Theoretical Design and Simulation Analysis of PV Based Pumping System for Domestic Applications in Bhopal, M.P, India

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Abstract: ***Electricity is an essential part of our way of daily life. In the present scenario, most of the electricity is provided from the conventional thermal or hydro power stations. Irregular power supply and frequent grid failure are regular phenomenon in most Indian cities especially during peak summer and winter seasons. The use of photovoltaic array for water pumping system is one of the most promising techniques in solar energy applications. Deployment of PV based solar pumping system for domestic applications is an viable alternative to replace conventional grid electricity .In this paper, theoretical design, performance and simulation analysis of PV based water pumping system with the use of the computer software PVsyst is carried out. According to the analysis, the solar water pumping system has a system efficiency of 21.9% which is in fair agreement with the previous literature .Therefore SWPS is strongly recommended for both urban as well as rural water supply system.***

Keywords: Solar Photovoltaic module, PVsyst software, Performance Analysis, Bhopal, Agriculture and Domestic applications.

1. Introduction

There is a big issue that fossil fuels are getting depleted at faster rate and another challenge is to face the climatic changes the world is undergoing [1] .In city like Bhopal, India, centralized water supply board provides water supply during certain hours of the day and also supply pressure is generally insufficient. Apart from the central water supply, households have independent groundwater deep wells from which water is to be lifted for consumption. In residential areas ground water from bore well is being used, hence there is need for pumping water to overhead tanks. In the current situation water pumps in every household are driven by electric motors and these electric motors uses conventional electricity [2]. Also the Per capita energy consumption is high in urban residential areas of Bhopal

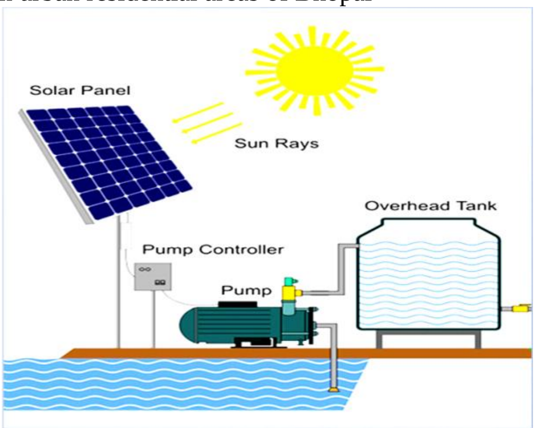

Figure 1: Schematic diagram of solar pumping system

Among all renewable sources of energy, solar photovoltaic energy is accepted as the most reliable and cleanest source of alternate energy. Solar water pumping system offers many advantages such as no fuel cost; require low maintenance, highly reliable, ease of operation and emissions. However, PV module still has relatively low conversion efficiency 15 to 19% depending on the type of PV cell [1-3]. Solar module constitutes 40 to 50% of the total cost of the solar PV system. Solar water pumping system is considered as viable and appropriate option especially in rural areas where grid connection is practically impossible [4].

In this context, this paper proposes a design and simulation of domestic solar pumping system for Bhopal, India

2. Methodology

2.1 Theoretical Analysis of Solar Water pumping

In order to study the energy conversion from solar radiation to water flow, the following equations were used. The incident solar radiation to the PV array gives the input power (Pi) to the system:

$$P_i = G \times A \text{ (W)} \quad (1)$$

Where G = solar radiation (W/m^2) and A = effective module cell area (m^2).

The DC output power (Po) from the PV array is given by:

$$P_o = V \times I \text{ (W)} \quad (2)$$

Where V = DC. Operating voltage (V); I = DC operating current (A). [5]

2.1.1 PV Sizing

The empirical formula based on energy balance equation has been used to compute the optimal size of PV module for critical limit of load as stated below [6]

$$\text{PVcell rating} = \frac{P}{\text{Sun hour}} \quad (3)$$

$$\text{The optimal number of PV module} = \frac{\text{PV rating}}{\text{Standard PV module}} \quad (4)$$

2.1.2 Battery Sizing

Battery stores the energy to a maximum value as per average load power requirement. [7]

$$\text{The battery capacity} = \frac{\text{Total energy requirement}}{\text{Max \%usable} \times \text{controller efficiency} \times \text{battery nominal voltage}} \quad (5)$$

2.1.3 Pump Motor

The pump is driven by ac motor whose optimal value can be computed by the following expression. [6]

$$\text{Motor Power} = Ph / \eta \qquad (6)$$

Where Ph = Hydraulic power of pump [W]
η = Efficiency of pump

The hydraulic power output of the pump (P_h) is the power required to lift a volume of water through a given head:

$$P_h = \rho \times g \times Q \times H \text{ (W)} \qquad (7)$$

Where ρ = water density (kg/m^3); g = specific gravity (m/s^2); Q = water discharge (m^3/s) and H = total pumping head (m).

2.1.4 System Efficiency

Array efficiency (E_a) is the measure of how efficient the PV array is in converting sunlight to electricity:

$$E_a = P_o/P_i \times 100\%. \qquad (8)$$

Subsystem efficiency (E_s) is the efficiency of the entire system components (inverter, motor and pump):

$$E_s = P_h/P_o \times 100\%. \qquad (9)$$

Overall/System efficiency (E_o) indicates how efficiently the overall system converts solar radiation into water delivery at a given head:[5]

$E_o = P_h/P_i$

or

$$E_o = E_a \text{ x } E_s. \qquad (10)$$

2.2 Simulation using PVSYST SOFTWARE

PVsyst software is able to import meteo data from many different sources as well as personnel data. The software consists of three main design steps [8]. The preliminary design option allows evaluating grid-connected, stand-alone and pumping systems, and using monthly values to perform a quick evaluation of system yield. For each project the location and the system to be used has to be specified. The program includes predefined values of locations of different parts of the world. The second one is project design option allows to create full-featured study and analysis of grid-connected, stand-alone, pumping, and dc-grid systems with accurately system yields computed using detailed hourly simulation data. Different simulation variants, horizon shadings, detailed losses, and real components can be added to make economic evaluations. Reports can be generated after the completion of the project and information can be exported to the clipboard. The last option includes meteorological data, components, solar toolboxes, and the analysis of actual data.

2.3 System parameters

Table 1 to 6 shows input parameters used in PVsyst software.

Table 1: Geographical Details

Site	Bhopal
Latitude	23.2 N
Longitude	77.4 E
Altitude	534 m

Table 1 depicts the geographical conditions of location is to be considered. The above details are given as input to obtain the solar irradiation for site.

Table 2: Well characteristics

Static level depth	50 m
Max. pumping depth	56 m
Pump depth	58 m
Well diameter	18 cm

Table 2 depicts the well characteristics of site to be considered. Static level depth of the well is taken as 50 m and well diameter is 18 cm.

Table 3: Storage tank

Volume	20.0 m^3
Diameter	3.5 m
Height (full level)	2.1 m
Feeding altitude	12.0 m

Table 3 depicts the features of storage tank, which is used in water pumping system for water storage.

Table 4: Hydraulic circuit

Piping length	70 m
Pipes	PE20(3/4")
Number of elbow	1
Other friction losses	0.450
Water needs(yearly constant)	5.00

Table 4 depicts the features of hydraulic circuit, the above details shows number of elbow used and daily water requirements.

Table 5: Pump characteristics

Model	4GS11
Manufacturer	Lowara
Pump Technology	Centrifugal multistage
Motor	Async. AC motor, mono phased
Power	867

Table 5 depicts the pump characteristics. 4GS11 Model pump Lowara make is used. The power of motor is 867 watt.

Table 6: PV Array characteristics

PV module	Si-mono
Number of PV modules	18
Unit nominal power	100 W_P
Array global nominal power	1800 W_P
Max. operating power(50^0 C)	1615 W_P
V_{MPP}	276 V
I_{MPP}	5.8 A
Module area	14.9 m^2

Table 6 depicts the details about the Specification of the PV module. Number of modules required for 1800 watt solar PV plant is 18. The area requirement for installing the plant is 14.9 m^2. It also represents the operating conditions of PV system.

3. Results and Discussion

3.1 Climate data of Bhopal

Table 7: Monthly Climate Data for Bhopal

	Horizontal global kWh/m²	Horizontal diffuse kWh/m²	Extraterrestrial kWh/m²	Clearness Index	Ambient Temperature °C	Wind Velocity m/s
Jan.	135.7	41.2	217.9	0.623	17.8	2.0
Feb.	147.2	44.2	229.6	0.641	20.6	2.4
Mar.	191.5	57.6	292.2	0.655	26.5	2.6
Apr.	205.3	60.4	314.3	0.653	30.8	3.2
May	213.5	76.9	341.2	0.626	33.6	4.3
June	170.8	92.3	334.6	0.511	30.2	4.5
July	128.8	91.0	342.9	0.376	27.0	4.1
Aug.	126.7	83.7	330.8	0.383	25.5	3.7
Sep.	138.9	75.5	294.8	0.471	26.0	2.7
Oct.	170.4	51.5	267.1	0.638	25.6	1.6
Nov.	140.4	41.7	220.2	0.637	22.2	1.5
Dec.	131.6	35.5	206.5	0.637	18.7	1.5
Year	1901.1	751.2	3392.3	0.560	25.4	2.8

3.2 Design calculation for solar pumping system

Approximate water requirement for the domestic building is taken as 5000 liters per day.
Total water demand =5000 liters/day
For storage of water, 20000 liter water tank is appropriate.
Taking peak sun hour as 6 hours/day, Duration of pumping = 4 hours
Flow Rate, Q = $(5000\times10^{-3}) / (4\times60\times60) = 0.000347\ m^3/sec$
Total dynamic head = elevation head + friction head loss + pressure head
Total dynamic head = 68 + 68×20% (20% for losses) + 0 = 81.6
Total water head = 81.6 m
For 81.6 m total water head, the hydraulic power for this flow rate is,
Hydraulic power = ρgQH = 277.488 W
A pump converts the mechanical energy to hydraulic energy with an average efficiency of 45 %.
DC Motor converts electrical energy to mechanical energy with an average efficiency of 55%. [9]
Electrical power required= (hydraulic power) / $(\eta_{pump}\times\eta_{motor})$ = 1121.16 W
Pump run for 4 hour
Energy Requirement = 1121.16 ×4 W-hr /day = 4484.65 W-hr /day

Photovoltaic panel sizing
PV-power tolerance: -10%/+10%
Heat loss: 10%
Dirt loss: 2-15%
Wiring loss: 2-10%
Inverter/charger loss: 2-15%
Batteries: 30%
Here considered average loss
PV power loss: 2%
Heat loss: 10%
Dirt loss: 5%
Wiring loss: 3%
Inverter loss: 7%
Battery loss: 30%
Total loss = 57%
Taking average total loss =50%
Energy requirement = 4484.65W-hr/day
After including 50% for losses,
Total requirement of energy =2×4484.65 = 8969.30 W hr/day
Peak sun hour =6 hours/day
Recommended wattage for PV panel = (8969.30) / (6) = 1494.88 W
In solar pumping system, 12 V deep discharge battery is commonly employed. Since the energy requirement is 4484.65 W-hr, the energy storage requirement for 2 days of no sun, the required battery size is obtained as follow:

Battery sizing

$$\frac{\text{Total energy requirement}}{\text{Max\%usable} \times \text{controller efficiency} \times \text{battery nominal voltage}}$$

= (2×4484.65)/ (.7×.98×12)
=1089.56 Ah
A 12 V, 1100 Ah deep discharge battery is sufficient for operation.

3.3 Performance Analysis of Solar Pumping system

Table 8: Simulated results of solar water pumping system

	GlobEff kWh/m²	EArrMPP kWh	E PmpOp kWh	ETkFull kWh	H Pump meterW	WPumped m³	W Used m³	W Miss m³
January	173.1	258.7	50.88	190.5	74.57	163.3	155.0	0.000
February	173.3	253.8	42.27	193.7	75.91	140.2	140.0	0.000
March	202.8	285.5	49.01	218.1	74.60	155.0	155.0	0.000
April	194.5	268.3	50.11	201.9	72.08	150.0	150.0	0.000
May	187.3	257.3	54.18	185.3	70.61	155.0	155.0	0.000
June	147.9	210.3	55.24	135.0	69.25	150.0	150.0	0.000
July	115.4	169.6	61.46	80.4	67.96	155.0	155.0	0.000
August	116.4	171.4	57.84	83.1	69.73	155.0	155.0	0.000
September	136.7	198.8	55.30	121.8	69.69	150.0	150.0	0.000
October	193.0	274.1	52.35	206.4	72.43	154.8	155.0	0.000
November	175.6	255.2	50.47	190.0	72.52	150.2	150.0	0.000
December	176.6	262.5	49.36	195.6	74.17	155.0	155.0	0.000
Year	1992.6	2865.5	628.47	2001.8	71.51	1833.5	1825.0	0.000

Table 8 depicts the balance and main results of PV based water pumping system.

Yearly Global Effective irradiation is 1992.6kWh/m². The Yearly Array virtual energy at MPP is 2865.5 kWh. Total Energy used by pump throughout the year is 628.47 kWh. Yearly Average total head at pump is 71.51 meter. Yearly water used by the user is 1825.0 m³.

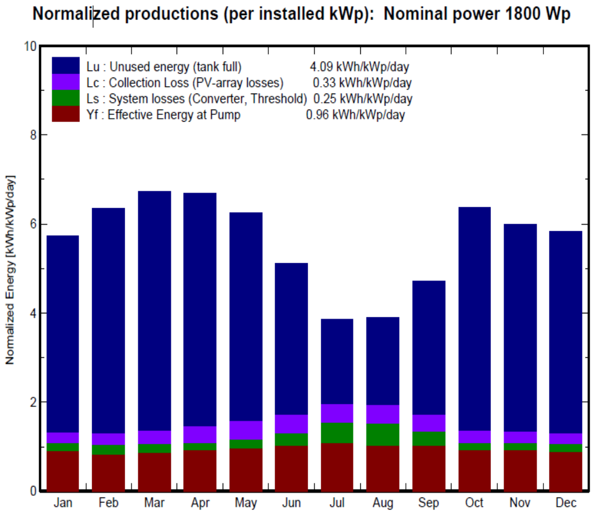

Figure 2: Normalized energy

Performance Ratio (PR) is the ratio of final PV system yield (Y_f) and the Reference yield(Y_r) [10].

$$PR = \frac{Y_f}{Y_r}$$

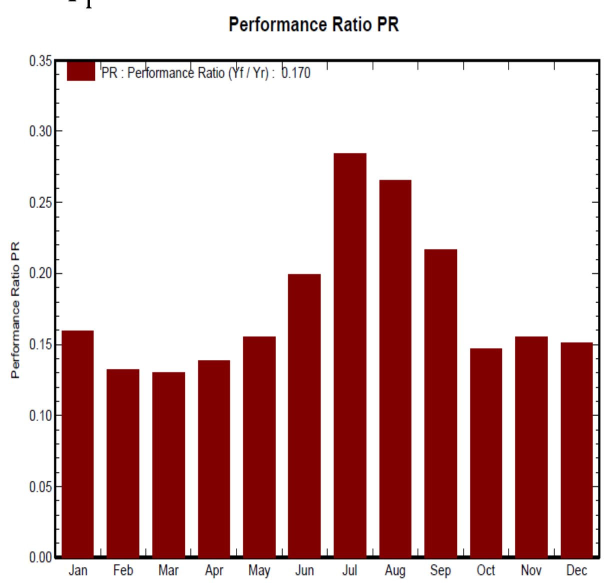

Figure 3: Performance ratio

Fig. 3 represent the Performance Ratio of the Incident energy for the entire month of the year graphically. The average Performance Ratio is 0.170.

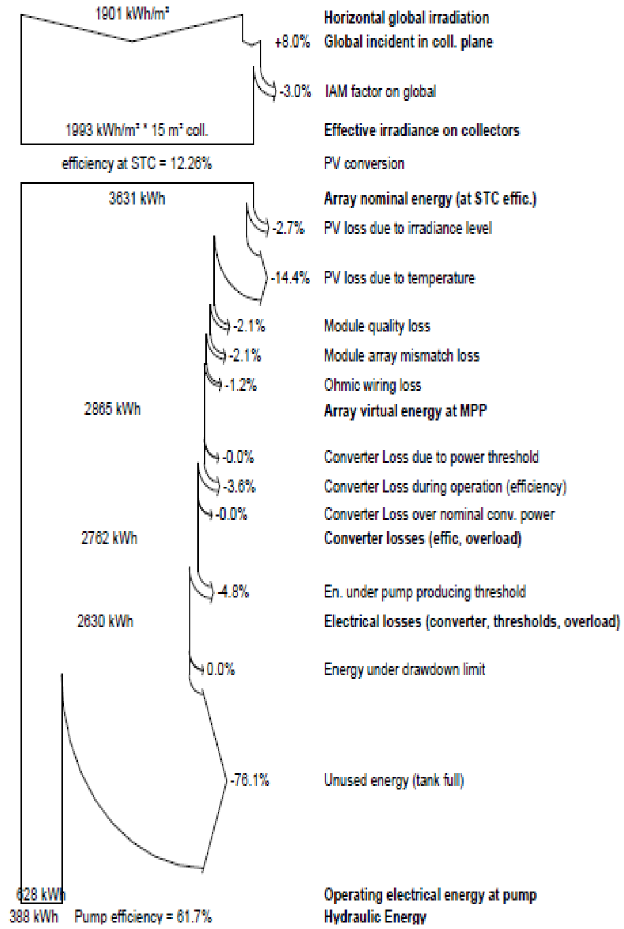

Figure 4: System loss diagram.

Fig. 4 represents the overall system loss diagram for the system. The horizontal global irradiation is 1901 kWh/m^2. The effective irradiation on the collector plane is 1993 kWh/m^2. Then the PV cell converts solar energy into electrical energy. After PV conversion, array nominal energy is 3631 kWh. The efficiency of PV array is 12.26% at Standard Test Condition (STC). Array virtual energy obtained is 2865kWh. After the converter loss and Electrical loss, the available energy at the output is 2630kWh. The used operating electrical energy at pump is 628kWh. According to the analysis, the solar water pumping system has a system efficiency of 21.9% which is in fair agreement with the previous literature [11-12].Therefore SWPS is strongly recommended for both urban as well as rural water supply system Ministry of New and renewable Energy, Govt of India is providing subsidies for Installation of solar water pumping systems in India. However the initial investment cost is very high for the public to install such systems

4. Conclusion

A detailed analytical investigation of a typical SWPS is carried out in order to realistically estimate the solar PV sizing for the proposed installation. PVsyst software is used to design and perform simulation of water pumping system.

- The solar water pumping system is used to provide 5m^{3}water per day.
- The simulation results have shown the pump efficiency of the water pumping system is 61.7% and System efficiency of the water pumping system is 21.9%.

- The energy performance of the SWPS is satisfactory and may significantly contribute to the urban and rural water consumption needs.
- SWPS are already widely adopted in several rural areas where the vital need for water cannot be always supported by a local electricity network and the respective PV-application
- Thus, it is quite reasonable that SWPS may be used for covering both irrigation needs and potable water supply.

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