Solar Photovoltaic Integrated Pump for Advanced Irrigation System

Bidrohi Bhattacharjee, Arijit Chakrabarti, Pradip Kumar Sadhu

***Abstract*: This paper describes how the underground water can be collected using a submersible pump that is fed by Solar Photovoltaic (SPV) Systems using solar energy in remote areas where the water level is quite low. The submersible pump uses the induction motor to utilize the underground water. The integrated system includes a solar charge controller connected to an inverter in order to supply a steady voltage to the pump motor. In addition, the controller protects the system against overcharging and over discharging. The integrated system has been implemented to test the usefulness of the system. The study includes cost analysis as well to show the financial benefits that one can achieve through implementation of such integrated systems in real world especially in village areas where there are issues in getting useful water for agriculture and domestic purpose.**

***Index Terms*: Charge controller, induction motor, payback, solar photovoltaic, sunlight.**

I. INTRODUCTION

In some villages of Nepal, the water level is quite low from normal ground level and it becomes very difficult for the villagers to collect sufficient water using normal tube well or normal pump. To fix such issues, submersible pumps can be used. A submersible pump is capable of collecting water at places with lower water levels, but the main challenge is the availability of electricity. In those villages of Nepal, electricity cut is a common issue and running submersible pumps becomes a nightmare for most of days affecting their irrigation process. In order to overcome the electricity issues, the solar photovoltaic system has been used. Solar energy is widely used form of renewable energy source [1]–[4]. Solar photovoltaic system (SPV) has been implemented in the model village considering the water requirement for all the people and irrigation process in that village. Such implementation using the renewable energy source has been successful and has been meeting the water need of the village completely promoting use of green energy.

In the system, the SPV cells collect the solar energy and convert it into a DC voltage source, which is later fed to an AC drive that converts the DC to the AC power supply. Using this ac power supply the submersible pump runs. The main advantage behind using this system is the continuous power flow from natural source of energy like sun. Here, the solar energy based system is totally an off-grid interfaced system, especially in the villages. Energy storage management is one of the key components in off-grid solar energy conversion system [5]–[8]. Solar photovoltaic is a promising environment friendly power generation technology that comes with minimum maintenance and running cost [9]–[18].

This paper discusses about the implementation of an integrated solar photovoltaic system that generates the electricity needed for running a submersible pump. The SPV module contains few photovoltaic cells in series-parallel combination to achieve the required voltage level. The solar photovoltaic panel absorbs the solar energy and converts it into electrical energy to produce the DC voltage. However, the DC voltage does not remain steady due to change in sunlight throughout the day. Therefore, the electrical energy produced needs to be stored in batteries to generate a steady DC voltage. A solar charge controller is used to protect the battery against overcharging and over discharging. It also eliminates the current flowing back to solar panel during night. The DC voltage is fed to an ac drive to generate AC voltage at the output. The output AC voltage is applied to the submersible pump.

In this paper, the integrated system is outlined in Section 2. Section 3 includes pump capacity calculation. Section 4 indicates the pump installation steps. Section 5 discusses about the results. Cost analysis and payback calculation are mentioned in Section 6. The paper is finally concluded in Section 7.

II. THE INTEGRATED SYSTEM

A Photovoltaic (PV) system comprises an array of solar panels that converts solar energy to electricity. PV cells, made up of semiconductor materials, are arranged to form the solar panel. The capacity of a PV cell will depend on cell efficiency and fill factor. The PV cell efficiency (η) is defined as the ratio of the maximum power output to input power of the system and it is calculated as [19]:

$$\eta = \frac{V_{mxpk} I_{mxpk}}{AI} \quad (1)$$

Here
V_{mxpk} = Voltage at peak power
I_{mxpk} = Current at peak power
A = Area of solar cell
I = Solar intensity per square meter

The PV cell can deliver maximum power for favorable environmental conditions of irradiance and temperature and the efficiency is highest in such cases. The Fill Factor (F_f) is defined as the ratio of

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maximum power from the solar cell to the product of open-circuit voltage (V_{oc}) and short-circuit current density (J_{sc}) and is expressed as [20]:

$$F_f = \frac{V_{mxpk} I_{mxpk}}{V_{oc} J_{sc}} \quad (2)$$

The authors of the accepted man The fill factor along with V_{oc} and J_{sc}, determine the maximum power from a solar cell. For a normal silicon PV cell, the Fill factor is 80% approximately.

The integrated photovoltaic (PV) system consists of the PV panel, a solar charge controller, batteries, and the submersible pump. Fig. 2 shows the integrated system. The solar PV panel is responsible for generating electrical energy from solar energy to produce the DC voltage. This DC voltage varies due to change in sunlight throughout the day. So batteries have been used to generate a steady DC voltage.

There are few factors that can affect the performance of solar panels and few of them have been mentioned below.

1) Direction: The panels with fixed position without any sun tracking mechanism should be facing south direction for better output throughout the year.
2) Tilt/Angle of Inclination: It should be as per the latitude of the place preferably.
3) Shading: Even a small part of shaded panel can affect the entire output of the panels largely. The shading effect affects the performance of PV panels and the output energy of the panels reduces due to this effect in presence of trees, clouds, buildings, etc. Shading can be uniform or non-uniform. For identical shading, the panels receive same amount of sunlight for a given amount of shading. So, reduction in sunlight is uniform across all the PV cells. Whereas, for non-uniform shading, the cells in the panel don't get same insolation. Thus, cells receiving lower irradiance will act as loads and behave in reverse biased condition that will lead to decrease in current, power and efficiency. It also needs to be ensured that the panels are placed such that there is no shadow on them throughout the day and the panels should be free from dust.
4) Temperature: If the temperature is higher, the output from solar panels will be lower.

Usually, panels are rated according to standard test conditions (i.e., temperature: 250C, insolation 1000 W/m2, Air Mass: 1.5). If temperature is higher than this, the panels will provide less than rated output.

The solar panels should be efficient ones as higher the efficiency, higher will be the energy generated per unit area. The solar panel block is capable of minimizing the shading effect and it contains 30 Tata BP Solar panels each of 150 W. The DC voltage from the photovoltaic system is fed to a couple of batteries to store the electrical energy and can be used consistently. After a battery is fully charged, it will not store incoming energy further.

If charging still continues, the battery will degrade rapidly leading to overheating. Therefore, there is a requirement of preventing the overcharging of batteries. PV panels work by pumping current through the batteries in one direction. At night, the panels will pass small current in reverse direction leading to slight discharge from batteries. Therefore, a charge controller is required to protect the system against overcharging and to block this reverse current. Some charge controllers protect the system from electrical overload as well. The charge controller provides three sets of terminals, one set for input from PV panels, one set for battery connection and the other set for inverter connection. The inverter generates 415 V AC. This system uses the 5 HP single-phase induction motor for Water pump. Table 1 shows the specification of the components. Fig. 1 shows the block diagram of water supply system using submersible pump used in this study. It consists of four blocks mainly, e.g., solar panel, solar charge controller, a battery and a submersible pump set.

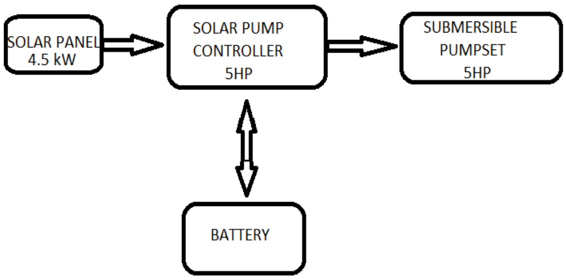

Fig. 1. Block diagram of water supply system using submersible pump

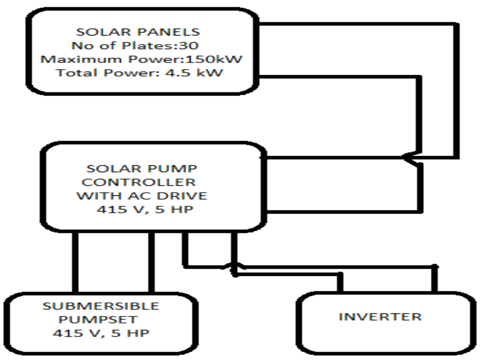

Fig. 2. Integrated SPV system for submersible pump

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Table 1. Specifications of the system.

Name of the component	Specification
Solar panel	Number of panels: 30 Maximum power=150 Maximum operating voltage=17.90V Optimum operating current=8.3amp Weight=26.5lbs Open circuit voltage=22.5V Short circuit current=9.05amp Dimensions=39.5*39*1.4 inches
Submersible pump	5 HP(3.728KW), 415V, 3 PHASE, 50-60cycle,VFD055E43A,INPUT DC VOLTAGE RANGE = 250V-780V,RECOMMENDED DC VOLTAGE(SOLAR PANEL)750V 10 Amp, 200 rpm, shut-off dynamic head=150 meters, water output=40800 liters per day from a total head of 100 meters
Solar pump controller with AC drive	3 PHASE,415V,3.7KW,5HP,in built PLC and EMC filter braking,VFD037E43A,inverter protection IP54
Mounting structure and tracking system	High wind velocity up to 150KM per hour, hot dip galvanized iron with minimum 80 micron thickness
Cable	10 sq mm single core cable

During daytime, the solar panel works as a source and provides electricity towards load and battery continues charging. During night, panel voltage becomes nearly zero and battery starts discharging to keep the load constant. By this process, it works efficiently.

III. PUMP CAPACITY CALCULATION

Following factors have been considered for calculating the pump capacity in the model village of Nepal with population of 1001.

- Daily water demand = 40 kLit and availability of solar energy per day for 5 hrs
- Water required per hour = 8 kLit and water required per minute 8000 /60 = 133.33 Lit
- Watt = HP x 746 Watt = 5 x 746 = 3750 Watt.

<u>Pump Requirement</u>

- Water required/day as 40 Lpcd
- 5 HP pump discharge = 500 Lpm for 30 m Head.
- Total discharge in 5 hours
- 500 x 60 = 60,000 Lit.
- In 5 Hrs.= 30,000 x 5 = 15,0000 Lit.
- Pump HP = 5 HP
- Discharge = 500 Lpm
- Head = 50 m

<u>Panel Requirement</u>

- 1m x 2m Panel = 0.15 KW.
- 1 m x 1 m panel x 7 no. – 1KW
- For 3.7 KW
- Panel required = 7 x 3.7 = 26 (1x2) [total 30 number of panel for extra load if required]
- Area required for Panel fitting: 1 x 2 x 30 = 60 m2
- Add 100% more space for gap between the panel and area around it, say, 60 m2 x 2 = 120 m2 = 1291 Sq. ft.

To adjust the wattage, loss of electricity in the cable and the control during transmission and conversion of electricity to the mechanical movements of the pump have been considered. The average efficiency rate of such pumps is about 85%.

IV. SOLAR SUBMERSIBLE PUMP INSTALLATION STEPS

The installation of the solar submersible pump has been achieved through the following steps.

- Determination of the irrigation requirement of the specific village according to the characteristics of its soil-type and climate.
- Doing a hydraulic analysis of the pumping system according to the depth of the aquifer and the height needed to stabilize the pressure in the water distribution network.
- Determination of the peak photovoltaic power required to irrigate a 10 HA sub-plot of the village considering the overall yield of the PV pump irrigation system.
- Selection of suitable PV panel size of the required output.

Following the above-mentioned steps, the solar submersible pump set has been installed in the model village of Nepal.

V. RESULTS

The rating of solar panel is 24 V/150 W. Here we are considering the voltage of panel under sunlight is 17~18 V that is within 24 V rated voltage. At this voltage, the battery charges and the motor rotates. Due to irregular irradiation, the intensity of the sunlight does not remain constant throughout the day, so the panel output voltage or load voltage fluctuates in nature. However, the charge controller always provides the constant voltage to the load. Therefore, the load voltage does not fluctuate. It also controls the reverse current flow and the battery can control the overcharging. Thus, the solar charge controller circuit is being used for controlling the load voltages.

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Table 2. Load values.

Solar panel voltage DC (Volt)	Load Voltage (submersible pump)(AC)	Load (submersible pump)KW	Load current through submersible pump (Amp)
24.3	414.8	3.7	6.437

Fig. 3. Installed Solar Panels

Fig. 4. Installed Water Pump

Fig. 5. Pump Controller

Fig. 6. Submersible Pump Set

Table 3. Cost analysis details.

Sl No.	Name of material	Cost (Rs.)
1	Solar panel (Number of panels: 30, Maximum power=150)	55/- per watt. (55x150) = 8250/- (per panel). Total panel cost: 8250/- (each) x 30=247500
2	5 HP(3.728KW),415V submersible pump	26000/-
3	Solar pump controller with AC drive for 5hp submersible pump	16000/-
4	Cost of mounting structure with installation cost	72000/-
5	Cost of cable	15000/-

VI. COST ANALYSIS AND PAYBACK CALCULATION

Since the initial investment cost seems to be high, it is expected to select the PV panels with long warranty period, generally 15-20 years. Some manufacturers promise the performance guarantee such as panels generating 90% of the rated output for the first ten years, while 80% of the rated output for next ten years. Some manufacturers also provide linear performance guarantee that seems to be a better option.

1) Cost of running Submersible Pump by electrical energy

Power consumption by the Submersible Pump is 3.7 kW per hour. Considering the use of pump for 3 hours per day and 30 days in a month, the total energy consumption would be 333 kWh almost. Now in Nepal, the applicable tariff per unit per month would be USD 0.12. So monthly cost would be USD 40.00, whereas annual cost would be USD 480.00. Thus, total cost due to energy consumption by the submersible pump over 12 years would be USD 5760.00 and for 25 years, USD 12000.00 approximately as it is known that the useful life of solar PV is 25 years.

2) Cost of Submersible Pump implementation and running the pump by electrical energy generated from solar energy

Total installation cost for 3.7 kW Solar Power generator would be USD 6100.00 and maintenance cost including battery and charge controller replacement per year would be USD 100.00 almost. Thus, cost at the end of 5 years would be USD 6600.00 and at the end of 12 years would be USD 7300.00, whereas at the end of 25 years it would be USD 10750.00 approximately. Although payback will start little late, the main advantage of such system comes from the unavailability of electricity in the village of Nepal under consideration. Electricity generation and transmission in remote villages of Nepal involve many challenges. In addition, power cut is a common problem and can continue for 5-6 hours daily during daytime causing disturbances to irrigation system leading to fall in agricultural productivity.

VII. CONCLUSION

In Nepal, the availability of electricity by conventional methods is decreasing day by day and it leads to increase in the cost of electricity. As a result, the load of expenditure on the Government funded schemes that includes supporting the irrigation process in dry areas of Biratnagar district increases gradually. Moreover, the whole fund would be consumed in a short period if the entire irrigation process including water extraction depends on conventional or non-renewable energy only leading to failure of such irrigation model dependent solely on the conventional or non-renewable energy only. The initiative to look for alternative options of implementing irrigation system has led to using the solar photovoltaic system for running the system making the solar pump system the most economical remedy for the scheme. Solar pumping decreases the electric charges and saves the money, which can be used in other schemes. In addition, the submersible pump and equipment have low maintenance cost and running cost making the system more ecofriendly.

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