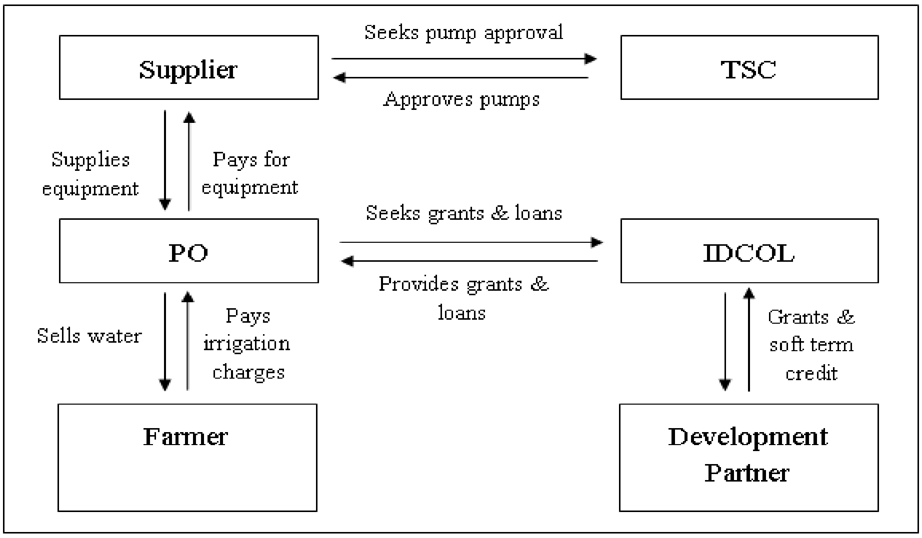

Figure 4: Schematic of Fee for Service Model of IDCOL.

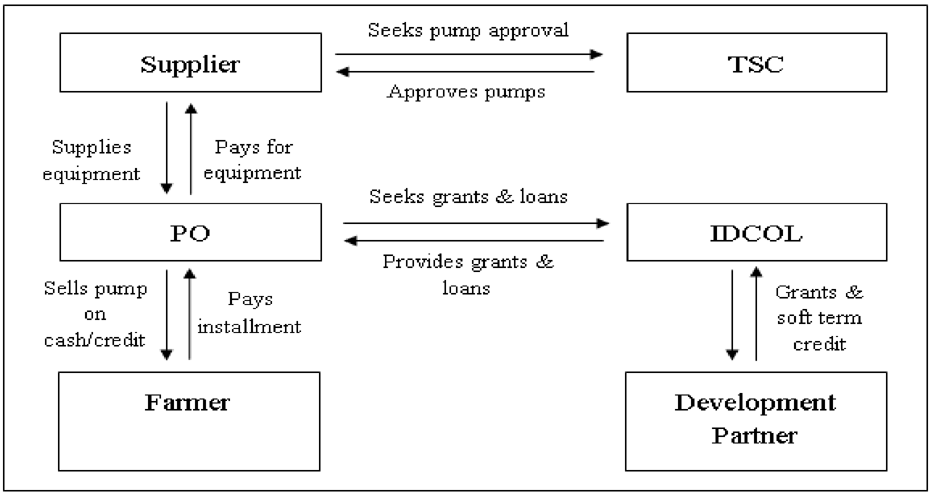

Figure 5: Schematic for Ownership Model of IDCOL.

Even though IDCOL has the largest share of SIP installation throughout the country, there are other government organizations that are acting as implementing agencies; e.g., BREB, BADC, BMDA etc. REB has implemented 2 solar irrigation pump projects. The details for the projects are presented in Table 2.

Table 2: REB Implemented SIP Project Summary.

Project title / Parameters	Solar Powered Irrigation Pump as well as Power Management & Distribution System to Mitigate Energy Crisis and Climate Change	Solar Powered Irrigation Pump & Solar Home System
Funding source	Climate Change Trust Fund (GoB), 100% as grant	KOICA and GoB
Project period	April 2010 to June 2012	July 2011 to June 2013
Target	20 SIP and 300 connections	20 SIP and 1250 SHS
Pump capacity	5 HP	5 HP
Type of Pump	Submersible DC	Submersible, 3phase AC
PV module capacity (pump)	6.72 or 7.2 kWp	5.16 kWp
Water discharge capacity	1-1.5 Lac L/d	1-1.5 Lac L/d
Pump commanding area	3.5 acre	3.5 acre

However, as mentioned previously, none of these SIP systems are grid connected. Salam (Salam, 2016) has reported an investigation of grid connected SIP system, established at Jahangirnagar University campus, Savar, Dhaka. The PV array of the model system consists of 16 modules, each having 260 W maximum rated power. During a sunny day when the pump is not operating, the surplus energy is fed into the national grid and on a cloudy day, the pump receives energy from the grid to meet the demand. The system configuration is shown in Figure 6.

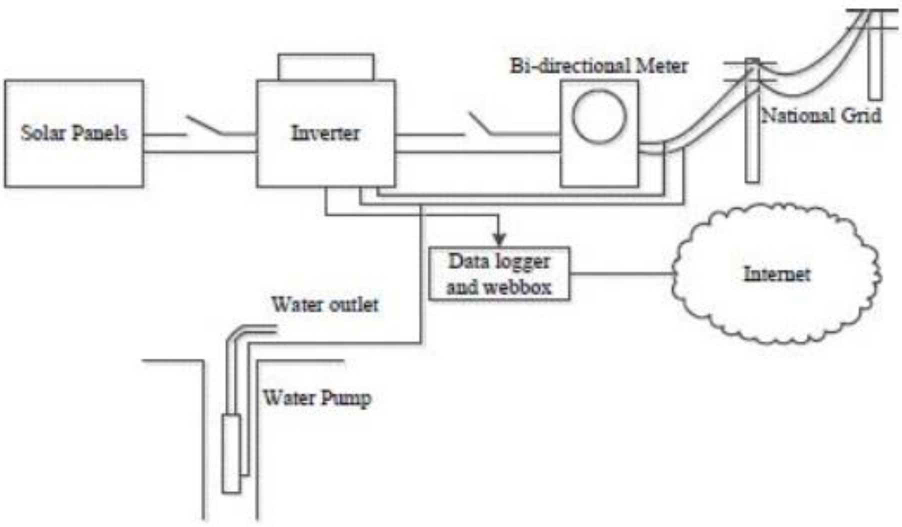

Figure 6: Grid-connected SIP system configuration at JU, Savar (Salam, 2016).

3 Technical aspects of SIP-grid integration

3.1 Existing off grid SIP systems

IDCOL has been actively working along with the Government and development partners such as WB, BCCRF, KfW, GPOBA, USAID, ADB, IDA, and JICA to promote the use of SIPs in the agricultural sector of Bangladesh (IDCOL, 2018). A typical off-grid SIP system installed under IDCOL's financing scheme is illustrated in Figure 7 and comprises the following components:

a. PV panels;
b. AC or DC pump;
c. Motor with a minimum power factor of 0.8 and a minimum insulation of 'F' class; and
d. Variable Frequency Drive (VFD) to control the pump, which may have Maximum Power Point Tracker (MPPT) technology.

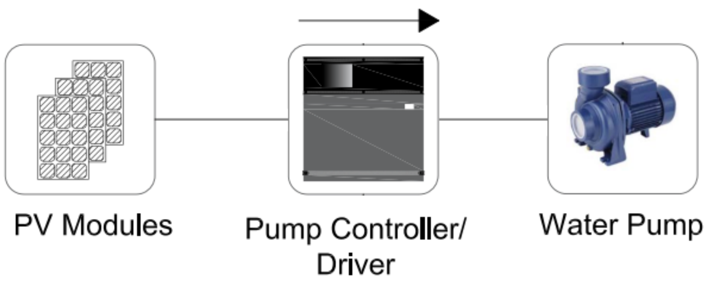

Figure 7: Schematic diagram of existing SIP systems installed by IDCOL.

Since the connection of VFDs directly to the grid is challenging and replacing existing VFDs with other equipment is not economically viable, technical solutions for integrating VFD-coupled SIPs with the grid need to be devised. The following section proposes three possible technical solutions for grid integration of SIPs.

3.2 SIP–grid integration modes

Technical solutions for integrating solar powered irrigation pumps into the national grid during off-season are devised based on whether the SIP already exists or to be installed in future. Based on this criterion, two possible cases of grid integration of SIPs are presented as Case 1 and Case 2.

3.2.1 Case 1: Existing off grid SIPs connected to grid after grid reaches in the area

The integration mode of existing SIPs can be further divided into two possible types depending on the number of SIPs per grid connection point, which are as follows:

- *Case 1a–grid integration of a single SIP*: For grid integration of individual SIP, a DC circuit breaker, an interlocking switch, an inverter and a unidirectional meter will be required. During off irrigation season when the SIP will not be operational, the PV array will only export electricity to the grid via the inverter.

- *Case 1b– grid integration of SIP clusters*: Individual SIPs within close vicinity can be combined into clusters and then connected to the grid via an inverter with multi MPPT facility and a unidirectional meter.

Figure 8 and Figure 11 illustrates the schematic diagrams of two possible modes of grid integration of existing SIP systems in Bangladesh.

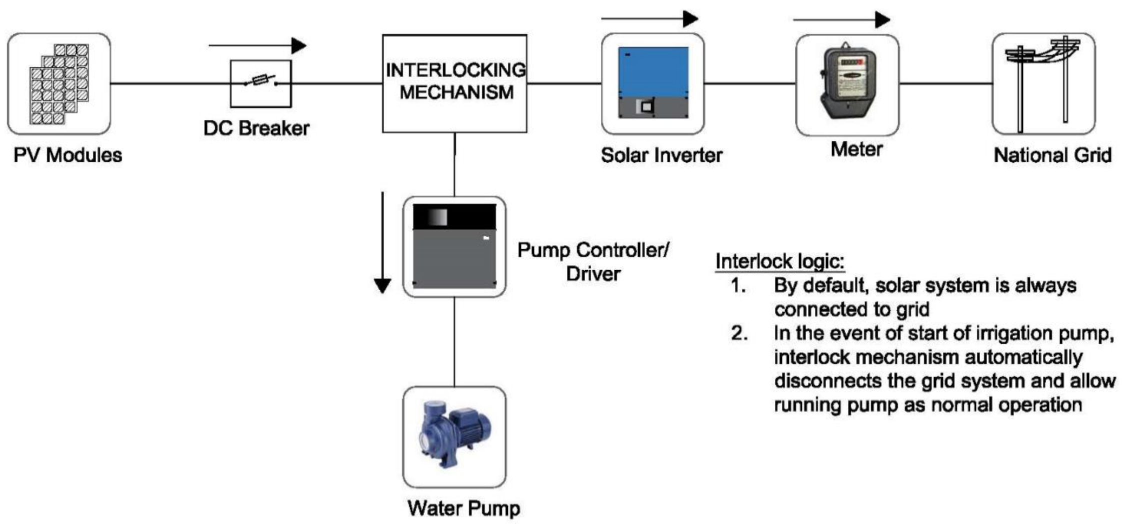

Figure 8: Schematic diagram of grid integration of individual SIP (single phase).

[At present there is no provision of Net Metering for single phase connection. Consumer needs special permission from utility to connect the SIP into the grid in single phase.]

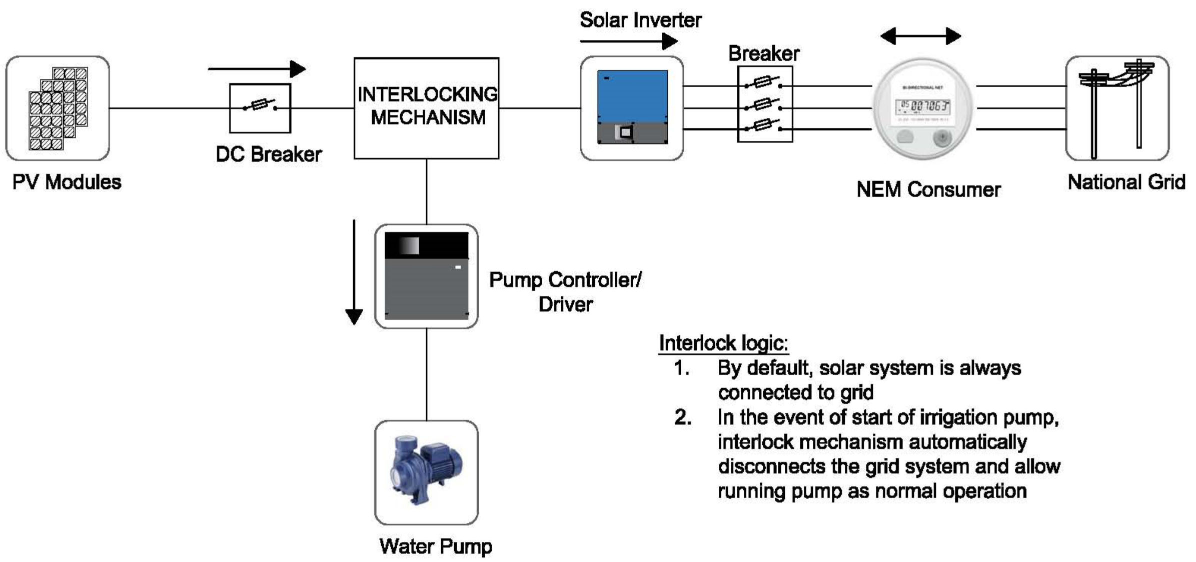

Figure 9: Schematic diagram of grid integration of individual SIP (three phase).

In case of 3 phase connection inverter the SIP can apply for NEM consumer.

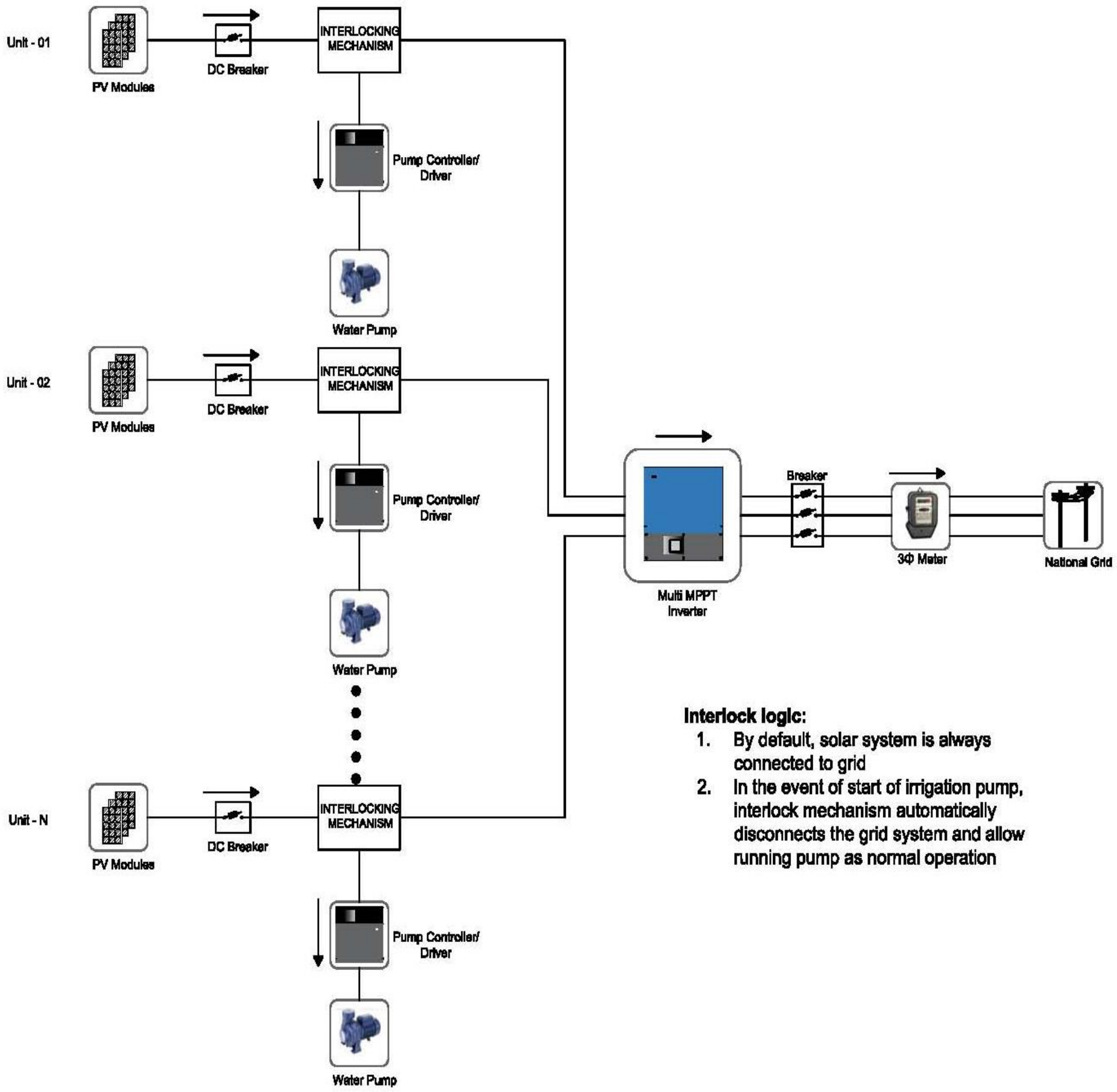

Figure 10: Schematic diagram of grid integration of SIP cluster.

3.2.2 Case 2: New SIPs in grid area

New SIPs to be installed within grid-area shall fall within the scope of Net Energy Metering (NEM) scheme, which has been approved by the Government of Bangladesh. This type of connections will have 3 phase AC motor pump set. Figure 11 and Figure 12 illustrate the schematic diagram of grid integration connection for new SIPs to be installed in grid area. In case of single phase SIP there is no provision for NEM scheme, the consumer needs to take special permission to connect the SIP system into the grid.

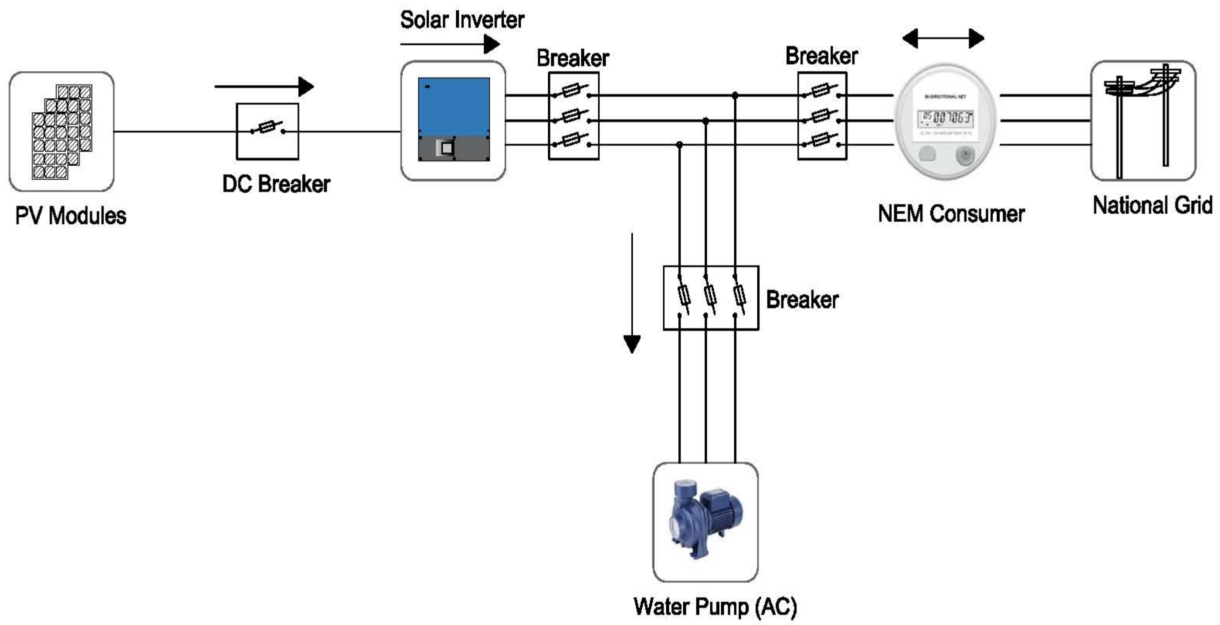

Figure 11 Schematic diagram of grid integration of new SIP systems in grid areas (3 phase).

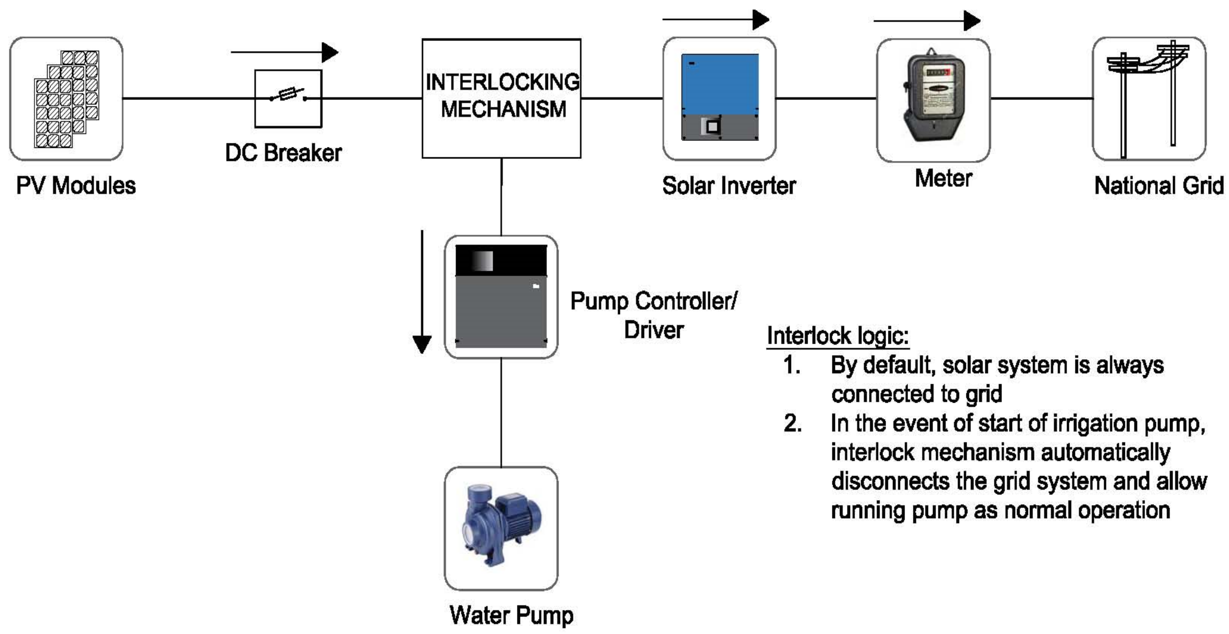

Figure 12 Schematic diagram of grid integration of new SIP systems (1 phase).

3.3 System Component Specifications

The component specifications of the SIP systems shall comply with the standards to be set by SREDA. The interconnection of the SIP with the national grid shall follow the interconnection requirements, protection guidelines and safety scheme as described in Sections 3.4 to 3.6 of this report.

3.4 General interconnection requirements

Irrespective of the connection type, all SIP systems connected to the grid shall abide by the general interconnection requirements specified in this section.

The interconnection shall not result in any enhancement of the existing utility supply infrastructure such as cable, fuse, switchgear, and transformer and protection scheme. The quality of the power at the point of interconnection shall not be worse than the existing quality of supply. Quality of supply is measured as per the standards on voltage, flicker, frequency, harmonics and power factor, as specified by relevant and concerned authorities. To ensure that the interconnection does not adversely impact the quality of supply, the following requirements shall be imposed and adhered to by the SIP owners and operators. Deviation from these standards represents out-of-bounds conditions and the SIP system shall be able to sense the deviation and disconnect itself from the distribution network accordingly.

3.4.1 Normal voltage operating range

The PV systems of the SIP injects current into the utility network and does not regulate voltage.

i. The PV systems of the SIP connected with a low-voltage (LV) interconnection shall operate within the voltage specified in Table 3.

ii. The PV systems of the SIP connected with a medium-voltage (MV) interconnection shall operate within the voltage specified in

iii.

iv. Table 4.

Table 3: Normal operating condition at LV interconnection

Nominal voltage [V]	Steady state voltage limit
400	± 10%
230	±10%

Table 4: Normal operating condition at MV interconnection

Nominal voltage [kV]	Steady state voltage limits
11	± 10%
33	± 10%

3.4.2 Voltage fluctuation

Power generation from the PV systems of the SIP varies due to the intermittent nature of solar irradiation throughout the day. The varying power generation injected into the distribution network creates voltage fluctuation at the interconnection point and other buses within the grid.

The maximum voltage fluctuation range allowed for varying solar radiation is 6%. Beyond this, there is a danger of utility and consumer equipment heating up. An appropriate voltage control is to be undertaken to mitigate the voltage fluctuation when necessary.

3.4.3 Power factor of the PV generator connected to the SIP

The power factor is defined as the ratio between the applied active power and the apparent power.

i. The PV generator with the SIP systems shall have a leading or lagging power factor greater than 0.9 when output is greater than 20% of the rated inverter output power. The smart inverters used shall automatically make necessary adjustments to ensure that the power factor does not cause a voltage rise beyond the permissible limit.

ii. The requirement of plant power factor shall be identified during the technical assessment.

3.4.4 Reactive power compensation

If the installed PV generator with the SIP systems is set to operate at unity power factor, reactive power for the consumer’s load will be totally imported from the utility and the real power will be a mix of on-site generation and imported electricity from the utility. This will result in a low power factor reading at the utility tariff meter as the ratio of reactive power is higher for own generation. Therefore, the customer is advised to consult the system integrator to provide internal compensation to avoid being penalized. This can be considered only when the capacity of the SIP is more than 25 kW.

3.4.5 DC injection

The PV generator with the SIP systems shall not inject DC current greater than 1% of the rated inverter output current into the Utility interface under any operating condition.

3.4.6 Harmonics

The harmonic of a wave is a component frequency of a wave that is an integer multiple of the fundamental frequency. In the presence of non-linear loads such as computer power supplies and other appliances, alternating current (AC) can be distorted by the introduction of various harmonic frequencies. Harmonics can be measured by the percentage of the fundamental frequency or by calculating total harmonic distortion (THD). When present at high levels, harmonics are detrimental to the electrical system and its loads. The following shall be maintained.

i. Output of the PV system connected to the SIP should have low current-distortion levels so that other equipment connected to the Utility system is not adversely affected.

ii. Total harmonic current distortion shall be less than 3% of the rated inverter output at the cable connected to the interconnection point.

3.4.7 Voltage imbalance

Voltage unbalance is defined as the ratio of the negative sequence voltage component to the positive sequence voltage component.

i. Infrequent short duration peaks with a maximum value of 2% over 1-minute duration are permitted for voltage unbalance.

ii. When multiple single-phase PV units are installed, the unbalance should be distributed evenly among the three phases of the power system.

iii. The unbalanced voltage shall not exceed 1% on five occasions within any 30-minute period at the terminals of the consumer's installation.

3.4.8 Short circuit level

According to the regulations, the utility is required to ensure that short circuit level of the network is within the equipment ratings. The regulations specify that network maximum sub-transient 3-phase symmetrical short circuit shall be within 90% of the equipment designed short-time make and break capacity.

3.5 Protection guidelines

Protection systems for the PV generator with the SIP systems shall be designed to isolate the faulty part of the system from the remaining properly functioning portion. SIP owners shall design a protection system, which shall suit her/his target of the degree of system security. Nevertheless, the SIP owner shall comply with the utility's protection requirements to ensure that the fault will not spread beyond her/his own system.

3.5.1 Protection coordination study

The SIP owner shall perform protection coordination study to determine suitable settings for protecting the system during a fault. Outcomes of such studies shall be communicated with the utility. After which, the utility shall advise the owner on appropriate settings at the point of common coupling. Interconnection feeder protection scheme shall prohibit unsafe synchronization.

3.5.2 Smart inverters

Connection of power generation to distribution network could cause voltage rise during low load conditions. Also, sudden loss or generation from distributed generation could cause instability of the network, especially for system with high distributed generation penetration. Advanced smart inverters can provide the following additional features in addition to the power conversion:

- Reactive power control;
- Active power control; and
- Grid management.

Inverters used by the consumer's system shall comply with the requirement of the smart inverter as described in Sections 3.5.3–3.5.10.

3.5.3 Frequency

The utility shall maintain the system frequency and the PV array connected to the SIP shall operate in synchronization with the utility's frequency. The utility shall operate with nominal 50 Hz system with ±1% range band. The inverter should be capable of producing power at the frequency band of at least ±6%.

3.5.4 Synchronization

Synchronization is an act of matching, within allowable limits. The PV generator with the SIP systems should be equipped with automatic synchronization system; i.e., an inverter.

3.5.5 Anti-islanding inverter

If a net metering site continue to feed electricity back into the distribution grid even during a utility power outage it can risk the safety of the line maintenance workers. Therefore, there must be a mechanism to prevent sending power back to the utility grid during a power outage.

Since the smart grid tie solar inverters have an inbuilt anti-islanding function which cannot be manually overridden by the customer upon loss of utility service, a separate islanding protection system is not required. So, the grid tie inverter must have anti-islanding protection.

3.5.6 Inverter fault current contribution

The fault current contribution by the inverter will be limited usually by the inverter control. Based on IEEE 1547, the typical range of short circuit current is between 100% and 200% of the rated inverter current. SIP system owner shall ensure that inverters used comply with the IEEE 1547 requirements.

3.5.7 Protection schemes

The basic requirements for the design of the protection schemes shall be as follows:

i. Any internal fault in the SIP system must not affect the Utility's system and its customers;
ii. For any distribution network fault occurring outside, the SIP system must be protected from any damaging effect; and
iii. SIP system owners shall be required to provide other protection devices to complement existing special features.

3.5.8 Frequency disturbance

The under frequency and over frequency levels and the corresponding inverter trip time shall be as follows:

i. When the Utility frequency is outside the nominal 50 Hz value by ±2%;
ii. Trip time shall be within 0.20 s; and
iii. Applicable for both LV and MV interconnection.

3.5.9 Voltage disturbance

i. The inverter should sense abnormal voltage and respond according to the conditions in Table 5. Consideration shall be given to the monitoring voltage in this clause to avoid problems due to voltage drop in various transformers, wiring or the feeder circuit. When the inverter senses that the voltage lies outside its operating limits, the actions recommended in Table 5 shall be taken.

Table 5: Voltage disturbance

Voltage at interconnection	Maximum trip time (s)
$V < 50\%$	0.10
$50\% \leq V < 90\%$	2.00
$90\% \leq V \leq 110\%$	Continuous operation
$110\% < V < 135\%$	2.00

ii. Inverters are expected to continuously operate during distribution network voltage fluctuation within ±10% of its nominal.

iii. Voltage disturbance can be the result of transmission network switching and distribution switching on the nearby feeder. During the time of voltage disturbance, inverters must be able to ride through the disturbance bands of 50% to 90% and 110% to 135%, to assist in stabilizing the utility's system.

iv. Loss-of-mains is indicated by voltage drop less than 50%.

v. Over voltage and under voltage detection shall be provided for all 3 phases.

3.5.10 Utility interface disconnect switch

SIP system interconnection must incorporate a utility interface disconnect switch to allow disconnection of the system output from interconnecting with the utility for safety. The requirement of such switch could be referred to as the Standard Switch. The switch shall be manual and lockable. Load break disconnect switch should:

- Provide clear indication of the switch position;
- Be visible and accessible to the maintenance and operational personnel; and
- Provide visual verification of the switch contact position when the switch is in open position.

3.6 Safety Requirements

The grid integration of existing SIP systems or installation of future grid-connected SIP systems shall comply with the relevant national and international safety standards. The provisions of this section are aimed at ensuring that system topologies and earthing arrangements are considered for the safe operation of the connected system.

3.6.1 Operation

i. It is important that for the safety of operating staff and public, both the utility and the SIP owner must coordinate, establish and maintain the necessary isolation and earthing when work and/or tests are to be carried out at the interface/ connection point.

ii. The safety coordination is applicable when work and/or test that are to be carried out involving the interface between the distribution network and the indirect PV array of the SIP system. It is the responsibility of the utility and SIP owner to comply with the requirements of the statutory acts, regulations, sub–regulations, individual license conditions, standardized safety rules and distribution code of the utility and the national grid operator.

3.6.2 Interconnection operation manual

Interconnection operation manual (IOM) shall be prepared by the SIP owner in cooperation with the utility for systems over 500 kW.

3.6.3 Labeling

Labels shall be clearly and visibly placed to remind the operator that equipment should be accessed with caution as there could be an energized part that comes from the PV array of SIP system.

4 Financial aspects of SIP-grid integration

4.1 Energy accounting and settlement

The specifics of energy accounting are as follows:

- Utilities shall be responsible for preparing and issuing electricity bills for each billing period and conduct energy accounting on a yearly basis.
- Utilities shall prepare an energy statement the components of which shall vary depending on the type of grid connection as specified in Section 3.2 of this report.
  - For Case 1a and 1b [section 3.2.1], the statement should include (a) the amount of electricity exported to the grid by the SIP system owner, (b) tariff rate and (c) total amount to be received by the SIP owner.
  - For Case 2 [section 3.2.2], billing will be done as per NEM guideline applicable for Rooftop Solar PV Systems (MPEMR, 2018).
- The utility shall settle monetary transactions at the end of settlement period on an annual basis.
- The settlement period is 12 months and it will be same as the fiscal year considered by the utility.

4.2 Tariff structure

The specifics of tariff structure are as follows:

- For each billing period, the utility will conduct the energy accounting based on the tariff order issued by the Bangladesh Energy Regulatory Commission (BERC). The accounting should accommodate the grid connection types as mentioned in Section 3.2 of this report.
- For Case 1a and 1b, the pump owner (POs or farmers) will export electricity to the grid during off-season at the BERC approved bulk tariff.
- For Case 2, the tariff of the exported electricity shall be at the BERC approved bulk tariff.
- The tariff rates will be subject to change according to the tariff structure determined by the BERC for any particular fiscal year.

5 Conclusion

Diesel and electricity from the national grid are predominantly used in 1.6 million units of irrigation pumps which are in operation in Bangladesh. Diesel-powered pumps account for 81% of the total at a considerable expense to farmers and the taxpayers in the form of subsidies. The remaining 19% of the irrigation units run on electricity from the national grid which adds to the growing demand for electricity.

The utilization of renewable energy is seen as ideal to reduce Bangladesh's reliance on fossil fuel for agriculture. Solar irrigation pumps have the potential to provide for irrigation needs during farming season while adding surplus generation to the grid during off-season.

In line with the overall aim of the SREPGen project to reduce the annual growth rate of GHG emissions from fossil fuel-based electricity generation, this report first investigates the policy, technology and existing applications of solar irrigation pumps. Findings are then translated to devise possible grid connection modes. Interconnection requirement, protection schemes and safety guidelines are then formulated for safe and efficient operation of grid-connected SIPs. Financial aspects of SIP-grid integration are discussed with reference to energy accounting and settlement and tariff structure, considering the existing governance mechanism and the approved net energy metering scheme. According to the approved Net Metering Guidelines only the 3 phase consumers are eligible for net metering scheme. If the single phase SIP owner wants to connect to the grid then they need take approval from the concern utility.

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Short Biography of the Consultant

Education & Employment

Shahriar Ahmed Chowdhury obtained his B.Sc. in Electrical and Electronic Engineering from Bangladesh University of Engineering and Technology (BUET) in 1997 and M.Sc. in Renewable Energy from University of Oldenburg, Germany in 2006 with the highest marks in the graduating class. He has the working experience in Bangladesh power sector for a decade. He worked in system control & grid circle (DESA) and planning & design (BPDB). Currently he is working as the Director of Centre for Energy Research at United International University. He has designed and initiated a course in Renewable Energy for the first time in Bangladesh for the undergraduate students of EEE department in 2007.

Research Achievements and Awards

Shahriar has invented a novel dry fabrication process (alternate buffer layer) for CIGS thin film solar cell with highest efficiency at the time (2006) in Centre for Solar Energy and Hydrogen Research at Stuttgart, Germany. In 2016 one of his research project “Peer-to-Peer Smart Village Grid” funded by IDCOL / WB won the “UN Momentum for Change” award in UNFCCC CoP 22 in Marrakesh, Morroco and “Intersolar Award” in Munich, Germany. His Research projects “Smart Solar Irrigation System” and “Demand Response Enabled Smart Grid” won the “Inter University Innovation Award” at Power and Energy Week 2016 & 2018 respectively, organized by the Ministry of Power, Energy and Mineral Resources. Mr. Chowdhury was the supervisor of the finalist student project for the IEEE International Future Energy Challenge, 2009 in Illinois Institute of Technology, Chicago, USA. In June, 2018 he received the “Education Leadership Award” from “World Education Congress, 2018“ in Mumbai, India for his contribution in Education, Research, Leadership and Teaching in the Renewable Energy sector.

Works and Affiliations

As a team leader he has performed the first two technical auditing of the SHSs installed all over Bangladesh under IDCOL program. He is extensively involved in developments of grid connected and off grid solar PV systems. He is the designer of the first ever utility scale grid connected solar PV project of Bangladesh (Engreen Sharishabari 3.28 MWp, came into operation in August, 2017). He is involved in designing Kaptai 7.4 MW (BPDB) and Sirajganj 7.6 MWp (NWPGCL) solar PV projects. He is also supporting RPCL for the development of their 250 MWp grid tied solar PV project at Mollahat, Bagerhat. So far he has designed more than 25 solar diesel hybrid minigrids for rural electrification (Out of 17 operational solar minidgrids for rural electrification under IDCOL financing, he has designed 16). He has also designed several rooftop solar PV systems ranging from 25 kWp to 3 MWp. He has drafted the Net Metering Guidelines for Bangladesh. The Guideline has been approved in July, 2018 by the Ministry of Power, Energy and Mineral Resources of Bangladesh.

As a power & energy sector expert he was involved in projects like Bangladesh Delta Plan 2100, Bangladesh Energy and Emission Modeling 2050, Supporting implementation of Bangladesh Climate Change Strategy and Action Plan (BCCSAP), Bangladesh off grid energy sector assessment, etc. He has working experience in projects funded by GoB, IDCOL, World Bank, UNDP, ADB, DFID, EPSRC, DECC, GIZ, kfW, JICA etc. He has developed a solar PV minigrid laboratory at his University by the grant support from IDCOL and the World Bank. Mr. Chowdhury has jointly initiated a bi-yearly International Conference on Renewable Energy (ICDRET), this is first conference of its’ kind in Bangladesh [So far successfully organized 5 events]. He is the author of more than 45 book articles, journal papers and conference proceedings. He has working and project experience in Bangladesh, Germany, UK, Kenya and Nigeria. He is the Member of Expert Panel of International Electrotechnical Commission (IEC) for Systems Evaluation Group (SEG 4) on "Low Voltage Direct Current Applications“.