Performance Evaluation of Standalone Solar Powered Water Irrigation System Using DC Pump

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Abstract. In the present scenario, the demand for agriculture is increasing abruptly due to the population in the world. In agriculture, irrigation plays a major role. As it requires electricity supply to irrigate the field, farmers find it an additional expense towards the electricity cost and also it is challenging to provide the uninterrupted supply to farmers. Though our government provides subsidies, the demand for electricity throughout the world is increasing. Especially as we tend to rely on agriculture for our daily life and considering the hardship faced by the farmers, nowadays people tend to move towards solar power but the existing grid connected system may lead to high cost, need of more space, and needs proper maintenance. The use of DC pumps overthrow the struggles of farmers and to pave a way to increases agricultural practices. This system consist of array of 3 panels connected to the DC motor of 0.75 kW. The use of DC motor assists in storing the power generated by the system and can be used during night time or in case of emergency situation, providing uninterrupted power supply. This system serves the important advantage to the environment that it reduces CO2 emission as it eliminates the use of fuel for pumps to operate. As the system is designed autonomous, it also reduces space occupancy. The panel setup is placed in an appropriate location so that it could receive more radiation, as a result generates maximum power. The parameters like power, power quality and pumping rate has also been analyzed under varying atmospheric conditions under specific period of time. Thus this system provides the more efficient way to utilize the solar power and to generate maximum energy for use.

Keywords: DC pump; DC motor; solar panel; grid-independent; eco-friendly; power quality; pumping rate

1. Introduction

Irrigation at reasonable cost and reduced usage of non-renewable energy are some of the biggest challenges faced by our country [1, 2]. The diesel based system is expensive, causes air pollution and creates noise [3]. Even though certain obstacles are found in implementing the renewable energy based systems, it is inevitable to adopt the renewable energy sources for water pumping applications [4-6]. Amongst many forms of renewable energy sources solar energy is the best candidate for pumping the water and irrigation for agriculture land and domestic purpose [8, 9]. Hence the solar photovoltaic (SPV) powered water irrigation method found to be the most favorable and emerging system nowadays. The water pumping system powered by SPV source need to be extensively used for agriculture purpose to improve the cultivation and also it avoids the issues such as intermittent electricity supply at rural areas, high price for electricity consumption and
polluting the environment etc., [10-12]. This article discusses the design, static and dynamic function and performance analysis of the solar PV powered water pumping system and the block diagram of the system is shown in below figure 1.

![Block Diagram of the System](image)

**Figure 1.** Block Diagram of the System

2. **Design of Solar Photovoltaic Powered DC Water Pumping System**

To make the water pumping solution the most reliable and nominal price, attention need to pay in the design part [13-16]. Improper design leads to malfunction, limitation in extends its maximum performance and hence less efficient system. This section gives the details on designing solar PV powered water pumping system. The figure 2 shows the sequential approach of the DC pump design.
Area of water need to provide for irrigation

**Sequence of Tasks**

- Determine the daily water requirement
- Calculate total dynamic head (TDH)
- Hydraulic energy requirement calculation
- Solar PV array calculation
- Calculation of DC pump capacity
- Battery Capacity calculation & charge controller selection

**Associated Tasks**

- Area of water need to provide for irrigation
- Elevation head
- Frictional head loss for fitting
- Mass
- Volume
- TDH
- Solar Radiation data
- System Losses
- mismatch factor
- operating factor for PV panel
- DC motor sizing
- Required Ah of a battery
- Hours of autonomy
- Charging current of battery

**Figure 2.** Design Flow Diagram

### 2.1 Design of Solar Powered DC Water Pumping System

The water pumping system which operated through DC pump has been designed and the suitable DC pump, battery and its charge controller is selected with respect to the designed values. The daily water requirement is 40 m³/day.

- Elevation head = (3+1) = 4 m
- Fitting’s frictional head loss = (0.11 m + 1.6 m) = 1.71 meter
- Total head loss for piping = 0.218m & Total frictional head loss = 1.928
- Total dynamic head = Frictional head loss + Elevation head = 5.828m ~ 6m
- Required hydraulic energy to pump the water = Mass x Gravity x Volume x Total dynamic head = 653.33 Wh/day

### 2.2 Sizing of solar PV panel and pump

- Total power of solar PV panels = \( \frac{\text{Calculated Hydraulic Energy}}{\text{Hours of Operation}} \) = 108.88W
- Considering System Losses = \( \frac{\text{Total wattage of PV panel}}{\text{pump efficiency} \times \text{mismatch factor}} \) = 426.98W

(Pump efficiency is assumed to be 30%, mismatch factor = 0.85)
Considering the PV panel’s operating factor = Total power of PV panel Excluding losses
                                            Operating factor
= 569.31 W

No of Solar PV panel required if panel rating is 250 Wp = 2.27 ~ 3 panels
              Power Rating of Motor = 0.76 ~ 0.5 HP Motor.

Totally 3 panels have been chosen. Parallel connection of all the 3 panels are made to fulfill the current rating of DC pump. The data sheet of the selected solar PV collector is given in below table.

| Parameters                        | Values   |
|-----------------------------------|----------|
| Peak Power (P peak)               | 250 W    |
| Current at P peak (I m)           | 8.33 A   |
| Voltage at Open Circuit (Voc)     | 36.8 V   |
| Current at Short Circuit (Isc)    | 8.83 A   |
| Rating of Series Fuse             | 20 A     |

No. of solar panel used = 3 (panels connected parallel)
Total panel power (Ppv) = 750 kWp
Current at the parallel connected panels = 24.99 A

2.3 Design/selection of charge controller and storage element

The charge controller (DC-DC converter) efficiency: 97 %
Power rating of DC-DC converter is 30% higher than the motor rating.

2.3.1 Sizing of Battery

The required hours of autonomy, T = 4 hrs
Power rating of DC pump, P = 0.5 HP = 373 W.
Required pump energy = 373 W × 4 hrs = 1492 Whr.

Required Ah of a battery = \[ \frac{1492 \, \text{Whr}}{24 \, \text{V}} \]
                         = 62.1 Ah

Since, DC motor requires 24 V & 20A, 2 nos (12V) of 75Ah battery has been selected and connected in series.
When DC pump operated with battery (when the absence of sunlight) it takes current of 20A (maximum).
Hence hours of autonomy will be calculated as
Hours of autonomy = \[ \frac{75}{20} \] = 3.75 hrs. ≈ 4 hrs.

Hence the batter capacity & its configuration is sufficient to run the DC pump for 4 hrs. Similarly while charging through the 3 nos of 250 W solar panels (connected in parallel) it takes current of 10A (Since battery has a C10 rating)

Therefore required charge time = \[ \frac{75}{10} \] = 7.5 hrs.
3. Results and Discussion

The function of the designed system is analyzed with various parameters with respect to irradiance [15]. Parameters include panel voltage, current, power water pumping rate and efficiency.

3.1 Performance analysis of DC pump through PV Syst

The performance analysis of DC pump is examined on the basis of manual calculations. From the manual calculations, for DC system 0.5 HP DC motor is required to pump 40 m³/day.

![Incident irradiation distribution](image1)

![Incident irradiation tail distribution](image2)

**Figure 3.** Incident irradiation distribution

**Figure 4.** Incident irradiation tail distribution

The Fig. 3 shows the graphical representation of global irradiation distribution which ranges from 2 kWh/m² to 75 kWh/m² against the global incidence in coll. plane between 0 to 1150 W/m².

The above fig.4 shows that the cumulated global incident irradiance in collector plane falls down as the global incident in collector plane increases and it almost reaches to zero when the global incident reaches the maximum value (1200 W/m²).

![Flow rate function of irradiance of DC pump](image3)

![Daily water production vs irradiance of DC pump](image4)

**Figure 5.** Flow rate function of irradiance of DC pump

**Figure 6.** Daily water production vs irradiance of DC pump

The figure 5 shows the graph obtained between the effective global corr. for 1 AM and shading in W/m² and the average flow rate. Figure 6 shows the amount of water pumped with respect to the effective global irradiance. From the above figures, it is understand that both the flow rate and amount of water pumping are directly proportional to the effective global irradiance collected on the installed solar PV array.

3.2 Static response of SPV based water pumping system through hardware results

The various performance parameters associated with the solar PV powered water pumping system of DC pump is measured at 800 W/m² and same are presented in the below figures. Fig. 7 shows the static response of SPV water pumping system of DC pump.
Figure 7. Static response of SPV water pumping system (a) \( V_{pv} \) & \( I_{pv} \) (b) \( V_{o} \) & \( I_{o} \)

From fig. 7, it is understand that, the non-distorted volatge and current are obtained from the solar PV panels. PV voltage is 28 V and its current is 20.4 A at 800 W/m\(^2\). Therefore the input power will be 571 W. This DC power is fed to the DC pump through charge controller. The output voltage and current are 24 V and 21.5 A respectively and hence the output power is 516 W. Therefore the calculated efficiency of the charge controller is 90 %.

3.3 Dynamic response of solar PV powered water pumping system

The dynamic analysis of the SPV water pumping system helps to understands the efectiveness of the entire system during irradiance changes. This analysis also ensures the ability of the components especially the controller which aid for the converters and the pump. The below fig. 8 shows that the dynamic results of \( V_{PV} \) and \( I_{PV} \) during the irradiance fluctuations from 650 W/m\(^2\) to 730 W/m\(^2\).

Figure 8. Dynamic result during the irradiance variations- 650 W/sq.m to 730 W/sq.m

From fig. 8, it is witnessed that the voltage and the curent of PV source changes from 27.4 V to 28 V and 16.2 A to 18 A respectively for the same irradiance changes mentioned above. The maximum power at the PV array while 650 W/m\(^2\) is 444 W and 730 W/m\(^2\) is 504 W. However its MPPT efficiency is almost constant as 99 %. And its tracking time delay is about 3 ms.

4 Performance Evaluation of solar PV powered water pumping system

The performance of the water pumping system which operated by the solar PV source has been analyzed through the results obtained from the preceding sections. The performance analysis of the system is used to eradicate the drawbacks or faults existing in the system and also to improve its efficiency and durability, so that the users or customers of the solar PV water pumping system getting benefitted. The various paarmeters have been considered as the performance factors.Fig. 9 shows the \( V_{PV} \), \( I_{PV} \) and \( P_{PV} \) values against different irradiance G.
Figure 9. Irradiance Vs V_{PV}, I_{PV} and P_{PV}

The measurement has been taken on the sample day of 12th March, 2020 and the same is presented in the fig. 9. From fig. 9, it is understood that when G changes, the V_{PV}, I_{PV} and P_{PV} are also changing correspondingly. Similarly, in the solar PV DC pumping system, the recorded minimum voltage is 24.5 V at 150 W/m$^2$ and the maximum voltage is 29 V at 1000 W/m$^2$.

The various output parameters of SPVWPS with DC pump have been analysed as follows,

Figure 10. Performance parameters associated with SPVWPS with DC pump for different irradiance

From the fig. 10, it is understood that when G increases, Vo, Io and Po also increase and hence flow rate and pressure of water increases as observed in the Fig. 10 (a) and (c) respectively. Fig. 10 (b) shows the relationship between irradiance and efficiency of the charge controller. At the irradiance 700 W/m$^2$, the required power for the DC motor is obtained from the solar PV source and hence above 700 W/m$^2$ the total power which is generated through solar PV source is not being exploited by the DC motor to its full extent. Therefore, its efficiency is declined above 700 W/m$^2$ as observed in fig. 10 (b). The difference in the input and the output power validates the losses existing in the charge controller. The efficiency increases when G increases. The maximum efficiency is obtained as 97% at 700 W/m$^2$.

When water pumping is not required from solar powered DC pump, it can be switched off and during that period, the battery bank connected with this system gets charging if its SoC is less than the prescribed set.
value. The various parameters during charging of battery while DC pump turned off and discharging of battery during non sun shine hour is given in Table 2.

| Irradiance (W/m²) | Ib (A) | Vb (V) | Pb (W) | Io (A) | Vo (V) | Po (W) | Flow rate (m³/h) | Pressure (psi) | η (%) |
|-------------------|--------|--------|--------|--------|--------|--------|-----------------|---------------|------|
| 400               | 11     | 24     | 260    |        |        |        |                 |               |      |
| 800               | 24     | 24     | 574    |        |        |        |                 |               |      |
| 0                 | 21     | 24     | 495    | 20     | 24     | 480    | 1.7             | 17            | 97   |

From table 2, it is understood that, when DC pump is turned OFF and the SoC of battery is less than 90 % the battery gets charging through charge controller. The charge controller maintain its output voltage as 24 V irrespective of the solar PV input voltage. The charging current is based on the irradiance. When less current generated by the solar PV source, the charging time gets increased and vice versa. During non sun shine hours, the DC pump can be run through the energy stored in the battery through charge controller. While the battery discharging, the current and voltage is constant since the motor consumed its own required power from the battery and therefore the flow rate and pressure of water does not change as seen from the table 2. In this particular case, flow rate and pressure is 1.7 (m³/h) and 17 psi respectively. The efficiency is noted as 97 %.

5. Conclusion

Performance Evaluation of Standalone Solar Powered Water Irrigation System Using DC Pump has been done using PVsyst software. Initially the design is performed manually and verified with the results obtained from PVsyst software and it is observed that both the calculations and simulation results are similar and it leads to the same sizing. The solar PV water pumping system is installed at an appropriate location where shading does not exist. The overall performance of the system is examined at varying atmospheric conditions in accordance to parameters like voltage, current, power, flow rate, pumping water pressure and the system’s efficiency. The designed DC pump based solar PV water pumping system is a good candidate for the replacement of the existing grid connected pumping system.

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