# Designing and Performance Evaluation of a Solar Water Pumping System

A thesis submitted to The Department of Mathematics and Natural Sciences, BRAC University, in partial fulfilment of the requirements for the degree of Bachelor of Science in Applied Physics and Electronics

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# Declaration

I do hereby declare that the thesis titled "Designing and Performance Evaluation of a Solar Water Pumping System" is submitted to the Department of Mathematics and Natural sciences of BRAC University in partial fulfilment of the requirements for the degree of Bachelor of Science in Applied Physics and Electronics. This research is the work of my own and has not been submitted elsewhere for award of any other degree or diploma. Every work that has been used as reference for this work has been cited properly.

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# Abstract

This study includes the detailed designing of solar water pumping system and its performance evaluation. Water pumping system is an ancient procedure and many methods have been established. Human energy, animal power, hydro power, wind, solar and fossil fuels for small generators are all used as power source, above all PV system is chosen because it is durable ecofriendly and long lasting. As Bangladesh is at semi-tropical region so sunlight is available for that PV system is perfect for generating power for pumping. A good sizing is important for having more efficient system. A flowrate equation related with input power of the PV system has been established based on $1^{st}$ affinity law, $2^{nd}$ affinity law, and efficiency law and power equation. With the help of equation, the input power and the Flowrate has been analyzed, based on that analyzation the sizing can be assumed more accurately and increased the efficiency. Thus the performance of the systems has evaluated.

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# Chapter 1

## Introduction

### 1.1 Objectives

The main objective of this thesis paper is to design and evaluate the performance of a solar water pumping system. Moreover, the specific objectives are, to study different types of pumping System, design a solar powered water pumping system, and evaluate the performance of solar powered water pumping system.

### 1.2Background

There is a long story of water pumping and so many methods have been developed for pumping water with a minimum of effort. Most developed water pumping tools are pumping motors. Centrifugal pump is widely used for this purpose and different types of power sources are used for example human energy, animal power, hydro power, wind, solar and fossil fuels for small generators. Above all solar powered water pumping system is used widely because of its durability, mobility and long term economic benefits. It has proven an ideal way to lift water for irrigation, drinking or livestock.

Since 1980 photovoltaic pumps are on the market and people are using them. PV system is a technology where light converts to electricity. In 1955 the development of PV system has stared and in 1980 it came of age. Initially it was known as "space age" because it was limited to the satellite. In 1980 the cost of the making modules reduced by two third and became affordable to general public [1].

Solar Photovoltaic (PV) Panels are undoubtedly the most ecofriendly system. Here are some reason for choosing PV system -

- PV panels provide clean and green energy. During electricity generation with PV panels there is no harmful greenhouse gas emissions thus solar PV is environmentally friendly.
- Solar energy is energy supplied by nature and it is thus free.

- Solar energy can be made available almost anywhere there is sunlight
- Solar panels cost is currently on a fast reducing track and is expected to continue reducing for the next years and consequently solar PV panels has indeed a highly promising future both for economic viability and environmental sustainability.
- Photovoltaic panels, through photoelectric phenomenon, produce electricity in a direct electricity generation way.
- Operating and maintenance costs for PV panels are considered to be low, almost negligible, compared to costs of other renewable energy systems.
- PV panels have no mechanically moving parts, except in cases of –sun-tracking mechanical bases; consequently they have far less breakages or require less maintenance than other renewable energy systems.
- PV panels are totally silent, producing no noise at all; consequently, they are a perfect solution for urban areas and for residential applications
- Because solar energy coincides with energy needs for cooling PV panels can provide an effective solution to energy demand peaks, especially in hot summer months where energy demand is high.
- Residential solar panels are easy to install on rooftops or on the ground without any interference to residential lifestyle.

Based on solar cell PV systems are made. It is a silicon made thin paper. When it comes under the sun it creates current. These solar cells are assembled in panels which is called modules. The whole solar water pumping system consist of three major components –

- PV Systems
- Electrical controllers
- Electrical pump

### 1.3 Methodology

Based on the water requirement of the land and depth of the water level, the system designer must select the pump. Based on the requirement and the other components of the solar water pumping systems are sized to satisfy the required energy demand of the pump. By establishing a relation between flowrate and input power of PV system based on basic fluid equation and PV system the performance of the system will be evaluated.

`

For irrigation water pumping systems are required for most of the months of a year except the rainy season. Solar water pumping system can be a good solution. In order to select different components of a solar water pumping system, sizing of its different components are essential. If the system are not sized properly, the cost of the energy of the system will be considerable high and system will not work efficiently,
Moreover, the flowrate of the water pumping must be linear function of the input energy generated by PV system. This types of empirical equation helps the system designer to select the proper combination of the PV and other major component of the system

**1.4 Assumption and Limitation**

For this evaluation propose, a PV system has assumed which is capable of 3000 watt or 3kW and a 2846W or 2.8 kW pump is assumed for water pumping. Pump's head is 2m.This pump ran by this PV system. All the values and evaluation are based on these assumptions.

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# Chapter 2

## Literature Review

### 2.1 Energy scenario of Bangladesh

Bangladesh is a small developing country with limited indigenous energy resources. Per capita consumption of energy in Bangladesh is one of the lowest in the world. Present consumption of energy and electricity in the country is about 200 KGOE/year and 130 kWh/year respectively in which about 65% of its per capita energy is derived from biomass resources. In recognition of the importance of energy in socio-economic development, the Government has given continuing attention to the overall development of the energy sector. But up to now, it has not been possible to achieve reasonable success in meeting the growing demands and the gap between the projected demand and the supply serve is increasing day by day because of inadequacy of indigenous resources, improper planning, unreliable policies and decisions on the development of power sector. Like many other developing countries, Bangladesh is facing enormous challenges to provide affordable, reliable and equitable energy supply to its citizens. About 25% of the population has only access to electricity. Consumption of energy and electricity in per capita terms is one of the lowest in the world. Noncommercial energy sources, such as wood, animal wastes, and crop residues, are estimated to account for 65% of the country's energy consumption. [2]

From the BPDB report, 2010 demand forecast was made based on 7 % GDP growth rate. The electricity development is required to be accelerated to increase access and attain economic development. The desirable economic growth rate would be about 7% p.a. Based upon this study the peak demand would be about 10,283 MW in FY2015, 17,304 MW in FY2020 and 25,199 MW in 2025. According to PSMP- 2010 Study year-wise peak demand forecast is given below. [3]

**Table 2.1: Peck demand chart [3]**

| Fiscal Year | **Peak Demand (MW)** |
|---|---|
| 2010 | 6,454 |
| 2011 | 6,765 |
| 2012 | 7,518 |
| 2013 | 8,349 |
| 2014 | 9,268 |
| 2015 | 10,283 |

| | |
|---|---|
| 2016 | 11,405 |
| 2017 | 12,644 |
| 2018 | 14,014 |
| 2019 | 15,527 |
| 2020 | 17,304 |
| 2021 | 18,838 |
| 2022 | 20,443 |
| 2023 | 21,993 |
| 2024 | 23,581 |
| 2025 | 25,199 |
| 2026 | 26,838 |
| 2027 | 28,487 |
| 2028 | 30,134 |
| 2029 | 31,873 |
| 2030 | 33,708 |

Bangladesh is a semi-tropical region lying in northeastern part of South Asia gets abundant sunlight year round. The average bright sunshine duration (figure 1 and table1) in Bangladesh in the dry season is about 7.6 hours a day, and that in the monsoon season is about 4.7 hours. The highest sunlight hours received is in Khulna with readings ranging from 2.86 to 9.04hours and in Barisal with readings ranging from 2.65 to 8.75 hours. These are very good statistics when compared to the 8 hours of daylight in Spain which produced 4 GW of energy covering 2.7% of national demand by the end of 2010. Moreover Germany produces 18 GW of energy which is 2% of their national demand with only half the solar radiation received by Bangladesh. Thus solar power could be used in Bangladesh if possible not as a direct generation scheme but in conjunction with the existing infrastructure. So Solar energy can be great source of solution of energy crisis. Here is the chart of the solar radiation of different area of Bangladesh. [2]

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**Table 2.2: Data of monthly average sunshine hour in six divisions over a period of 3 years [2]**

| Year | Months | Dhaka | Chittagong | Khulna | Rajshahi* | Barisal | Sylhet |
|---|---|---|---|---|---|---|---|
| 2008 | January | 4.68 | 7.39 | 5.73 | 0 | 6.48 | 4.94 |
| | February | 6.57 | 8.12 | 7.26 | 0 | 7.6 | 6.81 |
| | March | 5.92 | 6.57 | 6.91 | 0 | 6.9 | 6.2 |
| | April | 8.49 | 8.7 | 9.04 | 0 | 8.75 | 8.52 |
| | May | 7.75 | 8.14 | 8.34 | 0 | 7.53 | 6.37 |
| | June | 4.17 | 3.88 | 4.16 | 0 | 2.93 | 3.43 |
| | July | 3.1 | 4.07 | 2.86 | 0 | 2.65 | 3.26 |
| | August | 4.04 | 4.75 | 4.38 | 5 | 4.14 | 3.03 |
| | September | 4.43 | 5.55 | 5.11 | 5.98 | 5.01 | 5.54 |
| | October | 5.79 | 6.91 | 7.46 | 7.66 | 7.39 | 6.73 |
| | November | 7.95 | 8.47 | 8.81 | 8.87 | 8.61 | 9.32 |
| | December | 3.88 | 6.11 | 5.53 | 4.71 | 6.49 | 6.78 |
| 2009 | January | 5.71 | 7.32 | 6.19 | 5.48 | 6.81 | 6.52 |
| | February | 8.66 | 8.71 | 8.91 | 9 | 8.47 | 7.63 |
| | March | 7.27 | 7.44 | 7.97 | 7.56 | 7.51 | 7.24 |
| | April | 8.31 | 8.69 | 9.07 | 8.52 | 8.77 | 7.18 |
| | May | 6.75 | 7.76 | 7.8 | 7.11 | 7.2 | 6.77 |
| | June | 5.94 | 6.28 | 6.25 | 7.82 | 6.43 | 4.59 |
| | July | 4.7 | 4.45 | 3.68 | 5.39 | 3.66 | 5.3 |
| | August | 3.85 | 3.62 | 3.85 | 3.85 | 3.97 | 3.51 |
| | September | 4.13 | 6.01 | 4.1 | 6.27 | 5.31 | 5.64 |
| | October | 6.19 | 6.39 | 7.24 | 7.12 | 7.13 | 6.89 |
| | November | 6.73 | 5.62 | 7.31 | 6.8 | 7.67 | 6.86 |
| | December | 4.79 | 5.26 | 6.93 | 5.1 | 6.97 | 6.98 |
| 2010 | January | 5.7 | 7.63 | 7.5 | 5.99 | 7.08 | 7 |
| | February | 6.74 | 8.55 | 7.82 | 8.25 | 7.54 | 6.69 |
| | March | 8.35 | 7.56 | 8.41 | 8.24 | 8.25 | 6.65 |
| | April | 7.34 | 7.75 | 8.99 | 8.06 | 8.45 | 5.46 |
| | May | 6.74 | 6.97 | 7.08 | 7.29 | 6.66 | 5.26 |
| | June | 3.74 | 3.99 | 4.3 | 4.62 | 3.78 | 2.19 |
| | July | 4.93 | 5.42 | 5.14 | 5.91 | 4.75 | 3.52 |
| | August | 4.37 | 5.38 | 5.04 | 5.56 | 4.81 | 3.88 |
| | September | 3.83 | 6.09 | 5.49 | 5.79 | 5.05 | 4.32 |
| | October | 5.82 | 6.49 | 6.4 | 6.89 | 7.01 | 7.03 |
| | November | 6.24 | 8.03 | 6.63 | 7.42 | 6.94 | 7.39 |
| | December | 6.17 | 7.38 | 6.24 | 6.22 | 6.15 | 7.18 |

## 2.2 Electromagnetic spectrum

A spectrum of electromagnetic radiation is emitted by the sun. Solar radiation is actually an Electromagnetic radiation which consists of packet of photons. Energy can be transported through radiation because this is the 3rd manner by which energy is transferred .Other two are conduction and convection, unlike these two radiant energy transfer is not dependent on contact between source and sink. It moves at speed of light $c = 2.998 \times 10^8 ms^{-1}$in the vacuam.as we see $c = \lambda v$ means the speed of light is proportional to the product of the wavelength of the radiation and the frequency at which

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it oscillates. In the absorption and release of energy by electrons Radiation has origins. Energy possess by the molecules form of kinetic energy and electrostatic potential energy. The rotational and vibrational energy Aare also possessed by molecules Quantum's mechanics theory says that around each nuclear electron has unique configurations. Due to these rotation and vibration of energy, energy level is created. Whenever a molecule transfers to the higher level it absorbs electromagnetic radiation and when it goes down it emits electromagnetic radiation, this energy is emitted in packets called photons. Electron get excited because of this excitement it emits radiation energy. Continuous spectrum of energy is emitted by the sun, it has a range from short wave length to long wave length.

**Table 2.3: Electromagnetic Spectrum [4]**

| **Region** | **Wavelength (angstroms)** | **Wavelength (centimeters)** | **Frequency (Hz)** | **Energy (eV) per photon** |
|---|---|---|---|---|
| Radio | $> 10^9$ | $> 10$ | $< 3 \times 10^9$ | $< 10$ |
| Microwave | $10^9 - 10^6$ | $10 - 0.01$ | $3 \times 10^9 - 3 \times 10^{12}$ | $10^{-5} - 0.01$ |
| Infrared | $10^6 - 7000$ | $0.01 - 7 \times 10^{-5}$ | $3 \times 10^{12} - 4.3 \times 10^{14}$ | $0.01 - 2$ |
| Visible | $7000 - 4000$ | $7 \times 10^{-5} - 4 \times 10^{-5}$ | $4.3 \times 10^{14} -7.5 \times 10^{14}$ | $2 - 3$ |
| Ultraviolet | $4000 - 10$ | $4 \times 10^{-5} - 10^{-7}$ | $7.5 \times 10^{14} -3 \times 10^{17}$ | $3 - 10^3$ |
| X-rays | $10 - 0.1$ | $10^{-7} - 10^{-9}$ | $3 \times 10^{17} - 3 \times 10^{19}$ | $10^3 - 10^5$ |
| Gamma rays | $< 0.1$ | $< 10^{-9}$ | $>3 \times 10^{19}$ | $> 10^5$ |

## 2.3 Visible light spectrum

Solar radiation is made up of electromagnetic energy of various wavelengths. As it passes through the earth's atmosphere, half is reflected back into space while the other half makes its way to the surface of the earth. The air molecules react with this incoming radiation, scattering the light and absorbing most of the harmful rays. The filtered energy is what see and feel as sunshine. Visible spectrum is the portion of the electromagnetic spectrum that is visible to the human eye. Electromagnetic radiation in this range of wavelengths is called visible light or simply light. A typical human eye will respond to wavelengths from about 390 to 700 nm. As solar cells are made of N type and P type material, they can only use this visible light to generate electricity. This narrow is consisted with colors red (R), orange (O), yellow (Y), green (G), blue (B), and violet (V).This band is usually called ROYGBIV. Each color is characteristic of a distinct wavelength; and different wavelengths of light waves. The red wavelengths of light are the longer wavelengths and the violet wavelengths of light are the shorter wavelengths. Between red and violet, there is a continuous range or spectrum of wavelengths.

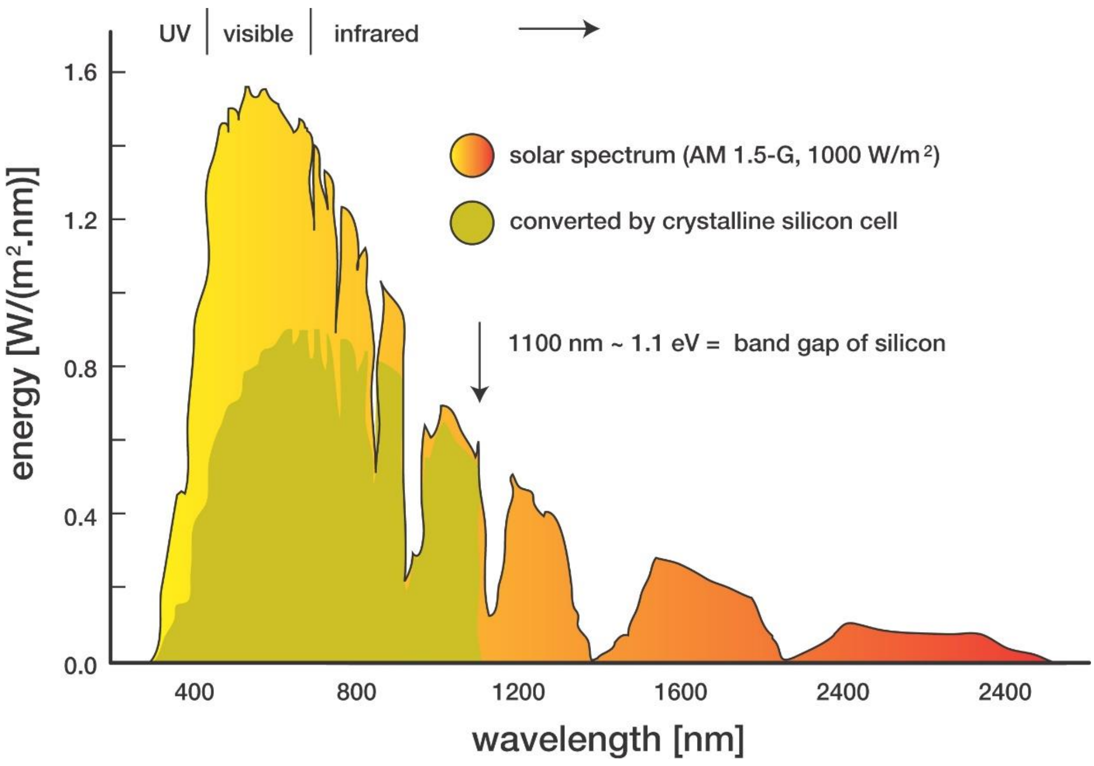


**Fig 2.1: Electromagnetic spectrum**

## 2.4 The Photoelectric Effect

Solar cells are made out of N-type and P-type semiconductor material that use the visual light spectrum to generate electricity. Solar radiation with wavelengths of 380 nm to

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750 nm is the visible light spectrum. The photoelectric effect occurs when photons from incoming sunlight hit and interact with a conductive surface, such as silicon cell or metal film. The electrons in the material then become excited and jump from one conductive layer to the other. When the sunlight hits the surface and excites the electrons the excited electrons move from the p-layer to n-layer. This results in voltage differential across the whole electrical circuit which causes electrons to flow through the rest of the circuit to maintain a charge balance. The system is designed with an external circuit which permits the current flow to perform any useful functions. In other words, the photoelectric effect in the solar cells create a voltage which then can be utilized.

## 2.5 Water pumping systems

There are several power sources for pumping water for irrigations or livestock for example human energy, animal power, hydro power, wind, solar and fossil fuels for small generators All the sources are used based on source's availability. All the sources have pros and cons. In this this the pros and cons of these sources are given.

**Table 2.4: Pros and Cons [5]**

| Name | Pros | Cons |
|---|---|---|
| Hand pumps | • local manufacture is possible<br>• easy to maintain<br>• low capital cost<br>• no fuel costs | • loss of human productivity<br>• often an inefficient use of boreholes<br>• low flow rates |
| Animal driven pumps | • more powerful than humans<br>• lower wages than human<br>• power<br>• dung may be used for<br>• cooking fuel | • animals require feeding all year round<br>• often diverted to other activities at crucial irrigation periods |
| Hydraulic pumps | • unattended operation<br>• no fuel costs<br>• easy to maintain<br>• low cost<br>• long life<br>• high reliability | • require specific site conditions<br>• low output |
| Wind pumps | • unattended operation<br>• easy maintenance<br>• long life | • water storage is required for low wind periods |

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| | | |
|---|---|---|
| | • suited to local manufacturer<br>• no fuel requirements | • high system design and project<br>• planning needs<br>• not easy to install |
| Solar PV | • unattended operation<br>• no fuel costs<br>• low maintenance<br>• easy installation<br>• long life (20 year) | • high capital costs<br>• water storage is required for cloudy periods<br>• repairs often require skilled<br>• technicians |
| Diesel and gasoline pumps | • quick and easy to install<br>• low capital costs<br>• widely used<br>• can be portable | • fuel supplies erratic and expensive<br>• high maintenance costs<br>• short life expectancy<br>• noise and fume pollution |

## 2.6 Solar water pumping system

For agricultural operations often Photovoltaic (PV) panels are used, especially in remote areas where alternative power source are needed for irrigation or other things. This solar panels can generate energy by converging solar radiation and can run pump for irrigation. The main benefit of using solar system is it can generate energy where no source is available. Some say it is a costly project but proper design of a PV panel can give long term cost saving power system and it will take smaller environmental footprint compared to conventional power system. The amount of the pumped out water is depended on the energy generated by the PV system. . The flowrate of the water pumped is determined by both the intensity of the solar energy available and the size of the PV array used to convert that solar energy into direct current (DC) electricity. The principle components in a solar-powered water pump system include:

• The PV array and its support structure,

• An electrical controller, and

• An electric-powered pump.

`

# Chapter 3

## Components of solar water pumping system

For setup a solar water pumping system may needs 5 principle components-

- The PV array and its support structure
- Battery
- DC to DC converter
- An electrical controller
- Inverter
- Electrical pump
- Water source

It is important to check the compatibility of the equipment are used.

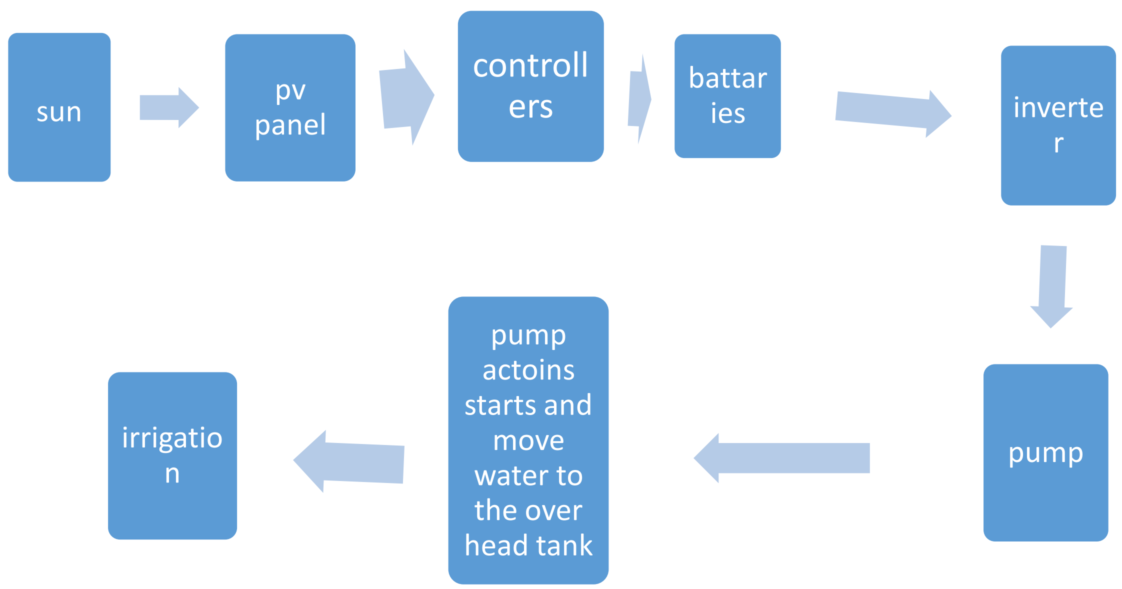


**Fig 3.1: Block diagram**

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## 3.1 PV array and its supportive structure

### 3.1.1 PV array

With series of solar cells PV panels are made of below. Each solar cell has two or more specially prepared layers of semiconductor. These material produce DC electricity when come under exposed to sunlight. A single, typical solar cell can generate approximately 3 watts of energy when it is under full sunlight. The semiconductor layers can be two different ways it can be either crystalline or thin film. Crystalline solar cells are generally made out of silicon. They have an efficiency of approximately 15%. Solar cells which are made out of thin films and other materials they can have efficiencies of approximately 8% to 11%. They are not as durable as silicon solar cells, but they are lighter and considerably less expensive. The combination of the cells are called and the combination on the modules are called array. .Then it is connected by electrical wiring to deliver power to a pump. [5]

### 3.1.2 Supportive structure

The structural supports used to attach the PV panels to their mounting. The supports must be installed per the manufacturer's specifications to avoid any unintended stresses or eccentric loading to the panels, structural supports, and mounting posts. These unintended stresses and eccentricities can overstress the connection of the panel to the post, even under normal loading, and damage the system. Any structural support used to mount the PV panels to the post that has not been provided by a certified solar panel manufacturer needs to meet all expected load cases.

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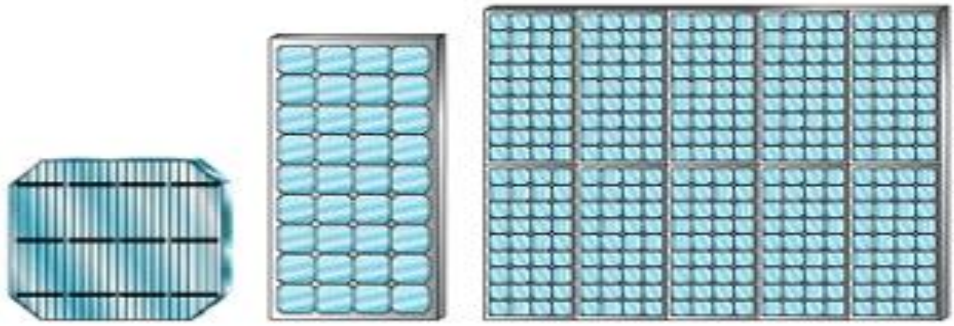

Solar cell PV solar panel array of PV solar pan

**Fig 3.2: Solar panel [5]**

### 3.2 Battery

A PV system incorporate storage batteries that are charged when incoming solar energy exceeds the pumping power requirement. The batteries are used to power the pump when the pumping requirement exceeds the solar power input. The battery charge and discharge can be regulated by the control unit.

### 3.3 Dc to Dc converter

Dc to dc converter converts higher dc voltage to lower pc voltage or it regulates the output voltage. Sometimes when the need power is less than produced power, dc to dc converter is used.

### 3.3 Electrical controller

Electrical controllers and safety devices are incorporated into PV-powered water pump systems to control the electric power input to the pump .These provide necessary electrical protection and switching. The controller normally includes a main switch to provide an electrical disconnect of the PV array from all other system components. Since the amount of power produced by the array depends on the intensity of incoming solar radiation, the controller can cause the pump to be switched off until sufficient power is available to meet the pump's specified minimum operating power input range. Likewise, when the PV panels produce too much power, the controller can limit the power output to the pump to prevent it from running faster than its maximum rated speed. The performance of the electrical controller will vary depending on the type of controller selected. However, an important safety device that should be included in most systems is a switch for low water dry run protection. The pump's operation can also be controlled by the use of a float switch in the storage tank, which responds automatically when a preset water level is reached in the tank. Alternatively, the pump's operation can be controlled by a pressure switch, which responds when a designated water pressure is attained in the system.


**Fig 3.3: Electrical Controller**

## 3.4 Inverter

Inerter is AC to DC or DC to AC converter. It converts current if it is needed and sometimes it work as a controller. Inverter are two types

1. Stand alone
2. Line-tied or utility-interactive

`

**Fig 3.4: inverter**

## 3.5 Water source

The configuration of the water system is defined by the type of water source used. The local topography and the locations of the delivery points are also important aspect which effects the system. Either of these two types of water sources may be used for the system. The sources are listed below

- Subsurface source ( A well)
- Surface source (A pond, stream or spring)

If it is a subsurface source, the following items will need to be determined:

- The static level of the water
- The pumping rate and any drawdown associated with it (along with any seasonal variation), and
- The quality of the water

If itis a surface water source, such as stream, pond, or spring, the following items will need to be determined while taking seasonal variations into account:

- The availability of water
- The pumping levels, and

`

- The quality of water, including the presence

With a surface water source, the availability of availability of water and water level can vary seasonally. In particular, during the summer, the quality and water level may be low. When it is needed most.

### 3.6 Storage

The water which is will get from pumping it must be stored, so storage is a very essential things. It should be placed near the work place.

### 3.7 Pump

For main system design we need a Pump .So pumps which run by PV system are powered by dc motors. Sometimes Ac motors are also used but in that case efficiency become less. Dc motors do not need inverters for that efficiency is more. The pump can be submersible, surface mount or floating. It is depended on the water source. Mainly there are 2 types of pump they are:

- positive displacement pump
- Centrifugal pump.

Where TDH is high and flowrate is low positive displacement is needed there. On the other hand centrifugal pump is needed where low TDH but high flowrate. Another thing must be kept in mind the voltage of the motor. Same functionality can be found in same type of motor but with different voltage level. The quality of the water is also matter of consideration. With the help of the performance curve water pump can be selected. Figure 3.5 is for positive displacement pump, figure 3.6 is for centrifugal pump.

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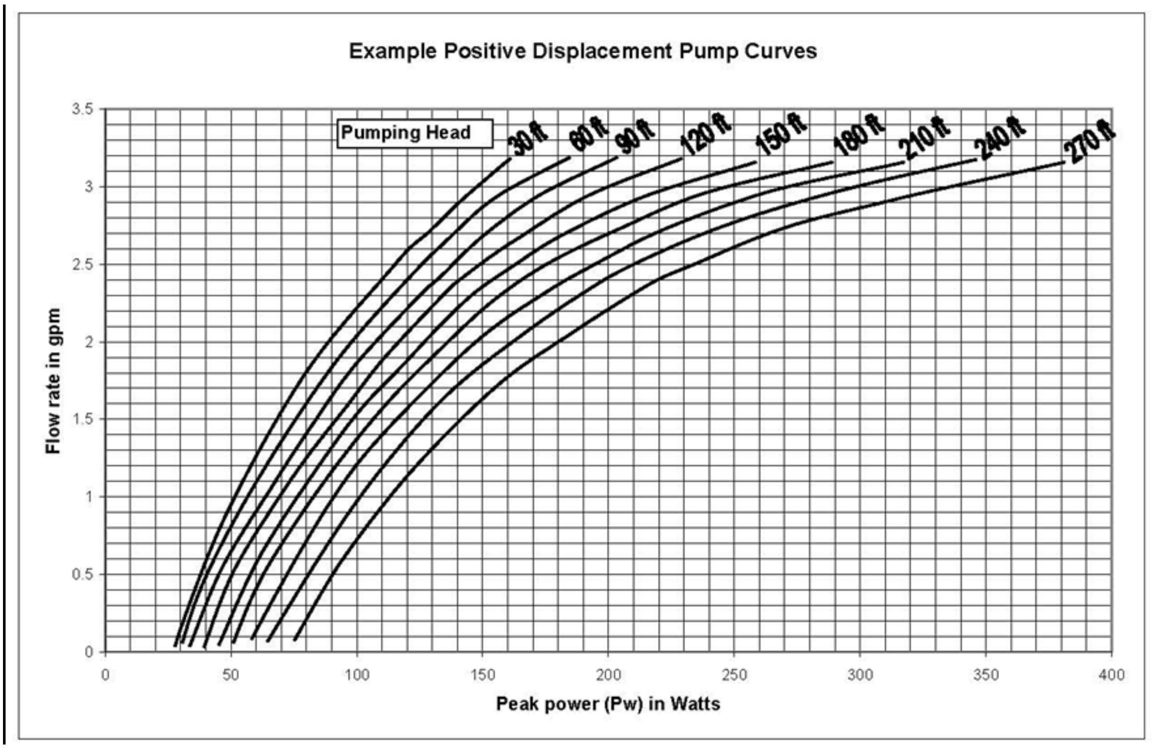


**Fig 3.5: Example solar-powered pump performance curves for a positive displacement pump [6]**

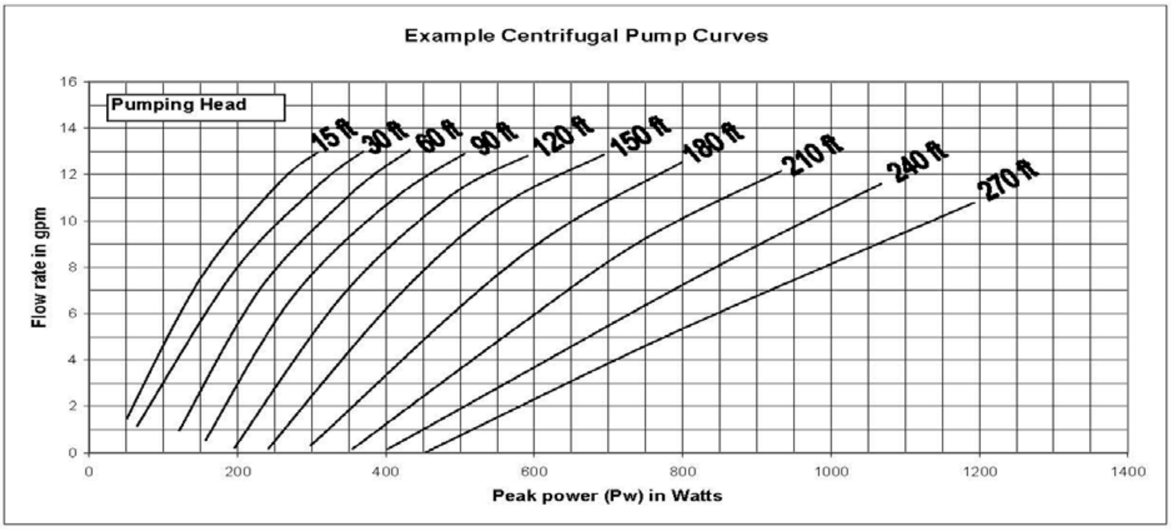


**Fig 3.6: Example solar-powered pump performance curves for a centrifugal pump. [6]**

`

# Chapter 4

## Relation between flowrate and input power

### Nomenclature

| | |
|---|---|
| $Q$ = | Volume flow rate through the pipe ($m^3s^{-1}$) |
| $N$ = | Shaft speed (rpm) |
| $U$= | velocity of impellers (pump) |
| $V$ = | Flow velocity |
| $D$= | Diameter |
| $b$= | Width |
| $H$= | Head of the water at designed speed |
| $g$= | Acceleration for gravity |
| $P$= | Power ($W$) |
| $m$= | Mass flowrate ($kgs^{-1}$) |
| $W$= | Specific work ($Nmkg^{-1}$, $Jkg^{-1}$) |
| $\rho$ = | Density ($kgm^{-3}$) |
| $\gamma$ = | Specific weight ($Nm^{-3}$) |

`

**4.1 1st affinity law** – Flow is proportional to the shaft speed, to proof that we assume,

$U=\pi DN$ (1)

$U \infty N$ (2)

$V \infty U$ (3)

From equation(2)

$V \infty N$ (4)

$Q=\pi DbV$ (5)

When $\pi Db$ are constant

$Q_1 \infty V_1$ (6)

and, from equation 4

$Q_1 \infty N_1$ (7)

Similar for changed condition

$Q_2 \infty N_2$ (8)

**Therefore,** $Q_1/Q_2=N_1/N_2$

`

**4.2 $2^{nd}$ affinity law** – Head is proportional to the square of the shaft speed,

$$H=\eta(UV)/g \quad (9)$$

$$H \infty UV \quad (10)$$

From equation *(4)*

$$H \infty VN \quad (11)$$

for changed condition

$$H \infty N^2 \quad (12)$$

Speed of a centrifugal pump is proportional to the square of the speed the impeller,

$H_1/H_2= (N1/N_2)^2$ *(proved)*

**4.3 Input Power $P_{in}$**

**Power gained by fluid**

The power gained by the fluid from a pump or fan can be expressed as:

$$P = m\ W \quad (13)$$

**Specific work**

Specific work - *W* - can be expressed:

$$W = g\ H \quad (14)$$

**Mass flowrate**

Mass flow rate - *m* - can be expressed:

$$m = \rho\ Q \quad (15)$$

`

Combining (13), (14) and (15) the power gained by the fluid from a pump or fan can be expressed as:

$$P = \rho\, Q\, g\, H \quad (16)$$

With specific weight expressed as:

$$\gamma = \rho\, g \quad (17)$$

Equation (16) can be modified so the power gained by the fluid from a pump or fan can be expressed as:

$$P = \gamma\, Q\, H \quad (18)$$

$$P_{in=} (Q \times H \times \gamma)/\ \eta \quad (19)$$

The power requirement for the pump can be calculated by:

$$P_{in=} (Q \times H \times \gamma)/\ \eta \text{ (proofed)} \quad (20)$$

## 4.4 Flowrate

$$Modules\ in\ series = \frac{DC\ voltage\ system}{Nominal\ Module\ system} \quad (21)$$

$$Module\ in\ parallel = \frac{Array\ peak\ amp}{Peak\ amp\ per\ modules.} \quad (22)$$

$$Array\ peak\ amp = \frac{\frac{Average\ Amp-hrs\ per\ day}{battery\ efficiency}}{peak\ sun\ hrs\ per\ day} \quad (23)$$

$$Average\ Amp\text{-}hrs\ per\ day = \frac{Ac\ average\ Daily\ load}{inverter\ efficiency} + \frac{DC\ Average\ Daily\ load}{DC\ System\ voltage} \quad (24)$$

$$V_{max} = Voc \times \frac{DC\ voltage\ system}{Nominal\ Module\ system} \times low\ temp\ correction\ factor \quad .(25)$$

`

$$I_{max}=\frac{Ioc}{\frac{(inverter\ efficiency)+(DC\ Average\ Daily\ load}{\frac{(DC\ System\ voltage}{\frac{Battery\ efficiency}{Peak\ sun\ hrs\ perDay}}}} \div peak\ \ Amp\ per\ module\ \ \times 1.5 \quad . \qquad (26)$$

$$P_{in}=(Voc \times \frac{DC\ voltage\ system}{Nominal\ Module\ system} \times low\ temp\ correction\ factor) \times$$

$$(\frac{Ioc}{\frac{(inverter\ efficiency)+(DC\ Average\ Daily\ load}{\frac{(DC\ System\ voltage}{\frac{Battery\ efficiency}{Peak\ sun\ hrs\ perDay}}}} \div /peak\ \ Amp\ per\ module\ \ \times 1.56 \qquad (27)$$

So therefore it can be written that,

Putting the $P_{in}$ value on equation (20)

$$Q\ \times\ H\ \times\ \gamma\ = Voc \times \frac{DC\ voltage\ system}{Nominal\ Module\ system} \times low\ temp\ correction\ factor) \times$$

$$(\frac{Ioc}{\frac{(inverter\ efficiency)+(DC\ Average\ Daily\ load}{\frac{(DC\ System\ voltage}{\frac{Battery\ efficiency}{Peak\ sun\ hrs\ perDay}}}} \div /peak\ \ Amp\ per\ module\ \ \times 1.56) \times \eta \qquad (28)$$

Using equation (24) and (25)…

$$V_{max} \times I_{max} = (Q \times H \times \gamma)/\ \eta$$

$$Q = (V_{max} \times I_{max} \times \eta\ )\ /\ (H \times \gamma) \qquad (29)$$

`

# Chapter 5

## Sizing and stimulation

Basic concept for solar water pumping system is, under the sunlight PV panel produced energy than it goes to the control panel. Control panel regulate the voltage and the electrical energy stored in the battery. Inverter converts the singles either into AC or DC Pumps run by this energy and water comes out. In this part all the components are going to sized and stimulate the system.

### 5.1 Head calculation

Water is pumped from the reservoir into a receiving tank. This kind of arrangement is used to lift water from a reservoir, or river. The water level in the reservoir varies but the discharge level in the receiving tanks remains constant as the water is discharged from a point above the water level. The operating pressure of a pumped system is calculated in the SI unit of meters (m). To maintain dimensional consistency, any pressure values used within the calculations are therefore converted from kPa into m using the following conversion:

1 kPa = 0.102 m

For the above system, the operating pressure or the total system head, $H_{Total}$, is defined as:

$$H_{Total} = H_s + H_D + (P_{RT} - P_{RES}) \qquad (30)$$

Where,

$H_s$ = Static head (m)

$H_D$ = Dynamic head (m)

$P_{RT}$ = Pressure on the surface of the water in the receiving tank (m)

`

$P_{RES}$ = Pressure on the surface of the water in the reservoir (m)

Although the atmospheric pressure changes with height, the change in pressure that occurs over the pumping height is often so small that it can be considered negligible. In this exemplar, the change in pressure over the elevation from the reservoir to the receiving tank is not that significant and hence is negligible.

$P_{RT} - P_{RES}$ » 0.

Therefore, equation (1) becomes:

$$H_{Total} = H_s + H_D \tag{31}$$

The static head $H_s$ is the physical change in elevation between the surface of the reservoir and the point of discharge into the receiving tank. As the water level in the reservoir can vary, the static head for the system will vary between a maximum and a minimum value:

$H_{S\,\min}$ = discharge level - reservoir T WL and

$H_{S\,\max}$ = discharge level - reservoir B WL where

$TWL$ = Top Water Level (reservoir)

$BWL$ = Bottom Water Level (reservoir).

If the discharge point is at a level of 110.5 m above the mean sea level (also known as ***Above Ordnance Datum (AOD)*** in technical language) and the reservoir level varies between 105.2 m AOD and 101.6 m AOD, then:

$H_{S\min}$ = 102.11 – 101.9 = 0.21 m

$H_{S\max}$ = 102.11 - 101. 6 = 0.51 m

As a result of the variation in the static head, the total system head, $H_{Total},$ will also have a maximum and minimum value which we need to calculate here.

The dynamic head is generated as a result of friction within the system. The dynamic head is calculated using the basic Darcy Weisbach equation given by:

`

$H_D = (kv^2)/2g$ (32)

where

$K$ = loss coefficient

$v$ = velocity in the pipe (m/sec)

$g$ = acceleration due to gravity (m/sec $^2$)

We can calculate the velocity in pipe using the following formula:

$v = Q/A$…

Where

$Q$ = flowrate through the pipe (m $^3$/sec)

$A$ = pipe cross sectional area (CSA) (m $^2$)

If $Q$ is 2500 m $^3$/hr and the flow is pumped through a 0.8 m diameter pipe then:

$A = (\pi D^2)/4$ (33)

$= (\pi \times 0.8^2) =.05$

Hence, using equation (4), we get:

$$V= (25000/3600) \times (1/0.5) = 1.39\ m/sec$$

The loss coefficient $K$ is made up of two elements:

$K = K_{\text{fittings}} + K_{\text{pipe}}$ (34)

$K_{\text{fittings}}$ is associated with the fittings used in the pipe works of the system to pump the water from reservoir to the receiving tank. Values can be obtained from standard tables and a total $K_{\text{fittings}}$ value can be calculated by adding all the $K_{\text{fittings}}$ values for each individual fitting within the system.

The following table shows the calculation of $K_{\text{fittings}}$ for the system under consideration:

`

**Table 5.1: Calculating $K_{\text{fittings}}$ for the system under** [7]

| **Fitting Items** | **No. of Items** | $K_{\text{fittings}}$ **Value** | **Item Total** |
|---|---|---|---|
| Pipe Entrance (bell mouth) | 1 | 0.05 | 0.05 |
| 90° Bend (short radius) | 10 | 0.75 | 7.5 |
| 45° Bend (short radius) | 2 | 0.3 | 0.6 |
| Butterfly Valve (Fully Open) | 2 | 0.3 | 0.6 |
| Non Return Valve | 1 | 1.00 | 1.00 |
| Bellmouth Outlet | 1 | 0.2 | 0.2 |
| **Total** *K* fittings **Value** | | | **9.95** |

Hence, the total $K_{\text{fittings}}$ for the system under consideration is 9.95. $K_{pipe}$ is associated with the straight lengths of pipe used within the system and is defined as:

$$K_{\text{pipe}} = (fl)/D) \quad (35)$$

Where,

$f$ = friction coefficient

$l$ = pipe length (m)

`

$D$ = pipe diameter (m) the friction coefficient

$F$ can be found using a modified version of the Colebrook White equation:

$$f=0.25/\,(log\,((k/3.7xD)+(5.74/Re^{0.9}))^{-2} \tag{36}$$

$k$ = Roughness factor (m)

$Re$ = Reynolds number

The pipe roughness factor $k$ is a standard value obtained from standard tables and is based upon the material of the pipe, including any internal coatings, and the internal condition of the pipeline i.e. good, normal or poor.

Reynolds number is a dimensionless quantity associated with the smoothness of flow of a fluid and relating to the energy absorbed within the fluid as it moves. For any flow in pipe, Reynolds number can be calculated using the following formula:

$$Re = (VD)/u \tag{37}$$

Where

$u$ = Kinematic viscosity ($m^2/s$).

If the total pipe length is 250 m, the pipe has a roughness factor of 0.3 mm and the kinematic viscosity of water is 1. 31· $10^{-6}$ $m^2$/sec, then from equation (8), we get:

$$Re = (1.39 \times 0.8) \div (0.31\times10^{-6}) = 8.49x10^5$$

Using this value in equation (36), we get:

$$f=0.25/\,(log\,((0.0003\div(3.7\times0.8))+(5.74\div(8.49\times10^5)^{0.9}))^{-2}$$

$$= 0.0165$$

Using this value in equation (35), we get:

$$K_{pipe} = (0.0165 \times.250)/0.8 = 5.16$$

`

Finally, using equation (34), the total *K* value for the system is:

$K = 5.16 + 9.95 = 15.11$

We can now calculate the dynamic head using equation (32) as follows:

$$H_D = (15.11 \times (1.39)^2)/0.8 = 1.49 \text{ m}$$

The dynamic head is the same for both the maximum and minimum static head conditions as the dynamic head is independent of the system elevation.

Hence, the maximum and minimum *H* can now be calculated using equation (31):

$$H_{Total\ \max} = 0.51 + 1.49 = 2 \text{ m}$$

$$H_{Total\ \min} = 0.21 + 1.49 = 1.7\text{m}$$

## 5.2 Flowrate Calculation

For flowrate calculation we need $H$ = 2m, Pump power is 2.8 kW,

$\rho$ = *Density* $(Kg/m^3)$ = 1000 kg/m $^{3,}$ $g = 9.8$ ms$^{-2}$

$$Q \times H \times \gamma = 84 \ kW \qquad (\gamma = g \times \rho)$$

$$Q = 2846 / (10000 \times 9.8 \times 10.39)$$

$$= 0.222 \text{ m3s}^{-1}$$

`

## 5.3 Load calculation

Hence, we can say that to overcome the required head of 2 m, we need a variable speed pump with 2.8 *kW*. Now we have our input power of motor that mean output power on PV system .we take M55 module for this purpose. It consists of 36 cell and 20 v 3.5 amp

$P=I\times V$

So. The module can produce

$P= 20 \times 3.5$

$= 70$ watt

But required power is 84000 watt or 84 kW

Now,

DC load current (amp) = Dc load power (watt) / nominal voltage

= 2846.87 / 48 (assume)

= 59.30 amp

So, daily dc load demand = Dc load current (amps) × hours of operation

We assume pump will be operated 8 hours at a day

= 59.30×8

= 474.4 W

## 5.4 Battery sizing

The basic formula for calculating battery size is presented below, it involves multiplying the number of the days of reserve times the amount needed daily for the load. This would give the 1st approximate to the size of the battery capacity. But we cannot allow all of the barratry capacity to be discharged during the days of autonomy manufactured recommended on 80% of even deep cycling batteries and only about 50% of shallow cycling batteries be discharged. So we must divide the maximum percentage usable to give the amount to install.

`

Deep cycling battery type can be up to the 80%

Shallow cycling battery type can be up to the 50 %

Putting all these correcting factors together, we develop a final formula for calculating the capacity of a photovoltaic battery bank.

1. The Maximum Percent Usable is either the standard value of 50% for shallow cycling batteries, 8O% for deep cycling batteries, or a reduced value based on freezing concerns. This value can also be reduced by the designer simply as a Way to build in more life to the system. For example, a designer might use a shallow cycling battery, but size based on using only 30% of the capacity and not the usual 50%. This might not impact the cost of the system too much, and would mean the battery life would be extended.

2. The Temperature Derating Factor is included, to make sure that more capacity is installed at 25 degree so that when the battery gets cold and loses some capacity, there will still be the required capacity present.

3. The Rate Factor is included to bring the calculation back to the manufacturer's standard rate. It may need 1500 Ah at slow rate, but this can be from 1000 Ah of battery capacity when it is measured (and sold) at the standard rate (usually 8 or 10 hours).

## 5.5 Battery efficiency

Battery efficiency is dependent on the type of battery, charging methods, rates of charge and discharge, depth of discharge and temperature. In general, the efficiency of a battery is much greater at lower states of charge than when the battery is nearly fully charged. The total or round-trip battery energy efficiency is composed of two types of efficiencies. There is a voltage or voltaic efficiency, and a charge or coulombic efficiency.

## 5.6 Battery voltage (voltaic) efficiency

The voltaic efficiency of a battery is determined by the charge and discharge rates and the battery temperature. The voltaic efficiency is expressed as the ratio of the battery

`

voltage under discharge to the voltage under charge. High rates and low temperatures act to decrease battery voltaic efficiency. Battery voltaic

*Efficiency =voltage during discharge ÷ voltage during charge*

Recall how battery voltage increases during charging and decreases during discharging as compared to the open-circuit voltage. Battery voltage in a PV system may vary considerably, depending on state of charge and rate of charge or discharge. An overall average voltaic efficiency can be calculated by assuming that on the average, a battery is charged at about 14 volts and discharged at about 12 volts at the given charge and discharge rates in the system. This approximation yields an overall voltaic efficiency of about 85%.

Approximate Voltaic Efficiency = 12/14 =.85=85%

**5.7 Battery sizing calculation**

*DC system voltage =48 v*

*DC average Daily load (wt-hr/day) = 474.4 wt-hr/day*

*Inverter Efficiency = 0.90*

*% Discharge limit on Battery =0.5*

*Days of autonomy = 4*

*Average Amp-hour/day=9.8 A*

*Battery in parallel = (Average Amp-hour per day/ Days of autonomy) / Battery capacity*

*= 0*

*Battery in series = Dc voltage / Battery voltage = 8*

*Total battery =battery in series × battery in parallel =8*

`

## 5.8 Array sizing

We must therefore modify the simple array sizing formula to account for these factors

1. Divide the Daily Load by the Battery Coulombic Efficiency. This effectively increases the daily load and gives the true load that the array must replace.

2. Multiply the Module Daily Output by the Derating Factor. This reduces the expected output from a module due to environmental and aging losses, and gives a more conservative estimate of what can be expected from a module in the real world.

## 5.9 Array sizing calculation

*Battery efficiency = 0.80*

*Peak sun hrs per day =4.10*

*Peak Amp per modules=5.02*

*Array peak amp= Average amp hrs per day/Battery efficiency / peak sun hour per day =3.01*

*Modules in parallel= array peak amp / peak amp per module = 5*

*Dc Voltage system / nominal voltage = Modules in Series = 4*

*Total module = 20*

`

## 5.10 PV controller sizing calculation

*Modules short circuit current =5.34*

*Modules in parallel =5*

*Array short circuit Amps =33.38amp*

*Dc total connected watt=2846A*

*DC System voltage = 48 V*

*Maximum Dc Amp = 1750*

*Dc load=59.3amp*

`

# Chapter 6

## Results

### 6.1 Outputs

After the sizing the system is ran and the flowrate is evaluated, in the chart, the calculated flowrates are given.

**Table6.1: Outputs**

| Output Power (W) | flowrate (m^3 / s) | PV Voltage (V) | PV Current (A) | flowrate at 80% efficiency | flowrate at 90% |
|---|---|---|---|---|---|
| 2544 | 0.244016327 | 422 | 6 | 0.218057 | 0.233633 |
| 2914 | 0.279506122 | 429 | 6.8 | 0.249771 | 0.267612 |
| 2953 | 0.283246939 | 426 | 7 | 0.253114 | 0.271194 |
| 976 | 0.093616327 | 431 | 2.3 | 0.083657 | 0.089633 |
| 2864 | 0.274710204 | 430 | 6.7 | 0.245486 | 0.26302 |
| 2934 | 0.28142449 | 425 | 7 | 0.251486 | 0.269449 |
| 2914 | 0.279506122 | 418 | 7 | 0.249771 | 0.267612 |
| 2739 | 0.262720408 | 423 | 6.5 | 0.234771 | 0.251541 |
| 2493 | 0.23912449 | 428 | 5.9 | 0.213686 | 0.228949 |
| 2592.33 | 0.248652381 | | | 0.2222 | 0.238071 |
| 668 | 0.064073469 | 449 | 1.5 | 0.057257 | 0.061347 |
| 795 | 0.076255102 | 455 | 1.7 | 0.068143 | 0.07301 |
| 1529 | 0.146659184 | 461 | 3.4 | 0.131057 | 0.140418 |
| 2517 | 0.241426531 | 438 | 5.7 | 0.215743 | 0.231153 |
| 2554 | 0.24497551 | 435 | 5.9 | 0.218914 | 0.234551 |
| 2324 | 0.222914286 | 436 | 5.4 | 0.1992 | 0.213429 |
| 2241 | 0.214953061 | 438 | 5.2 | 0.192086 | 0.205806 |
| 948 | 0.090930612 | 446 | 2.1 | 0.081257 | 0.087061 |
| 1697 | 0.162773469 | | | 0.145457 | 0.155847 |
| 2920 | 0.280081633 | 430 | 6.8 | 0.250286 | 0.268163 |
| 2936 | 0.281616327 | 434 | 6.9 | 0.251657 | 0.269633 |
| 2911 | 0.279218367 | 436 | 6.8 | 0.249514 | 0.267337 |
| 2800 | 0.268571429 | 437 | 6.4 | 0.24 | 0.257143 |
| 2887 | 0.276916327 | 435 | 6.6 | 0.247457 | 0.265133 |
| 2826 | 0.271065306 | 434 | 6.6 | 0.242229 | 0.259531 |
| 2698 | 0.258787755 | 428 | 6.2 | 0.231257 | 0.247776 |
| 2710 | 0.259938776 | 437 | 6.2 | 0.232286 | 0.248878 |

`

| | | | | | |
|---|---|---|---|---|---|
| 2836 | 0.27202449 | | | 0.243086 | 0.260449 |
| 2716 | 0.260514286 | 421 | 6.5 | 0.2328 | 0.249429 |
| 2797 | 0.268283673 | 424 | 6.6 | 0.239743 | 0.256867 |
| 1043 | 0.100042857 | 422 | 3.5 | 0.0894 | 0.095786 |
| 1053 | 0.101002041 | 422 | 2.5 | 0.090257 | 0.096704 |
| 1868 | 0.17917551 | 455 | 4.7 | 0.160114 | 0.171551 |
| 2469 | 0.236822449 | 450 | 5.4 | 0.211629 | 0.226745 |
| 2888 | 0.277012245 | 433 | 6.7 | 0.247543 | 0.265224 |
| 2430 | 0.233081633 | 431 | 5.7 | 0.208286 | 0.223163 |
| 2158 | 0.206991837 | | | 0.184971 | 0.198184 |
| 2760 | 0.264734694 | 420 | 6.6 | 0.236571 | 0.253469 |
| 2751 | 0.263871429 | 430 | 6.3 | 0.2358 | 0.252643 |
| 2750 | 0.26377551 | 430 | 6.5 | 0.235714 | 0.252551 |
| 2646 | 0.2538 | 433 | 6.3 | 0.2268 | 0.243 |
| 2669 | 0.256006122 | 430 | 6.2 | 0.228771 | 0.245112 |
| 2636 | 0.252840816 | 425 | 6.2 | 0.225943 | 0.242082 |
| 2540 | 0.243632653 | 429 | 6 | 0.217714 | 0.233265 |
| 2494 | 0.239220408 | 437 | 5.7 | 0.213771 | 0.229041 |
| 2655.75 | 0.254735204 | | | 0.227636 | 0.243895 |
| 1395 | 0.133806122 | 451 | 3.1 | 0.119571 | 0.128112 |
| 1061 | 0.101769388 | 449 | 2.4 | 0.090943 | 0.097439 |
| 1718 | 0.164787755 | 450 | 3.8 | 0.147257 | 0.157776 |
| 2006 | 0.192412245 | 448 | 4.5 | 0.171943 | 0.184224 |
| 1869 | 0.179271429 | 446 | 4.2 | 0.1602 | 0.171643 |
| 1916 | 0.183779592 | 445 | 4.3 | 0.164229 | 0.175959 |
| 1748 | 0.167665306 | 441 | 4 | 0.149829 | 0.160531 |
| 1594 | 0.152893878 | 446 | 3.6 | 0.136629 | 0.146388 |
| 1663.37 | 0.159548214 | | | 0.142575 | 0.152759 |
| 1640 | 0.157306122 | 444 | 3.7 | 0.140571 | 0.150612 |
| 1592 | 0.152702041 | 447 | 3.6 | 0.136457 | 0.146204 |
| 1487 | 0.142630612 | 449 | 3.3 | 0.127457 | 0.136561 |
| 1367 | 0.131120408 | 451 | 3 | 0.117171 | 0.125541 |
| 1342 | 0.128722449 | 452 | 3 | 0.115029 | 0.123245 |
| 1111 | 0.106565306 | 446 | 2.5 | 0.095229 | 0.102031 |
| 860 | 0.082489796 | 459 | 1.9 | 0.073714 | 0.07898 |
| 726 | 0.069636735 | 451 | 1.6 | 0.062229 | 0.066673 |
| 1265.625 | 0.121396684 | | | 0.108482 | 0.116231 |
| 2450 | 0.235 | 432 | 5.7 | 0.21 | 0.225 |
| 2490 | 0.238836735 | 436 | 5.7 | 0.213429 | 0.228673 |
| 2690 | 0.258020408 | 434 | 6.2 | 0.230571 | 0.247041 |
| 2663 | 0.255430612 | 434 | 6.2 | 0.228257 | 0.244561 |
| 2744 | 0.2632 | 431 | 6.4 | 0.2352 | 0.252 |

| | | | | | |
|---|---|---|---|---|---|
| 2625 | 0.251785714 | 436 | 6 | 0.225 | 0.241071 |
| 2603 | 0.24967551 | 436 | 6 | 0.223114 | 0.239051 |
| 2526 | 0.242289796 | 433 | 5.8 | 0.216514 | 0.23198 |
| 2598.875 | 0.249279847 | | | | |

### 6.2 Analysis

After the stimulation the power curves and the flowrates curves are shown in the chart. In the fig 6.1 there are three flowrate curves based on efficiency. It can be seen that higher efficiency .higher output. Now by analyzing fig no. 6.2, 6.3, 6.4, the designer can see that the power curves and the flowrate curves are almost same. Form this the designer can come to the point that if the output of the power can be stabilize more stable flowrate can be gained .So, based on that flowrate equation , the designer can design more efficient system.

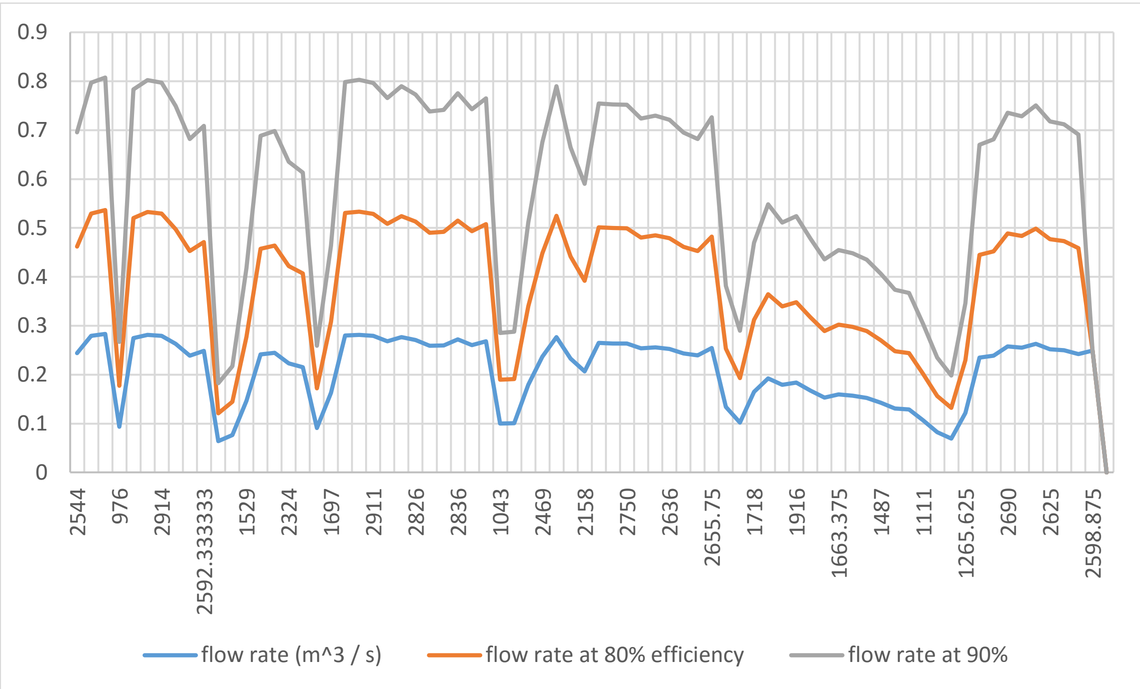


**Fig 6.1: Flowrate (94%, 80%, 90%)**

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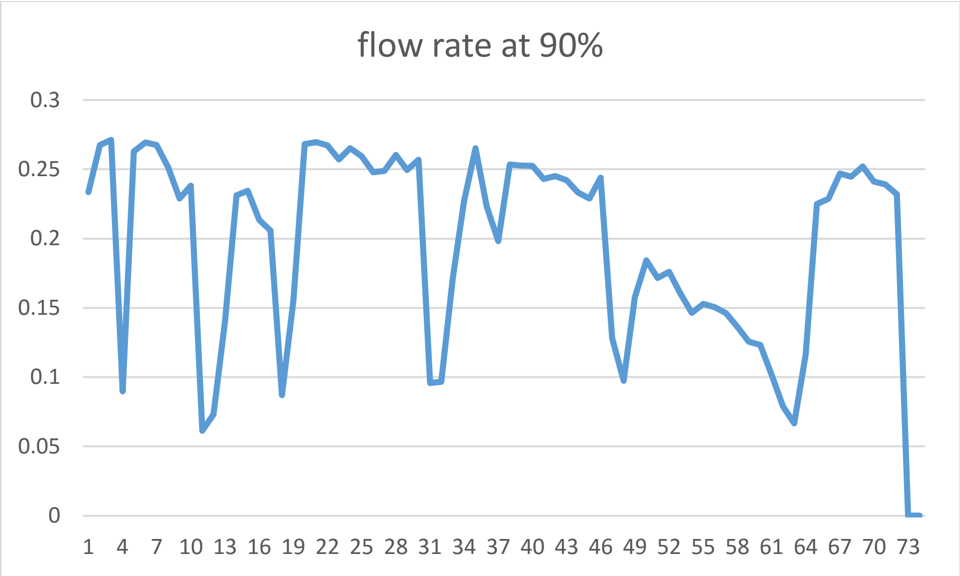


**Fig 6.2 Flow rate 90%**

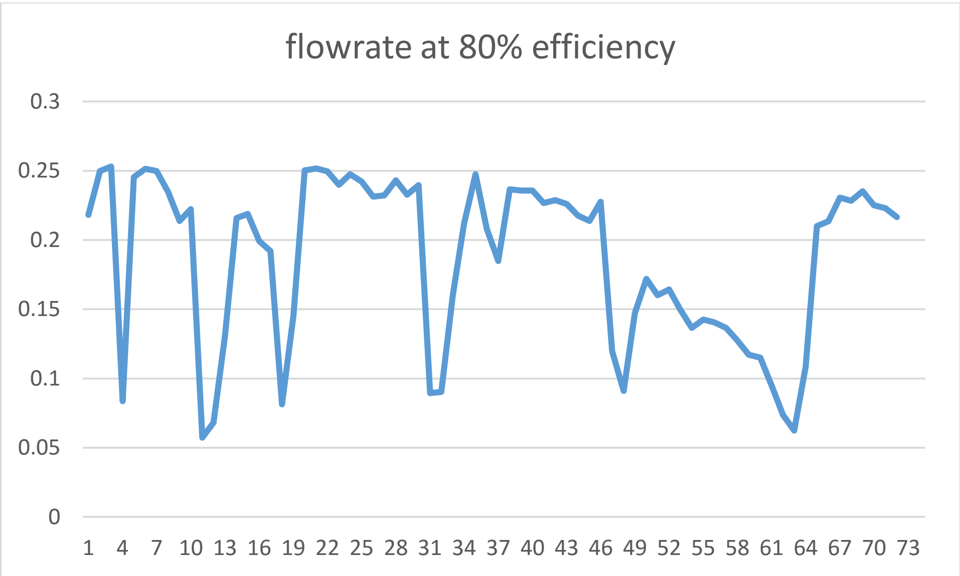


**Fig 6.3 Flowrate 80%**

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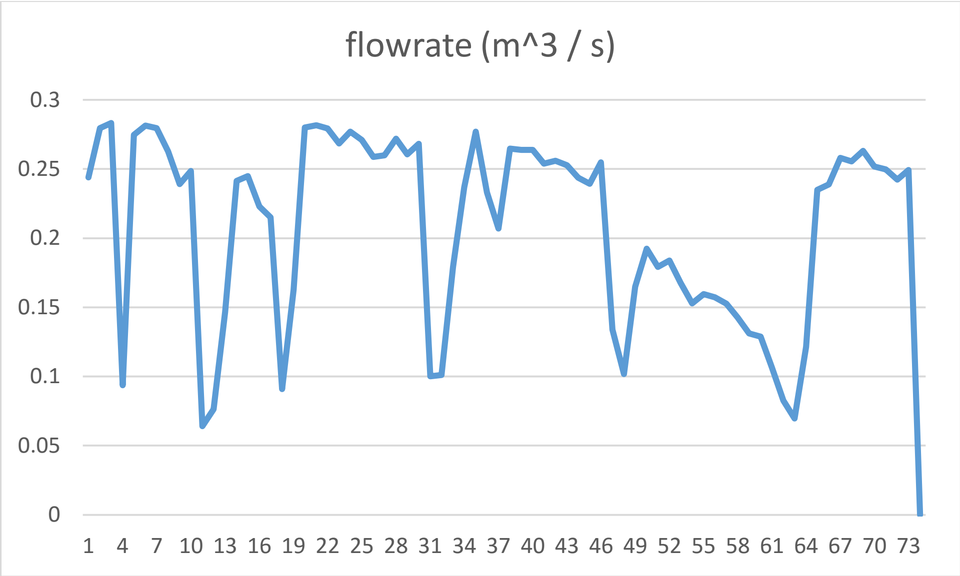


**Fig 6.4: Flo rate 94%**

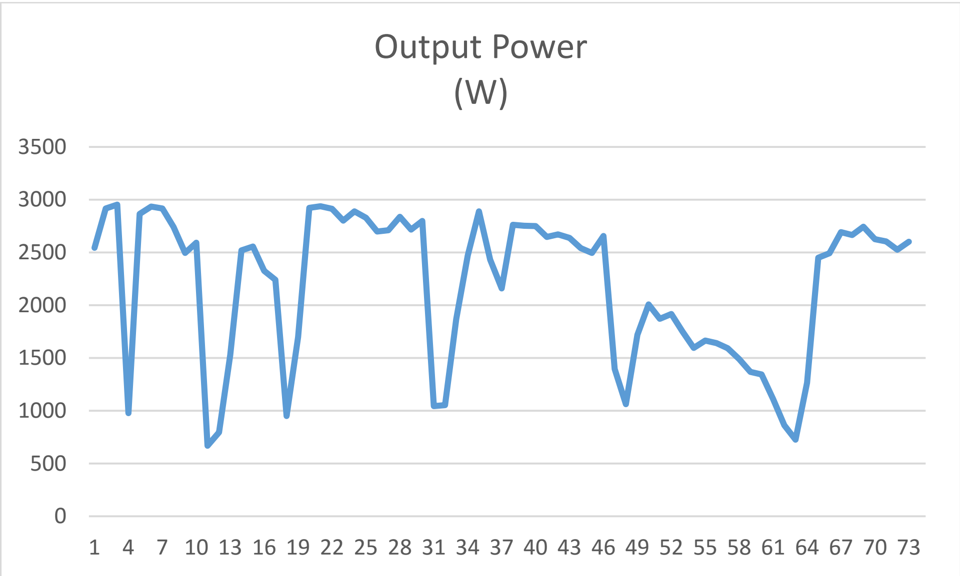


**Fig 6.5: Power**

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# Chapter 7

## Conclusion

Solar water pumping system is one of the most durable pumping systems. It is a perfect system for country like Bangladesh. More efficient designing can give more efficient output .For that purpose the equations as established in this report can help the designer to get the best result As solar energy is a free source of energy and it is available, it can be hoped that not only the pumping system but also every power sector can be solar powered to make a greenhouse and other bad effects free world.

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