



# **Optimization of a Solar Powered Water Pump for Crop Irrigation**

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## **Declaration**

We hereby declare that this thesis titled “Designing a Solar Powered Water Pump” done by the authors under the supervision of Dr. Md. Mosaddequr Rahman, Department of Electrical & Electronics Engineering of BRAC University. This is our original work and was not submitted elsewhere for the award of any other degree or any other publication.

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## **Abstract**

The main aim of this thesis is to design a solar powered water pump that can provide water for irrigation without the use of batteries or generators. We have designed the system such that necessary power can be obtained from panel arrangement to run the submersible pump which pumps water from underground. We have calculated different tilt angles to provide the energy necessary to pump water for the cultivation and crops to grow on our location situated in Shibpur, Narsingdi, Bangladesh. The system is designed to fulfill the water required for the irrigation of crops during February to April and September to November.

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# Chapter-1

## 1.1 Introduction

During the months from February to April and September to November, there is a huge demand of water in Bangladesh as it is essential for the irrigation of rice and for the cultivation of winter vegetables. We also know that Bangladesh faces severe energy crisis. Only 53 percent of the population in Bangladesh have access to electricity and most if it is limited to the urban areas. <sup>[3]</sup> Where ever the topography permits, irrigation water is achieved by diverting river flow to the farmland through gravity-flow distribution system. In many developed countries, large volume of water for irrigation is pumped using modern technologies in the agricultural sector. However, a very large percentage of the farmers in the less developed countries live under the poverty line and they cannot obtain even the minimum amount of water which is needed to irrigate their small plots of land without pumping. Many of these people live in geologically old, flat, low-lying valleys that have fertile soil and ground or river water only a few feet below their fields.

They cannot afford sophisticated pumping equipment and depend heavily on animal or even human power to lift small amount of water required for their plot of land. Due to this omnipresent situation, a simple mechanism having a low initial cost and not requiring costly fuel would be of great benefit to mankind. Solar powered water pumps offer considerable potential to meet this demand. Solar energy collection and its use in pumping can be reliable and trouble free. The solar energy itself is free and nonexpendable. Moreover, solar energy is widely available in countries where low-lift pumping is most needed, as we know irrigation water requirements are the greatest when the sunshine is mostly available. <sup>[4]</sup>

In this report we will take an attempt to design a feasible solar powered water pump to meet this need.

## **1.2 Literature Review**

The design of small photovoltaic solar powered water pump systems by- US Department of Agriculture October 2010, technical note-28. The principle components that are needed to design a solar-powered water pump system include the PV array and its support structure, an electrical controller, and an electric-powered pump. To ensure the compatibility of the system and how the system functions it is crucial to design the components as part of an integrated system. The information required to design a PV powered pumps are solar insolation, the volume of water required in a specific time period for irrigation and the total dynamic head (TDH) for the pump. They used manual tracking system for PV panels. Electrical controllers and safety devices are integrated into PV-powered water pump systems to have better control over the input electric power to the pump and to provide electrical protection and switching. <sup>[5]</sup>

## **1.3 Thesis Organization**

We have divided our thesis into several chapters so that we can discuss and explain our PV system, providing all the information possible. In chapter-1 we have introduced our thesis and have given a basic idea. In chapter-2, we have discussed about the climate, agriculture and the irrigation sector of Bangladesh. It also includes the detailed information about our location. In chapter-3, we have described the types of PV systems and the reasoning behind the system we chose. In chapter-4, we have described the components of our system which includes the solar pump and the solar panels. In chapter-5, we have included the different related theories and equations. In chapter-6, we included all our results and the calculations required to find the intensities, energies and flow rates needed to choose the panels for our design. In chapter-7, we have concluded our thesis and also mentioned the future aspects of our design.

## Chapter-2

### **2.1 Introduction**

In this chapter, we will discuss about the agriculture in Bangladesh, how climate change affects the crop production, water required and obtained for irrigation. Moreover, we will also discuss about the location we chose for our thesis work and the data obtained from the specific crop field.

#### **2.1.1 Agriculture in Bangladesh**

Bangladesh is an agricultural country. About 80% of the people depends on agriculture. It plays a main role in developing our country. Agriculture acts as an important aspect in Bangladesh's economy by employing 45 percent of the country's workforce and offering 19.6 percent to the national GDP.<sup>[6]</sup> Moreover, water has been an aid for farmers as quality of crops and yield gets damaged without proper water for a day. Since 2000, Bangladesh's rural economy and agriculture have helped to drive poverty. Between 2005 and 2010, agriculture accounted for 90 percent of the reduction in poverty.<sup>[7]</sup>

#### **2.1.2 Crops of Bangladesh**

Among the primary crops, rice and wheat are the main crops and food of Bangladesh. Tea is another primary crop grown in the northeast. Rice can be grown and harvested almost three times a year in many areas of Bangladesh due to the country's fertile soil and normally sufficient water supply.<sup>[8]</sup> Bangladesh is said to be the fourth largest rice producing country in the world. For few factors, Bangladesh's labor-intensive agriculture has reached a steady increase in food grain production even after the often adverse weather conditions. These include irrigation, better flood control and using the fertilizers more efficiently, and of better distribution and rural credit networks establishment.

#### **2.1.3 Climate of Bangladesh**

Bangladesh has a subtropical monsoon climate distinguished by wide seasonal variations in rainfall, somewhat warm temperatures, and high humidity. Mostly recognized three seasons are: a hot, humid summer from March to June; a cool, rainy monsoon season from June to October; and

a cool, dry winter from October to March. The maximum summer temperatures ranges between 32°C and 38°C. Most parts of the country is warmest during April. January is the coldest month giving an average temperature of 10°C for most of the country. <sup>[9]</sup>

Bangladesh agriculture is mostly dependent on the weather, also depends on the amount and distribution of the rainfall i.e. the southwest warm and humid Monsoon which comes during June-October.

#### **2.1.4 Irrigation**

Irrigation is defined as supply of water for dry agricultural land by means of dams, barrages, channels or other devices.

Estimated amount of 40,000l of water is needed for per hectare each day or about 16,325l per acre each day to irrigate 1 acre of land. However, issues like irrigation, flood control and drainage, which are contradictory in nature are forced by Bangladesh water availability over the years. Bangladesh receives about 7.5 meters of water, where 5.5 meters comes from surface flow and 2 meters from rainfall per year. During June to September, huge water volume of about 90% is available and remaining 10% is received during October to May. Hence, Bangladesh is compelled by water environment for irrigated agriculture supported by flood control measures and provision of drainage facilities. About 76% of the cultivable area can be irrigated of which about 64% are presently under irrigation with the water potential of the country. About 79% of the irrigated area use groundwater because of the fluctuation in availability and lack of control over surface water. <sup>[10]</sup>

## **2.2 About our location**

Selection of a suitable water pump for a particular situation depends on the characteristics of the source of water and the lifting device, the amount of water to be lifted, the depth to the pumping water level, the type and amount of power available and the economic status of the farmers. Keeping all of it in mind, we studied on a solar-pump owned by a farmer of a village of Shibpur Upazila, Narsingdi.

## **2.2.1 Shibpur, Narsingdi**

Shibpur is an Upazila of Narsingdi District of Dhaka, Bangladesh. It is located in between 23°56' and 24°07' north latitudes and in between 90°38' and 90°50' east longitudes. <sup>[11]</sup> The location is shown in Figure 2.1, below.



Fig 2.1 Shibpur Upazila Map

It has 44,365 households and total area of 206.89 km<sup>2</sup>.<sup>[14]</sup> Moreover, it is surrounded by Monohardi upazila on the north, Raipura, Narshindi Sadar and Palash upazilas on the south, Belabo and Raipura upazilas on the east, Palash and Kapasia upazilas on the west. <sup>[11]</sup>

The population in Shibpur is approximately 2, 37,246, where males constitute 50.77% of the population, and females 49.23%.



### **2.2.2 Crops of Shibpur**

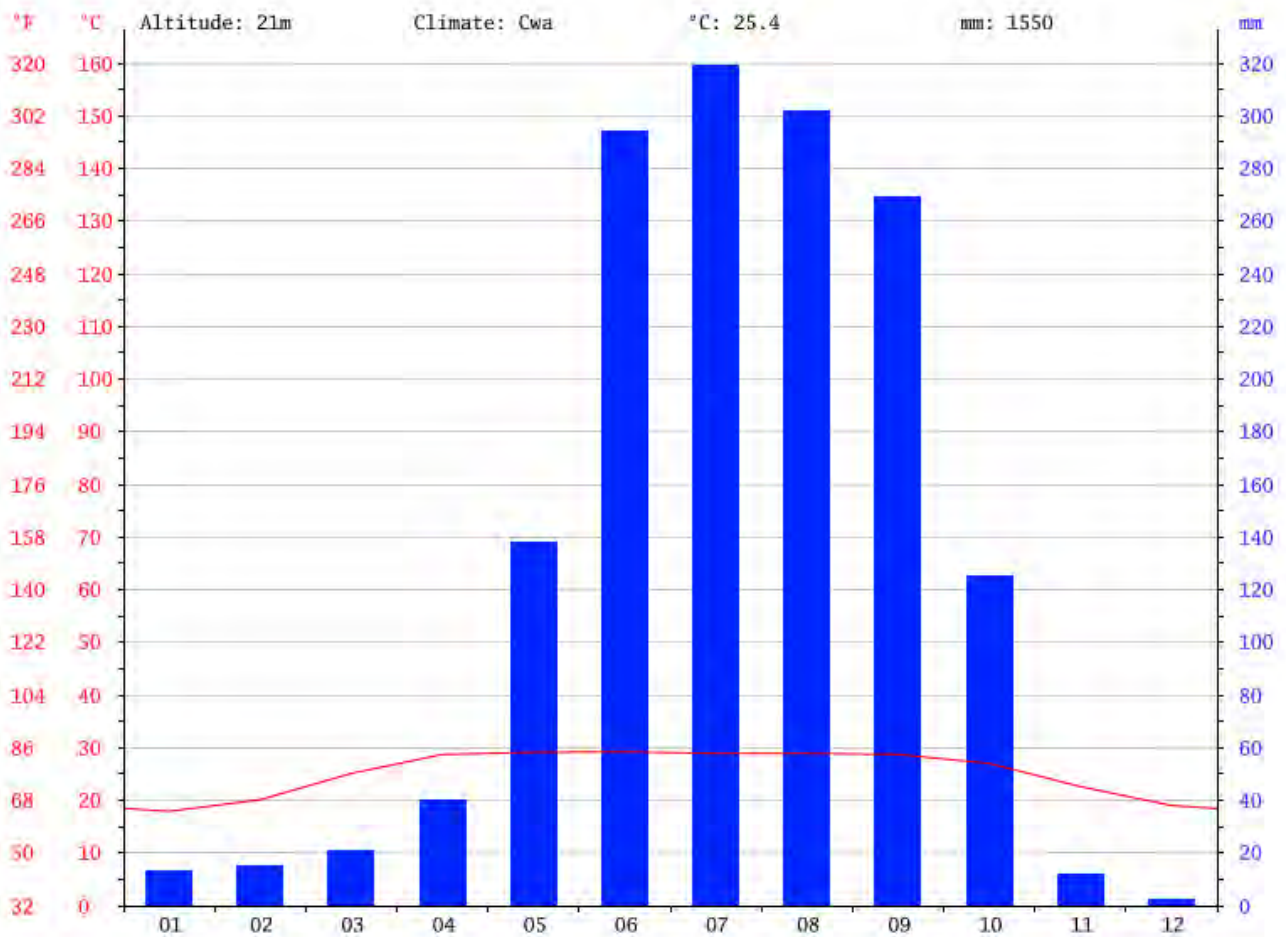
The main sources of income in Shibpur are Agriculture with a percentage of 54.55%, non-agricultural labourer with percentage of 2.08%, industry 3.16%, commerce 15.07%, transport and communication 4.77%, service 8.21%, construction 1.55%, religious service 0.22%, rent and remittance 2.41% and others 7.79%. <sup>[11]</sup>

Since Agriculture play an important role for the people in Shibpur, they grow various crops like paddy, jute, ginger, turmeric, vegetables. Rice is the most common and main crop grown here.

### **2.2.3 Climate in Shibpur**

The climate in Shibpur is comparatively warm. During summer, it is much rainier than the winters here. In Shibpur, the average annual temperature is 25.4°C. In a year, the average rainfall is 1550mm. <sup>[12]</sup>

The graph below, Figure 2.2 shows the average climate in Shibpur throughout the year.



**Fig 2.2** Climate for each month in Shibpur showing (a) rainfall in mm represented by Bar Graph and (b) temperature in °C and °F represented by line graph

### **2.2.4 Data Obtained**

Our first work was an accurate site assessment, which is critical to successfully design solar pump. This ensures that the system design and installation locations are site-specific so that the system delivers the required pumping outputs, with the least amount of wasted energy.

Site assessment includes collecting accurate information about:

- the land size
- what crop is grown

- type of soil
- water requirement
- water source
- water delivery
- time period for crop cultivation
- type of pump used

The land we chose for our thesis work is a paddy field of 10 acres in size. The variety of rice grown there are, BRRI Dhan 28 and BRRI Dhan 29, which are one of the most popular rice grown in Bangladesh. The soil available there is called Doash Mati.

The water amount required by the crops is approximately 4,41,919.2 litres, which is supplied for 14 hours (from 8am to 10pm) for two days. So, the minimum water required for one day is 2,20,959.6 litres.

The water required is supplied by using a centrifugal motor pump, which pulls up water from 80-85 feet below the ground. The motor runs on diesel where 2 litres is consumed per 3 hours. The details of the pump and motor that is used in this field are given below:

- 80-85 feet depth of water
- Centrifugal: Gazi Pump
- Motor: Double Bird Diesel Engine
- Pump bought in 2006
- Pump: Tk. 2500
- Motor: Tk. 14000
- Fuel: Diesel
- Fuel consumption: 2 litres/3hrs
- Fuel Cost: 70tk/litre

However, it takes 90 days for the crops to mature, from seeding to harvest. The rice are cultivated twice yearly in summer season during the Bengali month Boishakh ( April- May), and in winter during the Bengali month Poush (December-January). They do not cultivate in spring that is during rest of the Bengali month Falgun to Chaitro (February-April), as the water level below the ground decreases because of the dry season. Hence, less water can be pumped.



Fig 2.3 A diesel powered pump used in Shibpur for irrigation

## Chapter-3

### 3.1 Types of PV System

Photovoltaic power systems are classified generally in accordance to their functional and operational requirements, their component configurations, and how the equipment is connected to other power sources and electrical loads.

There are three types of Photovoltaic systems below:

#### 3.1.1 Battery-coupled solar pumping system

The components of battery coupled water pumping systems are photovoltaic (PV) panels, charge control regulator, batteries, pump controller, pressure switch, tank, and DC water pump. In the daylight hours, the electric current produced by the PV panels charges the batteries, which in turn supplies power to the pump anytime water is required. Battery helps to produce a steady supply of voltage to the DC motor of the pump. Hence, the system can deliver a constant supply of water during night and cloudy days. <sup>[13]</sup>

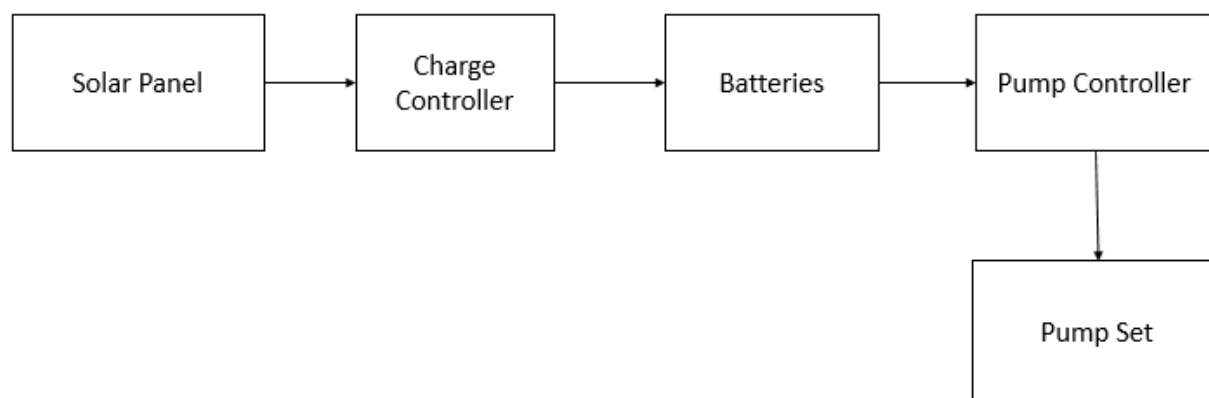


Fig 3.1 Block diagram of Battery Coupled Water Pumping System

The advantages of using batteries in PV systems are

1. To operate the PV array near its maximum power point
2. To power electrical loads at stable voltages
3. To supply surge currents to electrical loads and inverters.

In order to protect the battery from overcharge and over discharge, a battery charge controller is used in these systems. In stand-alone systems, a lead acid battery is used to generate power by the solar panels. Other types of battery are for example nickel-cadmium batteries. However, the advantages of the lead-acid battery guarantee its popularity.

A battery is composed of individual cells; each cell in a lead-acid battery generates voltage of about 2 Volts DC, so this means a 12 Volt battery needs 6 cells. A battery's capacity is measured in Ampere-hours or Amp-hours (Ah).

The use of battery has some demerits.

1. As the operating voltage is derived by the batteries and not the PV panels, this can decrease the efficiency of the entire system.
2. Based on how well batteries are charged and on its temperature, the voltage that is supplied might be lower by 1 to 4 volts than the actual voltage that is produced by the panels during the maximum sunlight hours. <sup>[14]</sup>

In order to fix the problem of the low efficiency, appropriate pump controller needs to be used so that it can boost the battery voltage that will be supplied to the pump.

Four types of PV Systems and its merits and demerits <sup>[15]</sup> is shown in the table below:

<b>PV Systems</b>	<b>Merits</b>	<b>Demerits</b>	<b>Approximate cost</b>
Grid-tie with Battery Backup	<ul style="list-style-type: none"> <li>• Can provide power to designated appliances (i.e. refrigerator or server)</li> <li>• Sends excess energy back into power grid</li> </ul>	<ul style="list-style-type: none"> <li>• Increase in cost</li> <li>• Complex</li> <li>• Increase in maintenance</li> </ul>	\$6-10 per watt or \$6,000 - \$10,000 per KW

	<ul style="list-style-type: none"> <li>for credits</li> <li>• Stores energy for use during an outage</li> </ul>	<ul style="list-style-type: none"> <li>• Decrease in savings credits</li> </ul>	
Grid-tie without batteries	<ul style="list-style-type: none"> <li>• Simple</li> <li>• Cost effective</li> <li>• Lower maintenance</li> <li>• Stores Energy through “Net Metering”</li> <li>• Excess Energy is sent back into the utility provided power grid for credits and refunds</li> </ul>	<ul style="list-style-type: none"> <li>• No back up during an outage even when the sun is shining</li> </ul>	\$4-6 per watt or \$4,000 - \$6,000 per KW
Off Grid/ Stand alone	<ul style="list-style-type: none"> <li>• Eliminates utility dependency</li> <li>• Works with wind or hydro power renewable energy generators</li> </ul>	<ul style="list-style-type: none"> <li>• Increase in cost</li> <li>• Complex</li> <li>• Increase in maintenance</li> <li>• Less efficient</li> </ul>	\$9-\$15+ per watt or \$9,000 - \$15,000+ per KW
PV Direct*  *Limited use for direct connect PV panels	<ul style="list-style-type: none"> <li>• Simple</li> <li>• Connects directly to motor or pump</li> <li>• Low maintenance</li> </ul>	<ul style="list-style-type: none"> <li>• Limited usage</li> <li>• Does not create energy surplus</li> </ul>	< \$2/watt*

Table 3.1 Four types of PV Systems and its merits and demerits

### **3.1.2 With backup generator**

A PV system with backup generator is the system where the PV system is connected with a fossil fueled generator for emergency use when the system has failed. Rainfall, heavy wind, earthquakes, floods, etc. are only a few examples that might cause the system to fail for extended periods of time. Both battery backup and generator backup have additional costs, but the extra maintenance is not as unappealing as the additional expense associated with having to replace batteries every 5 to 10 years. A generator backup system proves better than a battery backup system.

The basic configuration of PV system with backup generator is as follows:

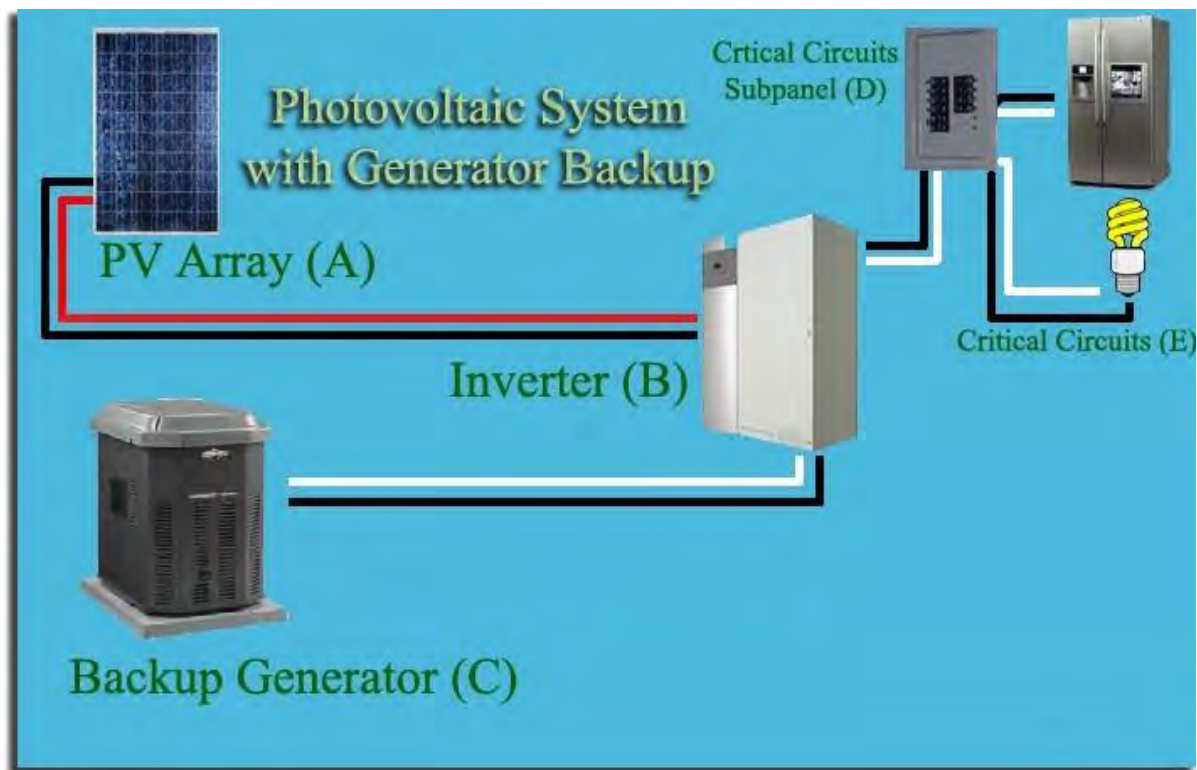


Fig 3.2 PV system with a backup generator <sup>[16]</sup>

(A) Photovoltaic Array

The solar system is sized as normal, since the generator has no relevance unless the power goes out.



(B) Inverter

Under normal conditions, the function of the inverter is the same as a standard inverter for the solar panels. However, when the power fails, the inverter will disconnect the solar back-feed and switch on the generator immediately. The generator will then power the critical circuit subpanel (D) until its fuel is used up.

(C) Backup Generator

The backup generator can use different types of fuel such as natural gas, gasoline, diesel, or propane, each associated with its own advantages and disadvantages. The most common type of generator for small scale systems is natural gas. This type of generator requires the least maintenance, since you do not have to worry about fuel going bad if not used. Only periodic running of the generator is needed.

	Natural gas	Gasoline	Diesel	Propane	Solar with Battery Backup
Requires refueling after use	No	Yes	Yes	Yes	N/A
Requires periodic fuel replacement	No	Yes	Yes	No	N/A
Dependent on Utility Company	Yes	No	No	No	No
Periodic Maintenance	Yes	Yes	Yes	Yes	No
Able to use power from solar panels during grid failure	No	No	No	No	Yes

Table 3.2 The differences between the different fuels and an additional comparison between a PV system with backup battery <sup>[16]</sup>

#### (D) Critical Circuit Sub Panel

The panel containing the circuit breakers leading to the critical circuit loads. Regardless of power status, these loads will always have power. Power will only be drawn from the generator in the event of a system failure.

#### (E) Critical Circuits

These critical loads are user defined, such as a water pump, lighting, security systems, etc. <sup>[16]</sup>

Advantages of using a PV system with backup generator:

1. Provides backup power after system failure.
2. Extends the system's backup duration indefinitely-until the fuel runs out.
3. An uninterruptible power supply.
4. A generator removes the need for oversized photovoltaic arrays which are utilized poorly and also costly.

Disadvantages of using a PV system with backup generator:

1. Overall system cost is high, e.g. installation cost, maintenance costs and lifetimes for all components.
2. There is now an additional recurring expense for fuel.
3. The system becomes more complex because of additional hardware and wiring.
4. High maintenance is required for the generator.

A solar power system with a backup generator is not as common because of the significant total cost increase, which ultimately reduces the financial return. However, it will guarantee peace of mind knowing that the system wouldn't be without power. <sup>[2]</sup>

### **3.1.3 Directly coupled system**

A directly coupled system is where the solar panels are directly connected to the motor that drives the centrifugal pump. Power is directly obtained from the panels. There are no batteries, inverters or circuit for power conditioning used in this system. The power supplied to the motor varies according to the sun's intensity. When the sun is shining brightly (high intensity), the panel output

will be high and when the sun is close to the horizon (when sunrise or sunset), the output obtained from the panel is quite low. The applications of this type of system includes some common uses such as fans, water pumps and solar powered thermal water heating systems.

Days where there is almost no sunlight or even seasons such as monsoon where there is low sunlight, the output obtained from the panel is quite low, sometimes lower than the optimum voltage required to run the motor. On sunny days the directly coupled system is able to pump enough water in extra to be stored in storage tanks. The stored water can be used in days when the weather is not favorable.

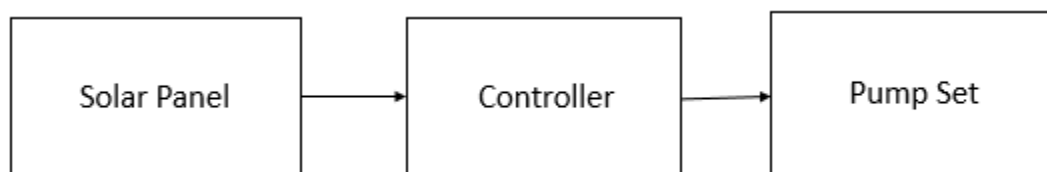


Fig 3.3 A block diagram of a directly coupled system

Advantages of using a directly coupled system:

1. No batteries are used, hence the cost of the overall system goes down.
2. It does not require the constant maintenance like the battery coupled system.
3. This system is the simplest of all the other solar pumping system.
4. No loss of efficiency since no extra components are being used
5. Low cost means more use in developing countries hence less use of electricity produced by burning fossil fuel.

Disadvantages of using a directly coupled system:

1. The output power obtained is not fixed throughout the day.
2. During a cloudy day or rainy season, the panel can produce power below the optimum level hence it becomes obsolete.
3. No battery means that if the panel does not get enough sunlight during the day time or during the peak time, the water available during the night time or cloudy days will be insufficient.

4. Backup system is required as this is not an entirely reliable system for ensuring optimum power throughout. [17]

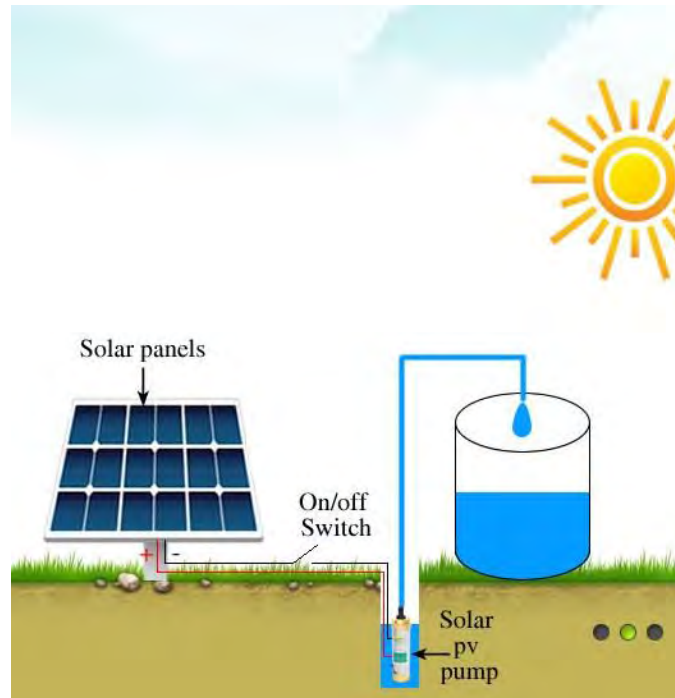


Fig 3.4 Simple example of a directly-coupled system [18]

### **3.2 Our system and reasons behind choosing it**

Previously, we discussed about the different types of PV systems that are available. However, our paper describes the experimental study carried out using a Directly-Coupled system. A direct-coupled PV pumping system is a group of interactive pieces of equipment designed to collect and convert the solar radiation into electrical energy (direct current) and to convert the electrical energy into mechanical energy to provide enough mechanical torque to spin a pump, or a set of pumps, to circulate a fluid.

In direct-coupled solar water pumping systems used in our work, the electricity from the PV modules is transferred directly to the pump, which pumps water through a pipe to a specific land.

This system is designed to pump water only during the day. The amount of water pumped is totally dependent on the amount of sunlight hitting the PV panels and the type of pump. Since the pump runs entirely on sunlight the amount of water pumped by this system varies throughout the day in direct correlation to the intensity and amount of sun is striking the PV panel at any given moment. During the periods of sunlight (late morning to late afternoon on bright sunny days) when the sun is in the highest position and the sky is clear the pump operates at or near 100 percent efficiency with maximum water flow. However, under low-light conditions, such as during early morning and late afternoon when the sun is not an optimal angle or there is cloud cover, pump efficiency will drop. The pump efficiency will drop even more during cloudy days. To compensate for variations in available sunlight, we calculated the incident energy for different tilt angles measured for three different seasons: February-April, September-November and February-November. Then we take the optimized value for each cases and consider that for each.

Direct-coupled pumping systems can store extra water on sunny days so it is available on cloudy days and at night. Water can be stored in a larger watering tank or in a separate storage tank. Later the water can be taken for other uses. Moreover, water-storage capacity is important for a solar pumping system.

In our work, the direct-coupled pumping system does not require battery. However, the use of batteries reduce the efficiency of the overall system as the operating voltage is controlled by the batteries and not the PV panels. The voltage supplied by battery runs 1 to 4 times lower than the voltage supplied by the solar panels themselves under maximum sunlight. Moreover, the use of battery will increase the price of the overall pump.

Despite the drawbacks, the direct-coupled system's efficiency is less than the efficiency of other PV systems. The system operates without batteries and complex electronic control, therefore not only the initial cost is low but also maintenance, repairing and replacement cost can be saved. Moreover, we will not be using or burning any fuels, so we can call this system environmental friendly as it is not causing any harm to our surroundings. As the directly-coupled system attains steady state soon after any abrupt change, we considered this system in our work.

## Chapter-4

### 4.1 Introduction to solar pumps

At present solar pumping system is becoming more and more demanding and is being applied for daily use (underground water), agriculture irrigation, forestry irrigation, desert control, pasture animal husbandry, water supply for islands, wastewater treatment engineering, and many more. Over the last decade, with the advancement in the utilization of non-traditional energy resources, solar pumping systems are used more and more in municipal engineering, city centre squares, parks, tourist sites, resorts and hotels. This system is made of a solar array, a pump and a pump controller. On the basis of the philosophy of the design, it is better to store water than electricity, as there is no energy storing device such as battery in the system.

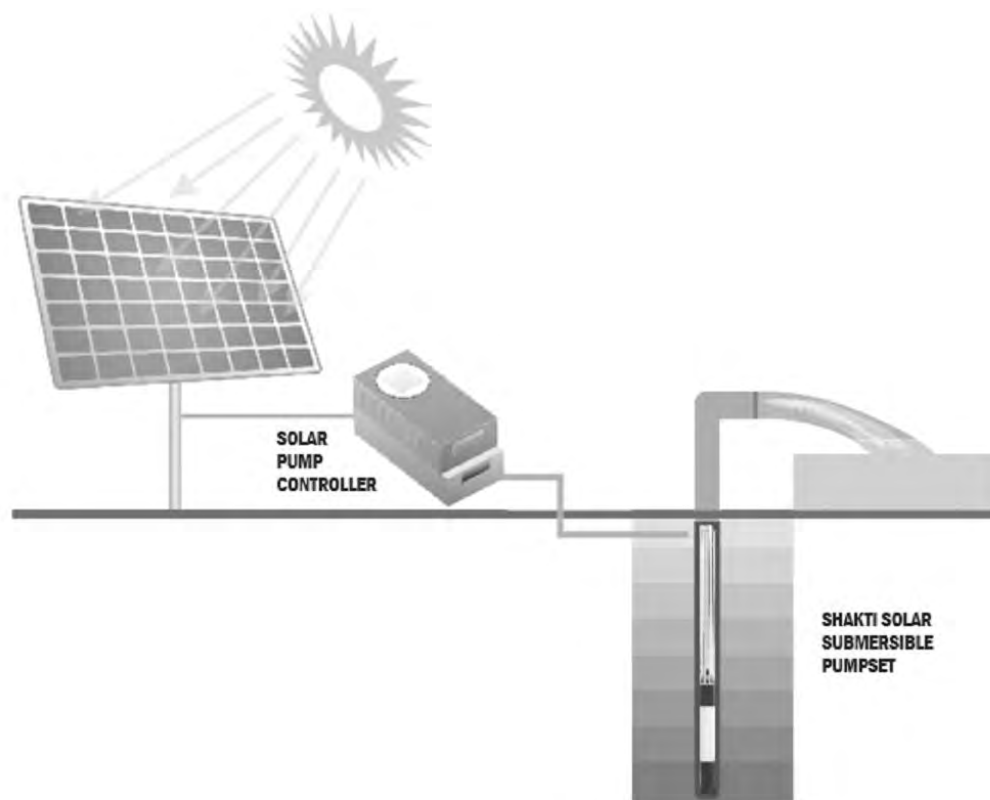


Fig 4.1 Shakti solar pumping system with a submersible pump

### **4.1.1 Structure of solar pumping system**

The solar array, a collection of solar modules connected in series and/ or in parallel. This array absorbs radiation from the light of the sun and transforms it into electrical energy. Hence, it helps in distributing dynamical water as a whole system. The pump controller controls and regulates the system operation, with respect to the change in intensity of the sunlight to perceive the maximum power point tracking (MPPT). The pump is capable to collect water from the deep wells or rivers and lakes and pour it into the water reservoir, or it can also be connected directly the irrigation system, fountain system, etc. According to the demand of the system and conditions of its installation, different types of pumps are used, such as centrifugal pump, axial flow pump, mixed-flow pump or deep-well pump.

### **4.1.2 Applications**

- Ground water lowering
- Irrigation systems
- Industrial Application
- Drip irrigation & sprinkler
- Tank / Cistern filling
- Wildlife refuge
- Rural water supply for ranches, cabins, and cottages
- Fountains Features
- High flow system for faster tank fill and significant water output.
- Proven motor and pump technology for long-term reliability
- Available Free of cost at your doorstep.
- Clean and pollution free energy, Eco-friendly.
- Ideal for remote areas, where electricity is not available or availability is capital intensive.

- Suitable for day time irrigation, Continuous supply for 6-8 hours in a day.
- MPPT – Max Power Point Tracking for maximizing efficiency of input power
- Soft start feature prevents water hammer and increases system life Easy to operate.
- Simple installation and maintenance free.
- MNRE approved.

### **4.1.3 All-in-One Package**

To meet the specific prerequisites of the solar pumping system, a solar drive is used. Shakti components are used to develop a rough, high-output system which handles the challenges of remote and hostile environments. No other system delivers the features, benefits, and reliability of solar drive such as this.

The Solar high efficient pump set consists of two pump technologies

1. Centrifugal Pump.
2. Helical Pump for High Heads and small flow rates.

The high Efficient Motor is designed based on the permanent magnet principle with independent electronics unit. The Motor speed range is 1000-3600 RPM depending on the load of the pump. The permanent magnet motor features a constant higher efficiency within power range compared to a traditional asynchronous motor.

### **4.1.4 The Components of Solar Water Pumping System**

- Shakti High Efficient Submersible motor
- Shakti Submersible pump
- Solar Panel and its mounting structure
- Solar Drive controller
- Cable



- Pipes
- Variety of flow rates available in: 5 to 2500 litres/min. (1.3 to 661.3 US GPM)
- Motor and drive ratings available in: 0.5 to 50.0 HP (0.37 to 41.5 kW)

#### **4.1.5 Overview**

The controller will initially start the pumps slowly and calibrate its speed according to the load of the pump and how much power is available from solar array.

The output power from the solar array is optimally matched to the load by maximum power point tracker (MPPT) in all the conditions.

The Shakti Solar drive is designed with high quality and durable Shakti products. The controller will attempt to start the pump and motor to deliver water even under hostile conditions, by reducing output in order to protect the components of the system from any damage, and only shutting the system down in extreme cases.

#### **4.1.6 Descriptions and Features**

The Shakti Solar drives controller continuously monitors the performance of the system and integrates a number of components for the preservation of the pump system. The Shakti Solar drives will indicate if any error occurs along with the type of fault through the displays.

The Shakti Solar drives system is optimized for pumping under unfavorable input power conditions unique to solar arrays.

- Internal diagnostics will endure a lower input voltage.
- Whenever possible, the controller will try to adjust the load of the pump in a way so that it optimizes the transfer of maximum power from the solar array.

An easy interface is provided to strengthen the configurability and allow remote system monitoring.

- A three-digit seven-segment display provides a detailed indication of system status.
- A small keypad offers flexibility for selection of user options.

- A continuous data connection for remote telemetry is made available via an RS-485 port. (Optional)

#### **4.1.7 Protection Features**

- Dry run Protection
- Overload Protection
- Open Circuit Protection
- Short Circuit Protection
- Over Heat

The most efficient way to get the water from ground is by using solar pumps. Advantage of using Solar-powered irrigation pumps are that they are low-cost and reliable irrigation alternative for farmers as solar technology and is convenient to the country's flat terrain and abundant sunshine. The quality of life for the farmers in Bangladesh are improved by solar irrigation pumps. They are cost-effective and more efficient than other pumps. Moreover, they do not harm or pollute our environment.

In this thesis, a simple but efficient solar-powered water pumping system is presented. It provides theoretical studies of the types of PV systems, system components and its modeling techniques. It also contains investigation in details about solar radiation and panel intensity. Moreover, MATLAB simulation of the system and comparison of different seasons are provided. <sup>[19]</sup>

## **4.2 Introduction to panels**

The possible technologies used for producing off-grid electricity and power for irrigation and daily uses are fossil-fuel based technologies such as diesel generators. Even though they are useful for us but they harm our environment in many ways. Hence we use renewable resources such as photovoltaic.

In this thesis, we describe the design of a photovoltaic (PV) solar power system that will be used for irrigation in the village of Shibpur Upazila, Narsingdi district. The system will provide 10,250W of DC power for irrigation at the site we selected.

#### **4.2.1 Photovoltaic (PV) Panels**

A series of solar cells make up a PV panel, as shown in Figure 1, below. Two or more specially prepared layers of semiconductor materials are found in each solar cell, which when exposed to sunlight, produces a DC electricity.

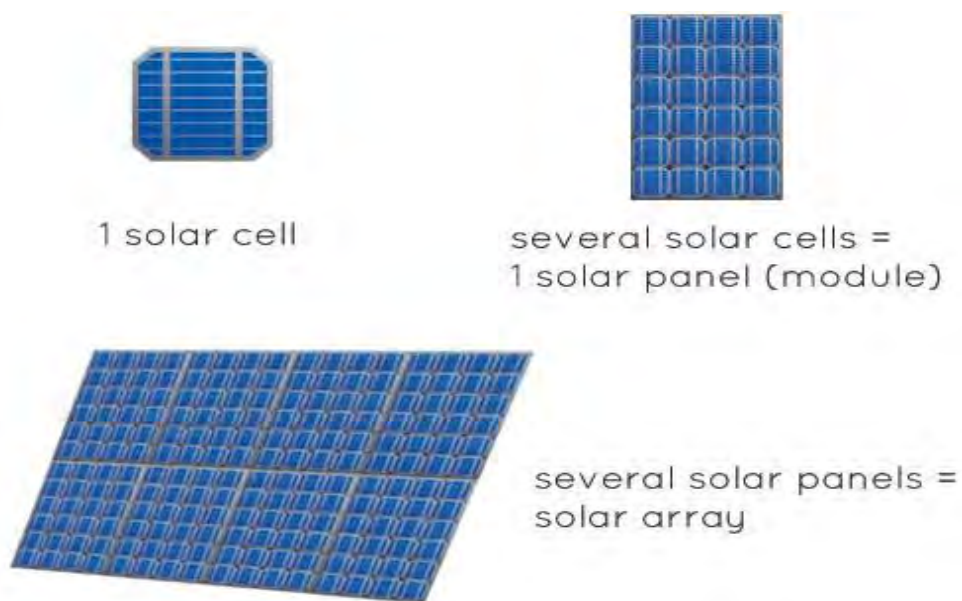


Fig 4.2 Solar cell, PV solar panel, and PV panel array <sup>[21]</sup>

The semiconductor cells are usually crystalline or thin film. Crystalline solar cells are usually formed out of silicon and have an efficiency of 15% approximately. Solar cells that are made out of thin films, that might contain a variety of different metals, have efficiencies of approximately 8% to 11%. <sup>[19]</sup> They are not as strong as silicon solar cells, but are less heavy and comparatively less expensive.

PV panels are connected by wirings as they are arranged in arrays to deliver power the pump.

PV panels must satisfy all NRCS required specifications, for both production and structural integrity.

### **4.2.2 Technical Overview**

The system will provide seasonal water for irrigation. The power is derived from 340W XL Silver Mono Solar Panel, <sup>[20]</sup> and delivered through a charge controller, which will adjust the power and deliver to the pumps.

### **4.2.3 PV Panel Electrical Characteristics**

According to the output, PV panels are rated, which is based on the incoming irradiance at specific temperatures of each season's month. Panel output data contains peak power (W), voltage (V) and current (A).

**Table 1- PV Solar Panel Electrical Characteristics**

<b>Characteristics</b>	<b>Value</b>	<b>Unit</b>
Peak Power	340	Watt
Max Power Voltage	38	Volts
Max Power Current	9.01	Amps

Table 4.1 Electrical characteristics for the solar panel 340W XL Silver Mono Solar Panel <sup>[20]</sup>

### **4.2.4 PV Panel Selection and Array Layout**

The PV panels we chose for our system will be able to provide the minimum energy requirements to run the pump.

For example, if we chose a submersible pump which requires a minimum power of 8200 W, the panel also takes some factors in account like high heat, dust, etc., so it must have some additional capacity. To account for these environmental factors, we increased the minimum peak power, 8200 watts, by 25%. <sup>[6]</sup> Hence the PV panel is sized to provide us with a minimum output power of 10,250 Watts.

$$1.25 \times 8200 \text{ W} = 10,250 \text{ W}$$

The PV panel we selected has the electrical characteristics shown above in Table 1, which includes a peak power output of 340 Watts at 38V and 9.01A.

To meet our pump's requirement and to provide necessary voltage for the pump, panels are to be wired in a combination of series and parallel. For example, the total output voltage for thirty PV panels are calculated below. The output voltage for fifteen panels wired in series is the sum of their individual voltages:

$$\text{Output voltage} = 38 \times 15 = 570\text{V}$$

The power obtained from the panel goes through the Maximum Power Point Tracker (MPPT) charge controller which adjust the high voltage DC output from the panels own to low voltage required by the pump.

Therefore, from the flowrate and the head obtained, we can select the appropriate pump model from the Shakti Pump catalogue. By considering the power of the selected pump model, we can design the panel arrangement to meet our water requirement.

# Chapter-5

## Solar Radiation

Sun provides enough energy to help sustain all life on Earth. The energy that it produces in one hour is enough to sustain life for a whole year. [1] Radiation from the sun as it reaches the Earth varies due to diffusion and absorption of that energy in the atmosphere.

Maximum solar radiation falls on the Earth's surface when the sun is directly overhead. The sunlight has to travel the shortest path when it is overhead and has to travel the longest path when it is along the horizon. [2] The path defined as 'Air Mass' (AM) can be approximated by:

$$AM = \frac{1}{\cos \alpha} \quad [5.1]$$

Once per the day, the Earth rotates around its own polar axis. The Earth is slightly tilted at an angle  $23.45^\circ$ . Because of this inclination, the sun is higher up in the sky in summer than in the winter. Declination  $\delta$  is the angle of deviation of the sun when it is directly over the equator. If 'n' is considered any given day of the year and angles of the north is taken as positive and the angles of the south is taken as negative, then the declination is calculated as:

$$\delta = 23.45^\circ \sin\left(\frac{360(n-80)}{365}\right) \quad [5.2]$$

Declination is important because it helps us to locate the position of the Sun in the sky any time of the year.

Any position on the Earth can be determined accurately with the help of its respective latitude and longitude. The latitude is normally written in this format, degrees°, minutes', seconds''.

For example, the location in Narsingdi that we have chosen has the latitude of  $24^\circ 2' 25.61''$ . Converting it to decimal format gives us, the latitude  $\phi$  of  $24.04^\circ$ . The  $\phi$  represents the latitude or the angular distance from the equator.

The sunrise and sunset angle of a location on a particular day of the year 'n' can be determined by [1].

$$\omega_s = \cos^{-1}(-\tan \phi \tan \delta) \quad [5.3]$$

The sunrise angle can be considered as  $-\omega_s$  and the sunset angle as  $+\omega_s$ . The difference between the sunrise and the sunset angle can be calculated as:

$$\Delta\omega = (2 \times \omega_s) \quad [5.4]$$

From the sunrise and sunset time  $T_{SR}$  and  $T_{SS}$  respectively of the day 'n', the difference between them can be calculated by:

$$\Delta T = T_{SS} - T_{SR} \quad [5.5]$$

Hour angle,  $\omega(t)$  is the difference between noon and a particular time of the day 't' in terms of  $360^\circ$  rotation in 24 hours.

$$\omega(t) = -\omega_s + \frac{2\omega_s}{\Delta T} \times (t - T_{SR}) \quad [5.6]$$

Now, using hour angle, we can find the solar altitude,  $\alpha$ . It is the angle between the horizon and the incident solar ray that is falling on that particular latitude. The solar altitude can be found by:

$$\sin \alpha = \sin \delta \sin \phi + \cos \delta \cos \phi \cos \omega(t) \quad [5.7]$$

Scattered or absorbed, the amount of sunlight depends upon the extent to which it has to travel through to the Earth's surface. A direct perpendicular path to the sea level, which is appointed as AM1 (air mass = 1) can be compared to the aforementioned length of path to the Earth's surface. The total extraterrestrial energy density that reaches at the top of the Earth's atmosphere (AM0) from the sun is  $1367 \text{ W/m}^2$ . After taking into account absorption, at AM1, the global radiation intensity of  $1367 \text{ W/m}^2$  decreases to  $1000 \text{ W/m}^2$  at sea level. Compared to the original AM0 value, the intensity of sunlight has decreased to 70% at AM1. This intensity can be expressed by:

$$I = 1367(0.7)^{AM} \quad [5.8]$$

For different air masses the above equation for intensity can be modified to <sup>[1]</sup>:

$$I = 1367(0.7)^{AM^{0.678}} \quad [5.9]$$

For finding out the optimum angle to place the solar panels at, different tilt angles ( $\lambda$ ) are used. The tilt angles taken are optimized for the time periods:

1. Latitude
2. September to November
3. February to April
4. September to April
5. December

For a specific time period,

$$\text{Average declination} = \text{Total declination } (\delta) \div \text{total number of days} \quad [5.10]$$

If average declination is less than 0, then the absolute of that average declination is added with the latitude of our location, i.e. 24.040, which gives us the tilt angle ( $\lambda$ ).

$$\lambda = 24.040 + \text{abs}(\text{average declination}) \quad [5.11]$$

If average declination is greater than 0, then the absolute of that average declination is subtracted from the latitude of our location, i.e. 24.040, which gives us the tilt angle ( $\lambda$ ).

$$\lambda = 24.040 - \text{abs}(\text{average declination}) \quad [5.12]$$

The angle between the incident sunlight and the panel normal is  $\theta$  and can be calculated by:

$$\cos \theta = \sin(\phi - \lambda) \sin \delta + \cos(\phi - \lambda) \cos \delta \cos \omega(t) \quad [5.13]$$

Now, to find out the intensity that will fall on the solar panel, we use the equation below:

$$\text{Panel Intensity} = I \cos \theta \quad [5.14]$$

With the help of MATLAB, the energy received by the solar panels can be calculated for the 15<sup>th</sup> of the months of September 2016 to April 2017. For one particular day, the panel intensity is integrated by its corresponding sunrise to sunset time to give us the total energy of the day (kWh/m<sup>2</sup> /day). Different tilt angles of the panels are then used to calculate different sets of energy calculations for the mentioned months.



# Chapter-6

## Results and data

The cultivation timing of our locations are based of two time periods September to November and February to April. With the help of MATLAB, for each of these time period we have calculated their individual intensities (I), energies (E), flow rates and hence the total water obtained is calculated. As discussed earlier, the minimum total water required is 2,20,959.6 litres and we have designed the solar panel system such that this requirement is fulfilled.

### 6.1 Calculation for optimized tilt angle

Optimized tilt angles ( $\lambda$ ) can be calculated using the equation 5.11 and 5.12 from Chapter 5.

#### 6.1.1 Optimized tilt angles

**Tilt angles calculated:**

- Tilt angle optimized for latitude ( $\lambda_1$ ) = 24.04°
- Tilt angle optimized for Sep-Nov ( $\lambda_2$ ) = 35.8427°
- Tilt angle optimized for Feb-Apr ( $\lambda_3$ ) = 25.5002°
- Tilt angle optimized for Sep-Apr ( $\lambda_4$ ) = 33.6864°
- Tilt angle optimized for Dec ( $\lambda_5$ ) = 47.1943°

## 6.1.2 Solar energy bar graphs for different optimized tilt angles

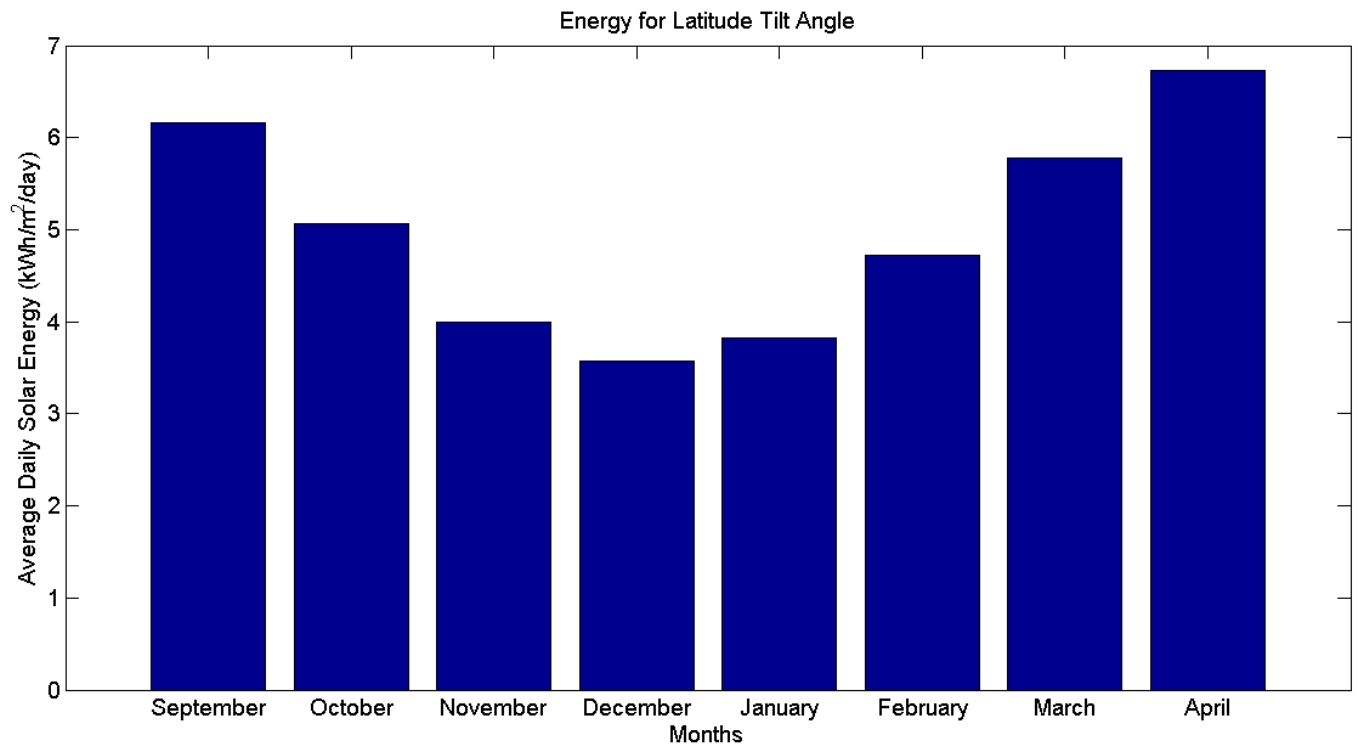


Fig 6.1 Average daily solar energy (kWh/m<sup>2</sup>/day) obtained from September to April for tilt angle equal to latitude

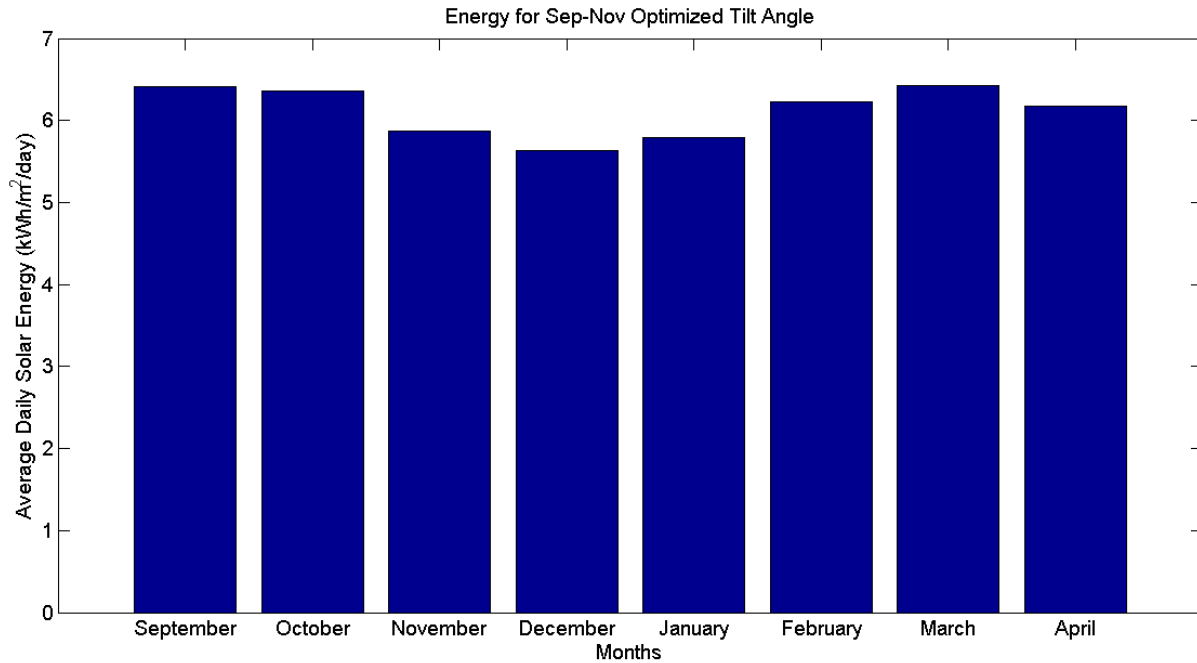


Fig 6.2 Average daily solar energy (kWh/m<sup>2</sup>/day) obtained from September to April for tilt angle optimized for September to November

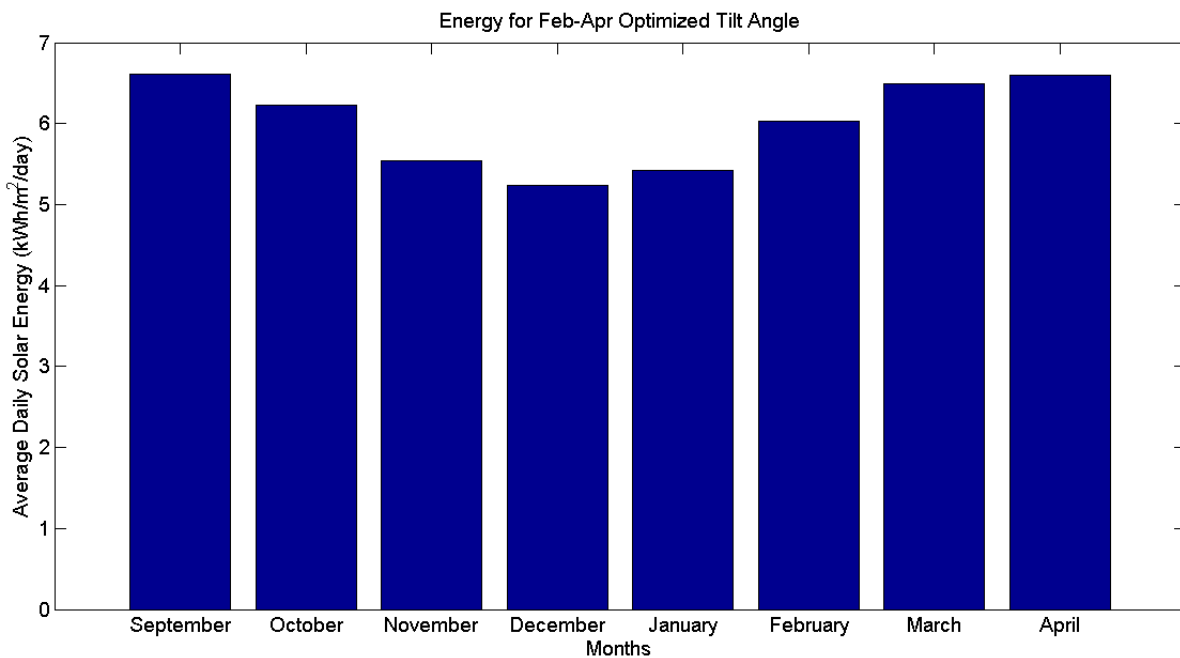


Fig 6.3 Average daily solar energy (kWh/m<sup>2</sup>/day) obtained from September to April for tilt angle optimized for February to April

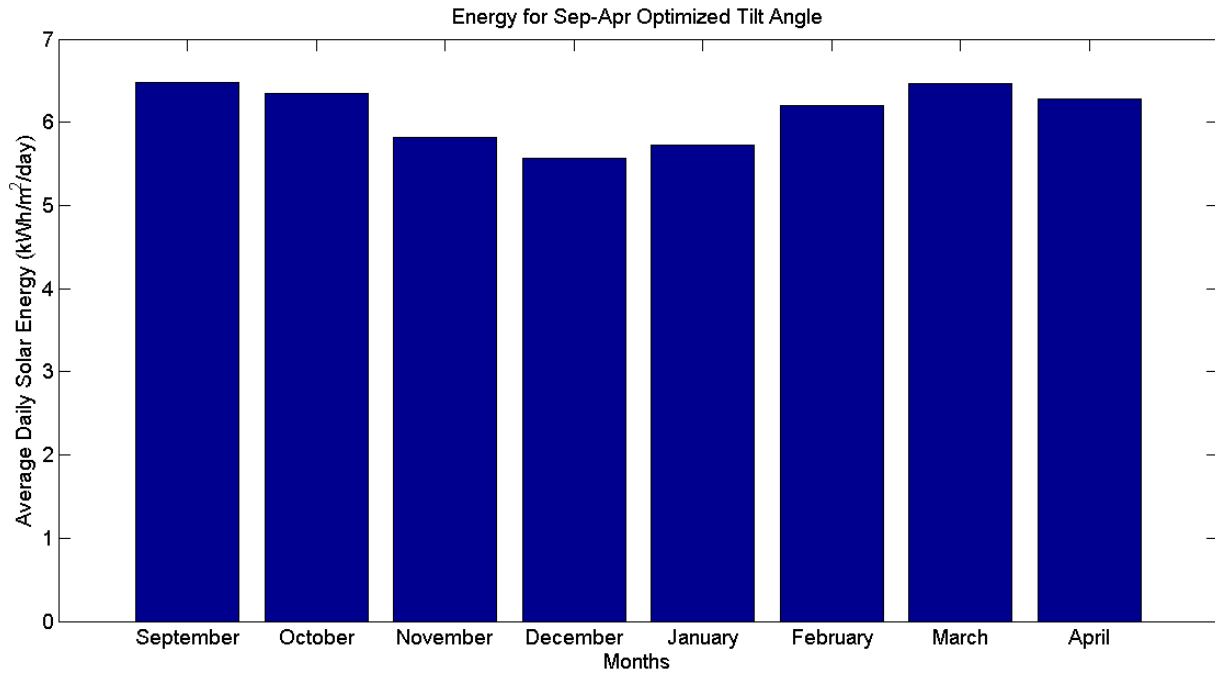


Fig 6.4 Average daily solar energy (kWh/m<sup>2</sup>/day) obtained from September to April for tilt angle optimized for September to April

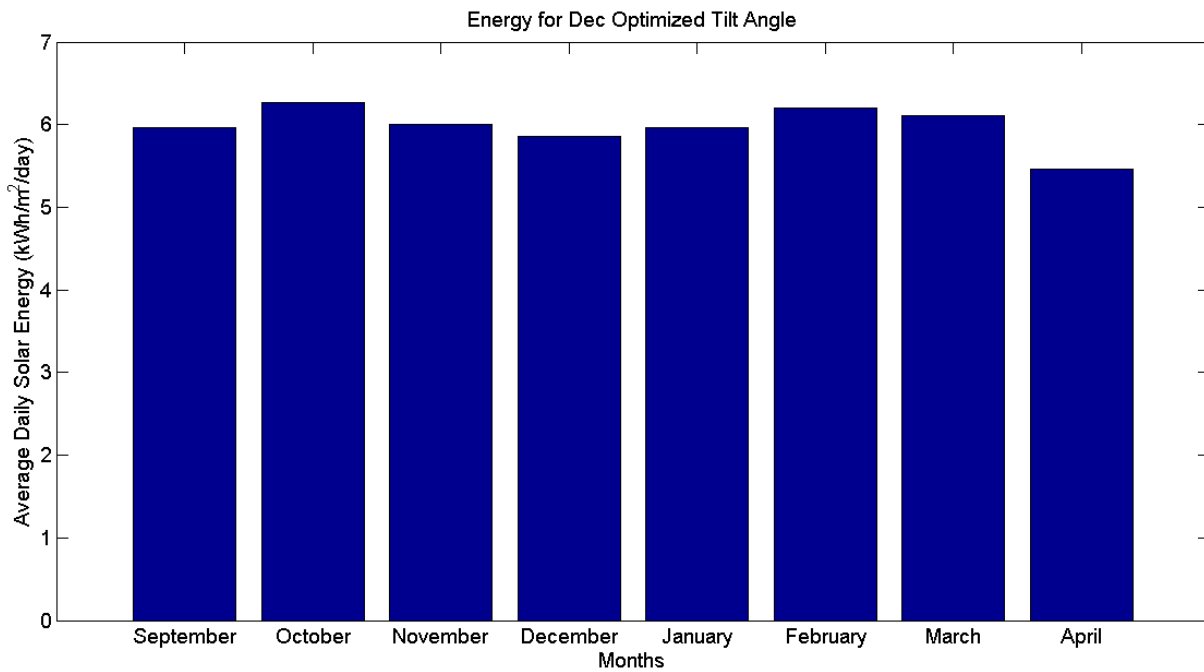


Fig 6.5 Average daily solar energy (kWh/m<sup>2</sup>/day) obtained from September to April for tilt angle optimized for December

Therefore, by combining all the total solar energy bar graphs in a single one from September to April will give us a bar graph consisting of 5 bars in a group for each month. Each bar gives us the total energy obtained for an optimized tilt angle for the 15<sup>th</sup> of that particular month.

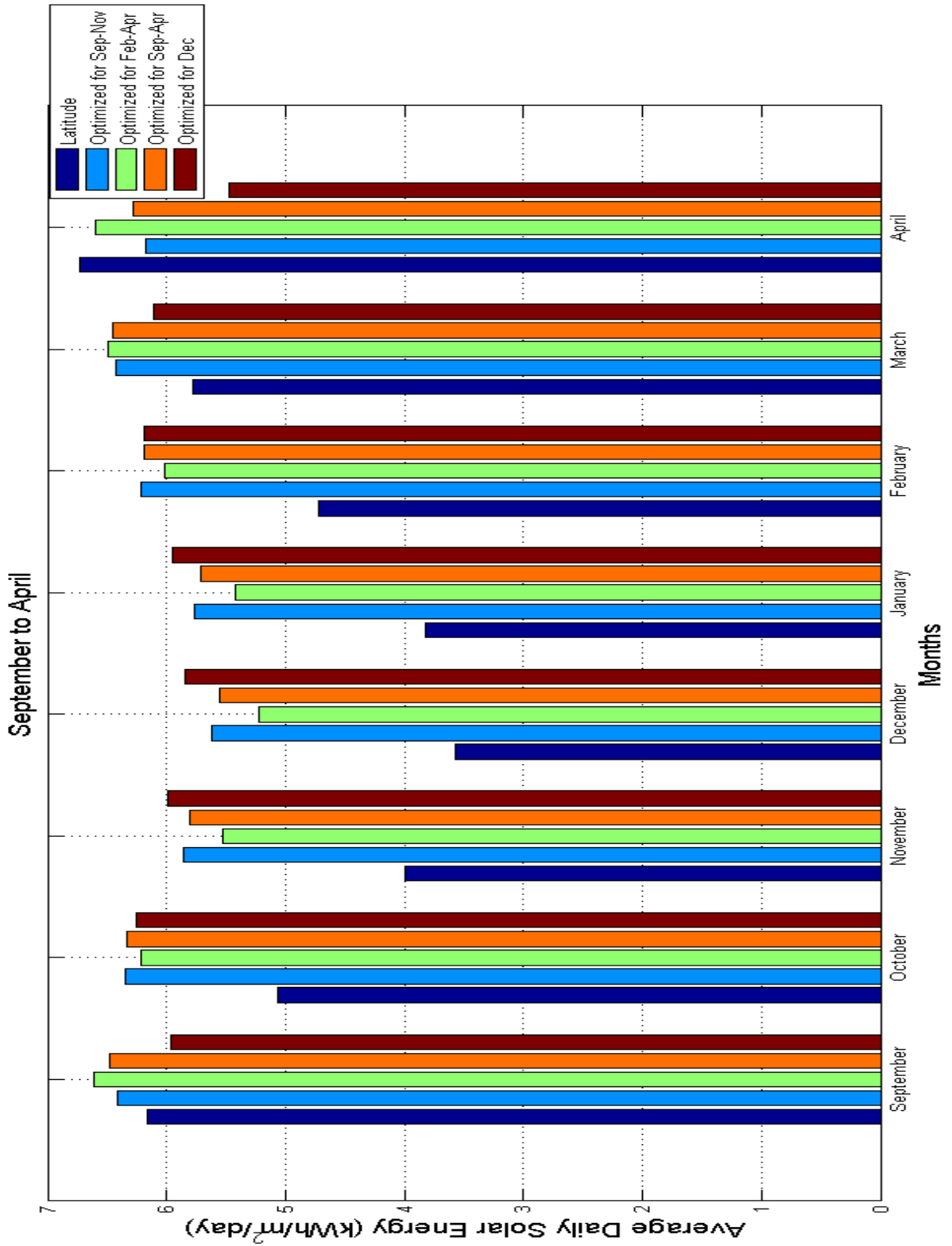


Fig 6.6 Average daily solar energy bar graph from September to April for different optimized tilt angles

From fig 6.6 energy graph, the following values of energy in kWh/day is obtained for the 15<sup>th</sup> of every month:

Months	Energy Obtained (kWh/day)				
	Latitude	Sep-Nov	Feb-Apr	Sep-Apr	December
<b>September</b>	6.16	6.42	6.61	6.47	5.97
<b>October</b>	5.07	6.35	6.22	6.34	6.25
<b>November</b>	4.00	5.85	5.53	5.80	5.99
<b>December</b>	3.60	5.62	5.23	5.55	5.84
<b>January</b>	3.83	5.77	5.42	5.71	5.95
<b>February</b>	4.73	6.21	6.01	6.18	6.19
<b>March</b>	5.77	6.42	6.49	6.45	6.11
<b>April</b>	6.73	6.18	6.60	6.28	5.48

Table 6.1: Total solar energy (kWh/m<sup>2</sup>/day) for the 15<sup>th</sup> of each month

By using the optimized tilt angle and calculating the total energy for the time periods, we can cross check if the energy obtained is indeed highest for the corresponding times as shown:

Tilt angle ( $\lambda$ )	Total Energy (kWh)		
	Feb-Apr	Sep-Nov	Sep-Apr
Latitude	17.23	15.23	39.89
Sep-Nov	18.81	18.62	48.82
Feb-Apr	19.10	18.36	48.11
Sep-Apr	18.91	18.61	48.78
Dec	17.78	18.21	47.78

Table 6.2: Summation of solar energy from different tilt angles

## **6.2 Pump Flow Rate Calculation**

The energy obtained from each of the optimized tilt angles for each of the period of time is ideal to find out the flow rate required for each of the cases. The flowrate demand will ensure that the minimum amount of water required is met by the system we are going to design. It will also help us to choose the solar pump that we need for our system based on its speed and head.

### **6.2.1 Solar Insolation and Flow rate calculation**

Solar insolation can be calculated by:

$$\text{Solar Insolation} = \frac{\text{Total Energy (kWh)}}{1 \text{ kW}} \quad [6.1]$$

And the flowrate for the corresponding flowrate can be calculated as such:

$$\text{Flow Rate} = \frac{\text{Total Water}}{\text{Solar Insolation}} \quad [6.2]$$

To calculate the solar insolation and flow rate, we are going to consider three optimizations:

- Latitude
- September- April
- December

Solar insolation and flow rate for tilt angle optimized September to April is shown below:

	<b>Solar Insolation(hrs)</b>	<b>Flow rate(litres/min)</b>
<b>September</b>	6.47	569.19
<b>October</b>	6.34	580.86
<b>November</b>	5.80	634.94
<b>December</b>	5.50	663.54
<b>January</b>	5.71	644.95
<b>February</b>	6.18	595.90
<b>March</b>	6.45	571.00
<b>April</b>	6.28	586.41

Table 6.3 Solar insolation and flowrate for tilt angle optimized September to April



From this calculation, we can tell:

- Minimum Flowrate= 569.19 litres/min
- Maximum Flowrate= 663.54 litres/min

Solar insolation and flowrate for latitude is shown below:

	<b>Solar Insolation(hrs)</b>	<b>Flowrate(litres/min)</b>
<b>September</b>	6.16	597.83
<b>October</b>	5.07	726.36
<b>November</b>	4.00	920.67
<b>December</b>	3.68	998.80
<b>January</b>	3.83	961.53
<b>February</b>	4.73	778.58
<b>March</b>	5.77	638.24
<b>April</b>	6.73	547.20

Table 6.4 Solar insolation and flow rate for tilt angle equal to latitude

From this calculation, we can tell:

- Minimum flow rate= 547.20 litres/min
- Maximum flow rate= 998.80 litres/min

Solar insolation and flow rate for tilt angle optimized for December is shown below:

	<b>Solar Insolation(hrs)</b>	<b>Flowrate(litres/min)</b>
<b>September</b>	5.97	616.86
<b>October</b>	6.25	589.23
<b>November</b>	5.99	614.80
<b>December</b>	5.84	630.59
<b>January</b>	5.95	618.93

<b>February</b>	6.19	594.94
<b>March</b>	6.11	602.73
<b>April</b>	5.48	672.02

Table 6.5: Solar insolation and flowrate for tilt angle optimized for December

From this calculation, we can tell:

- Minimum flow rate= 589.23 litres/min
- Maximum flow rate= 672.02 litres/min

### **6.2.2 Pump selection**

Since the maximum and minimum required flowrate is obtained, we can now select a pump from the Shakti Pumps catalog. The pump must fulfill our range of flowrate and the head. We chose the Shakti pump 60 DCSSP 8200 pump motor that can fulfill our requirements.

From Appendix B, the operating graph of the selected pump motor will be considered. The curve for the head of 28m is used and according to that the input variable power will change with solar intensity and our flow rate will vary as shown in the table in Appendix B.

### **6.3 Panel Size Calculation**

To calculate the total water obtained and the panel design we are going to consider three optimizations:

- Latitude
- September-April
- December

For the three scenarios, we are going to consider the month of December to design the whole system. This is because for the month of December, we get the lowest solar intensity and hence the lowest energy obtained. If our system can fulfill the demand for December, it will be able to do it for the other months. We are considering the September-April period only rather than

September-November and February-April because the aforementioned period covers the entire timeline which also includes the cultivation time of our location.

**6.3.1 Calculation for total water obtained for tilt angle equal to latitude**

**For 28 panels:**

If we arrange the solar panels of our system such that 14 panels stay in series in one group and other 14 in another one, we will obtain an output that can be used to calculate the total water obtained by that arrangement.

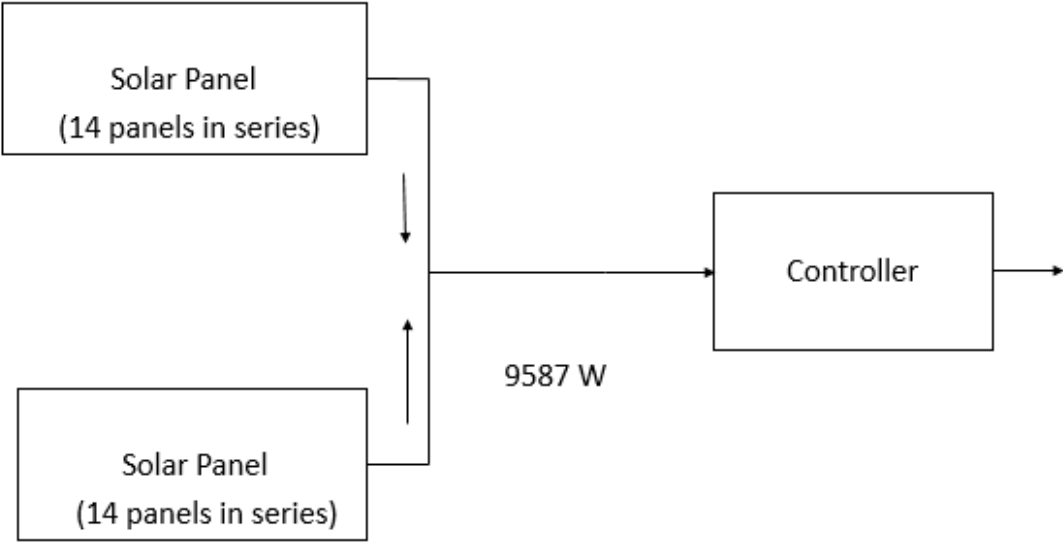


Fig 6.7 28 solar panels arrangement

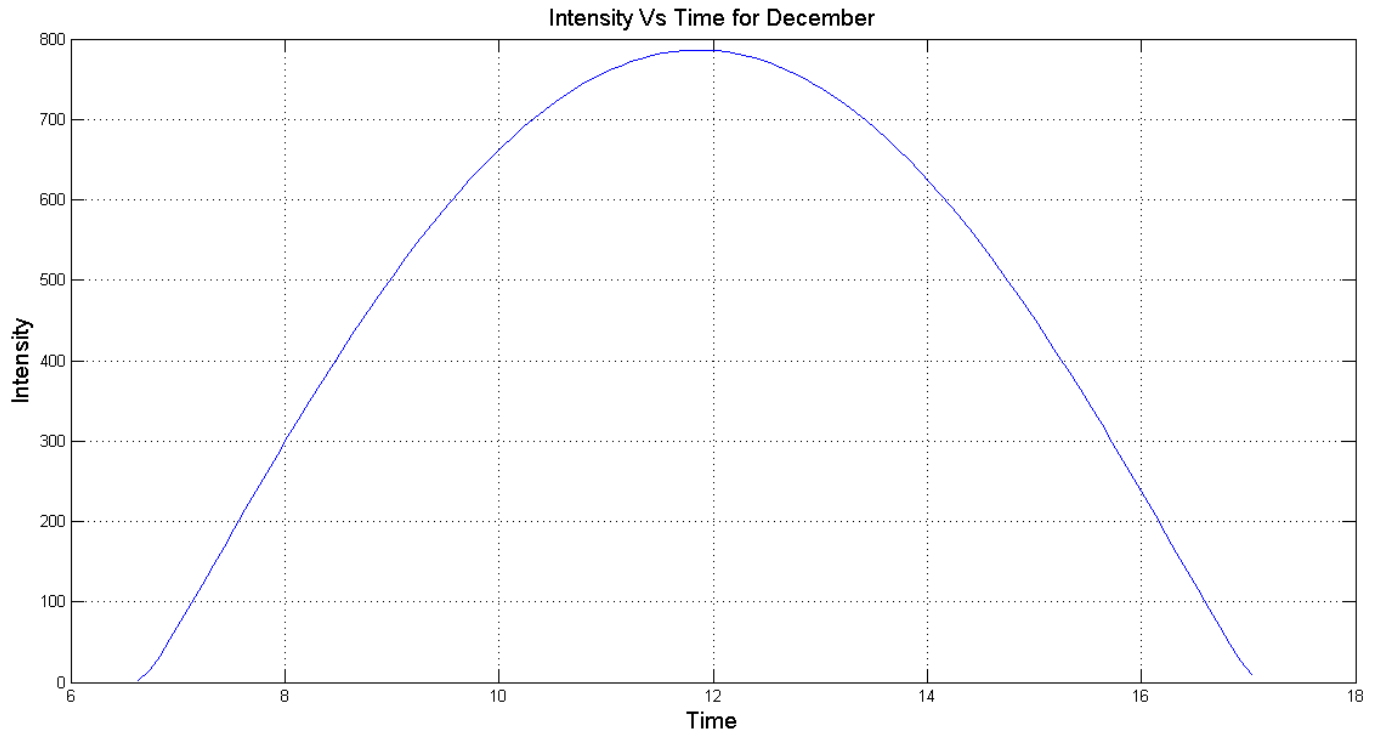


Fig 6.8 Intensity graph for tilt angle equal to latitude

The peak value of intensity i.e.  $788 \text{ W/m}^2$  is found from the intensity graph. If  $1000 \text{ W/m}^2$  is considered to deliver  $9587 \text{ W}$  then unitarily we can say that  $7555 \text{ W}$  will be obtained as output and accounting for the environmental and other factors, we can calculate the input power to the motor to be  $5666 \text{ W}$ .

In the next step, from the intensity graph the percentage decrease of intensity from the peak value to the next value in 30 minutes interval is calculated and their corresponding percentage drop (%),  $P_{\text{out}}$ ,  $P_{\text{in}}$ , flow rate(FR) in litres/minute is calculated and shown in the table below:

Time	Intensity ( $\text{W/m}^2$ )	%	$P_{\text{out}}$	$P_{\text{in}}$	FR (litres/min)
12	788	-	7555	5666	610
11.30	776	1.55	7438	5579	590
11	763	3.17	7316	5487	570
10.30	702	10.90	6732	5049	500
10	668	15.23	6404	4803	400
9.30	562	28.70	5387	4040	250

9	511	35.12	4896	3672	130
8.30	370	53.05	3547	2660	-
8	307	61.09	2943	2207	-
7.30	145	81.60	1390	1043	-
7	77	90.29	734	551	-

Table 6.6: Flow rate calculation for 28 panels for tilt angle equal to latitude

By plotting the flowrate (litres/min) versus time (min) graph we get:

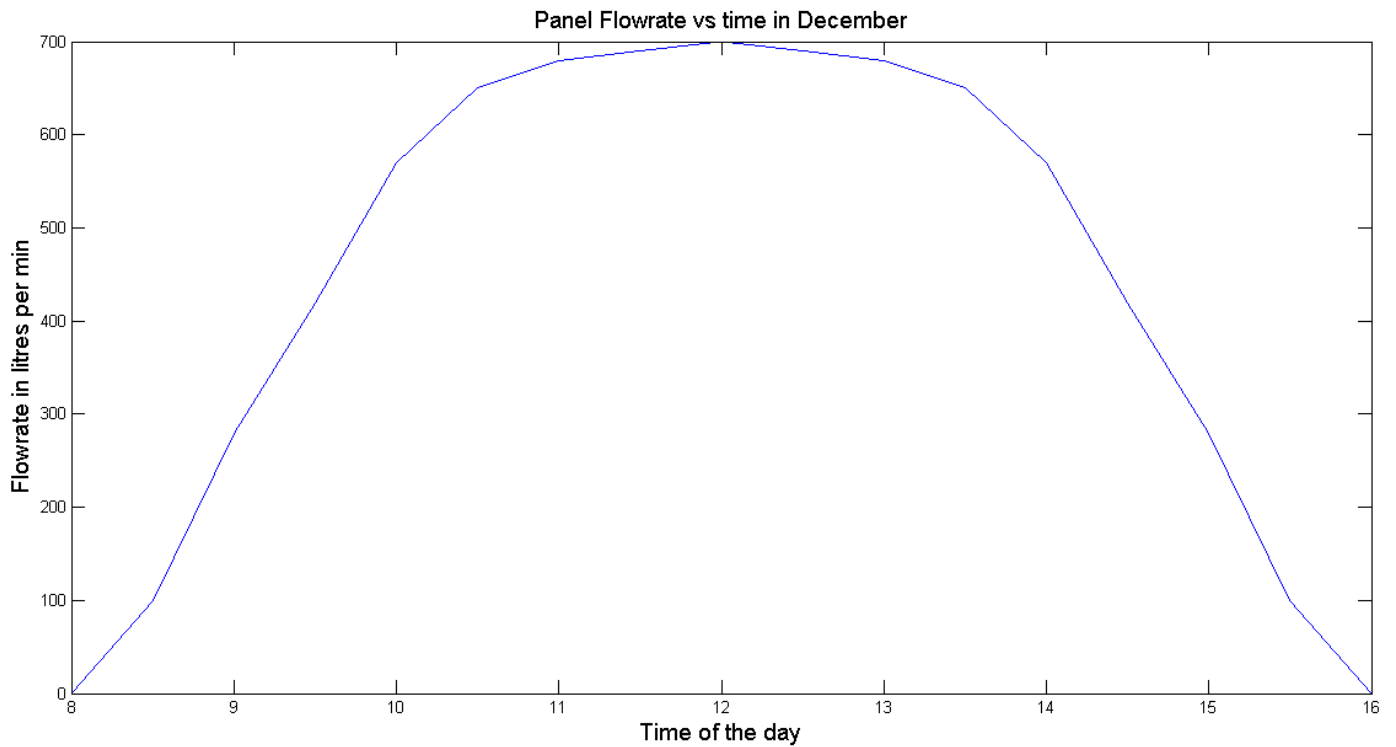


Fig 6.9 Flow rate vs Time for 28 panels tilt angle equal to latitude

From this we get the total water obtained to be 1,64,700 litres. Obviously, this is not fulfilling our requirement of 220959.6 litres. This means we have to increase our panel now.

**For 30 panels:**

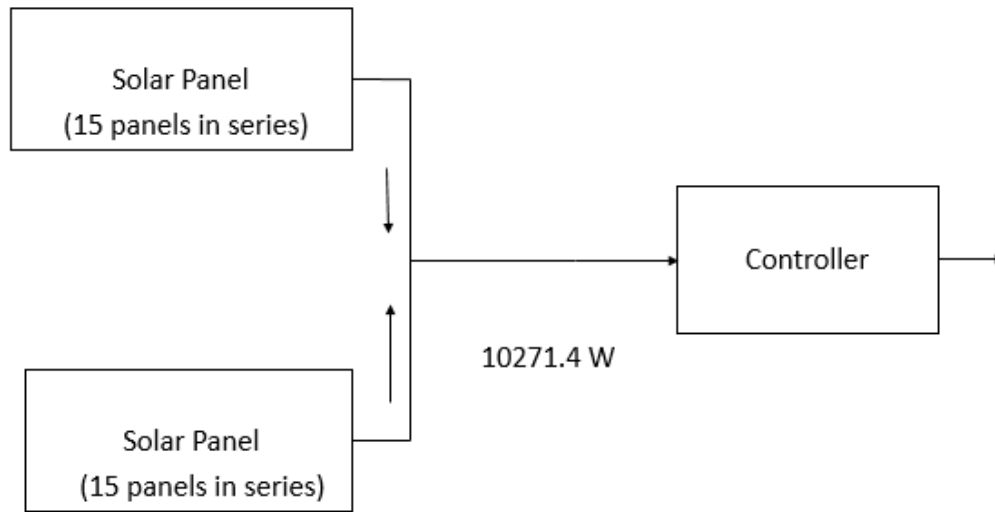


Fig 6.10 30 solar panels arrangement

As we know, the peak value of intensity i.e.  $788 \text{ W/m}^2$  is found from the intensity graph from Fig 6.8 and if  $1000 \text{ W/m}^2$  is considered to deliver  $10271.4 \text{ W}$  then unitarily we can say that  $8094 \text{ W}$  will be obtained as output and accounting for the environmental and other factors, we can calculate the input power to the motor to be  $6070.5 \text{ W}$ .

Percentage drop (%),  $P_{out}$ ,  $P_{in}$ , flow rate (FR) in litres/minute is again calculated and shown below:

Time	Intensity ( $\text{W/m}^2$ )	%	$P_{out}$	$P_{in}$	FR (litres/min)
12	788	-	8094	6070.5	700
11.30	776	1.55	7969	5976.8	670
11	763	3.17	7716	5787	630
10.30	702	10.90	7212	5409	570
10	668	15.23	6861	5145.8	490
9.30	562	28.70	5771	4328.3	320
9	511	35.12	5245	3933.8	190
8.30	370	53.05	3800	2850	-
8	307	61.09	3153	2364.8	-

7.30	145	81.60	1489	1774	-
7	77	90.29	786	1331	-

Table 6.7: Flow rate calculation for 30 panels tilt angle equal to latitude

By plotting the flowrate (litres/min) versus time (min) graph we get:

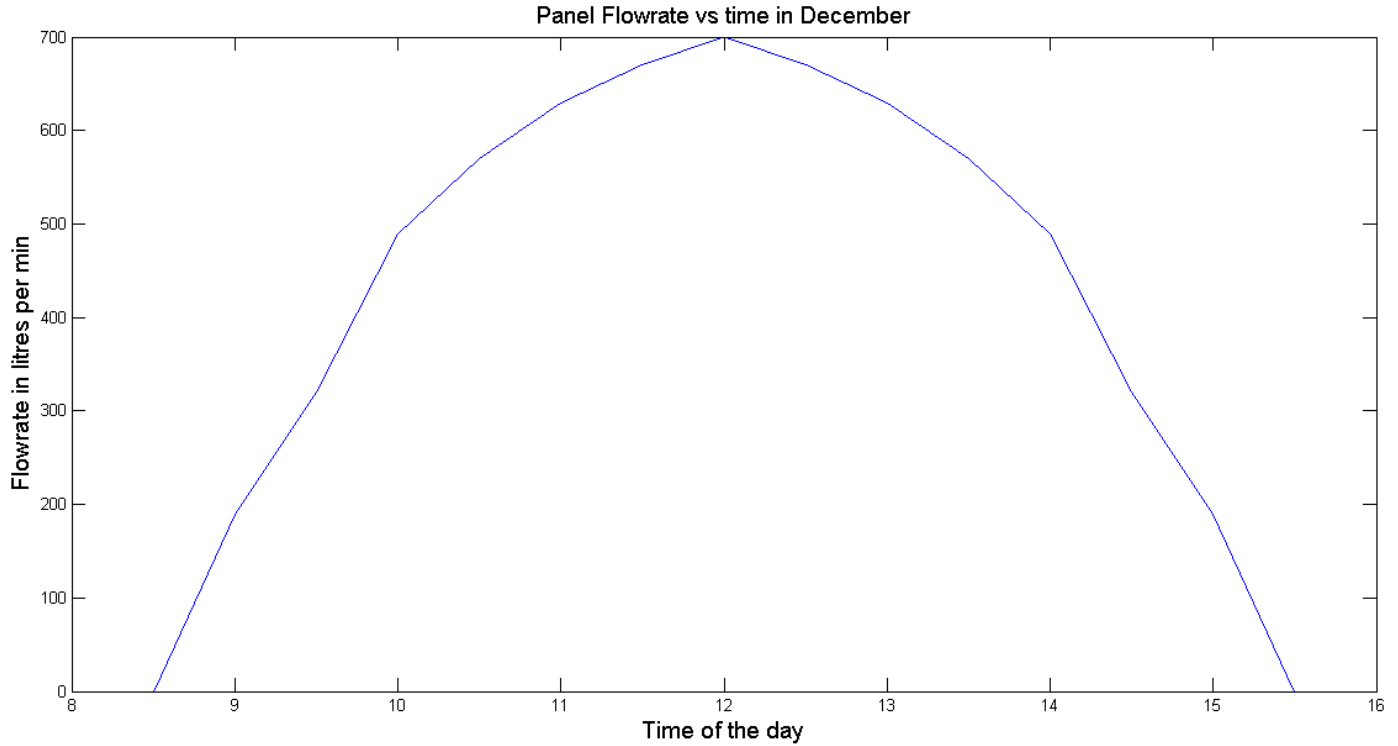


Fig 6.11 Flow rate vs Time for 30 panels tilt angle equal to latitude

From this we get the total water obtained to be 1,93,200 litres. Again, this is not fulfilling our requirement of 220959.6 litres. This means we have to increase our panel again.

**For 32 panels:**

If we arrange the solar panels of our system such that 16 panels stay in series in one group and other 16 in another one, we will obtain an output that can be used to calculate the total water obtained by that arrangement.

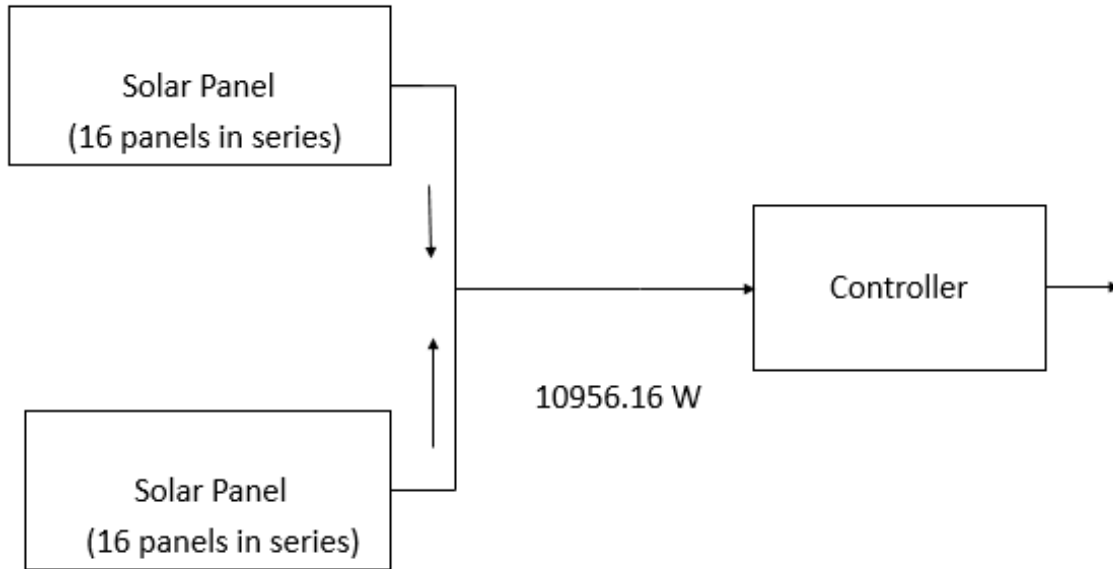


Fig 6.12 32 solar panels arrangement

Now, the intensity graph for latitude is plotted for December 15<sup>th</sup> and the peak value of intensity i.e. 788 W/m<sup>2</sup> is found from the graph.

Again, if 1000 W/m<sup>2</sup> is considered to deliver 10956.16 W then unitarily we can say that 8633 W will be obtained as output and accounting for the environmental and other factors, we can calculate the input power to the motor to be 6474.8 W.

Percentage drop (%), P<sub>out</sub>, P<sub>in</sub>, flow rate(FR) in litres/minute is calculated and shown in the table below:

Time	Intensity	%	P <sub>out</sub> (W)	P <sub>in</sub> (W)	FR (litre/min)
12	788	-	8633	6474.8	750
11.30	776	1.55	8499	6375	730
11	763	3.17	8359	6270	700
10.30	702	10.90	7692	5769	640
10	668	15.23	7318	5488.5	580
9.30	562	28.70	6155	4617	440
9	511	35.12	5594	4196	290
8.30	370	53.05	4053	3040	-



8	307	61.09	3363	2522	-
7.30	145	81.60	1588	1191	-
7	77	90.29	838	629	-

Table 6.8: Flow rate calculation for 32 panels for tilt angle equal to latitude

By plotting the flowrate (litres/min) versus time (min) graph we get:

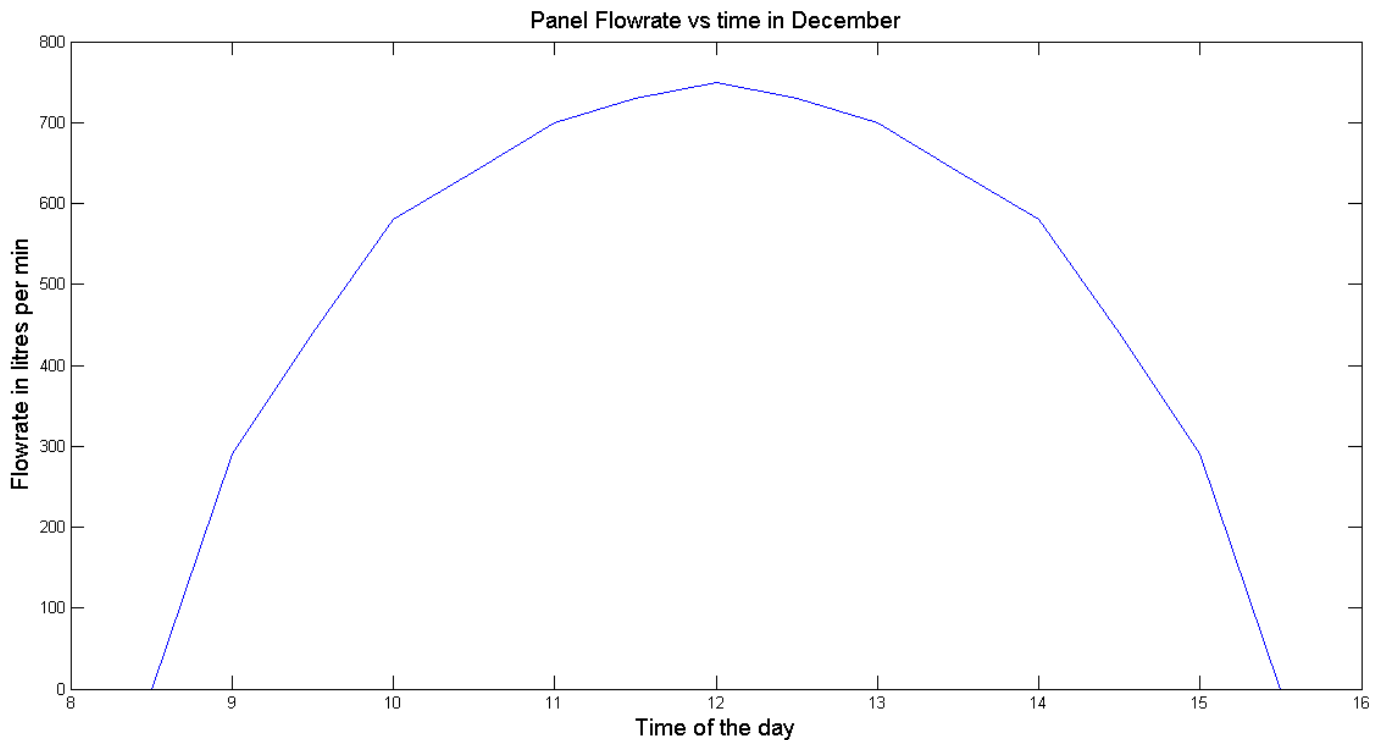


Fig 6.13 Flow rate vs Time for 32 panels for tilt angle equal to latitude

From this we get the total water obtained to be 2,25,300 litres. This meets our requirement of 220959.6 litres. This means we can get our desired amount of water from this system.

### 6.3.2 Calculation for total water obtained for tilt angle optimized for September-April

#### For 28 panels

If we arrange the solar panels of our system such that 14 panels stay in series in one group and other 14 in another one, as shown in fig 6.7 we will obtain an output that can be used to calculate the total water obtained by that arrangement.

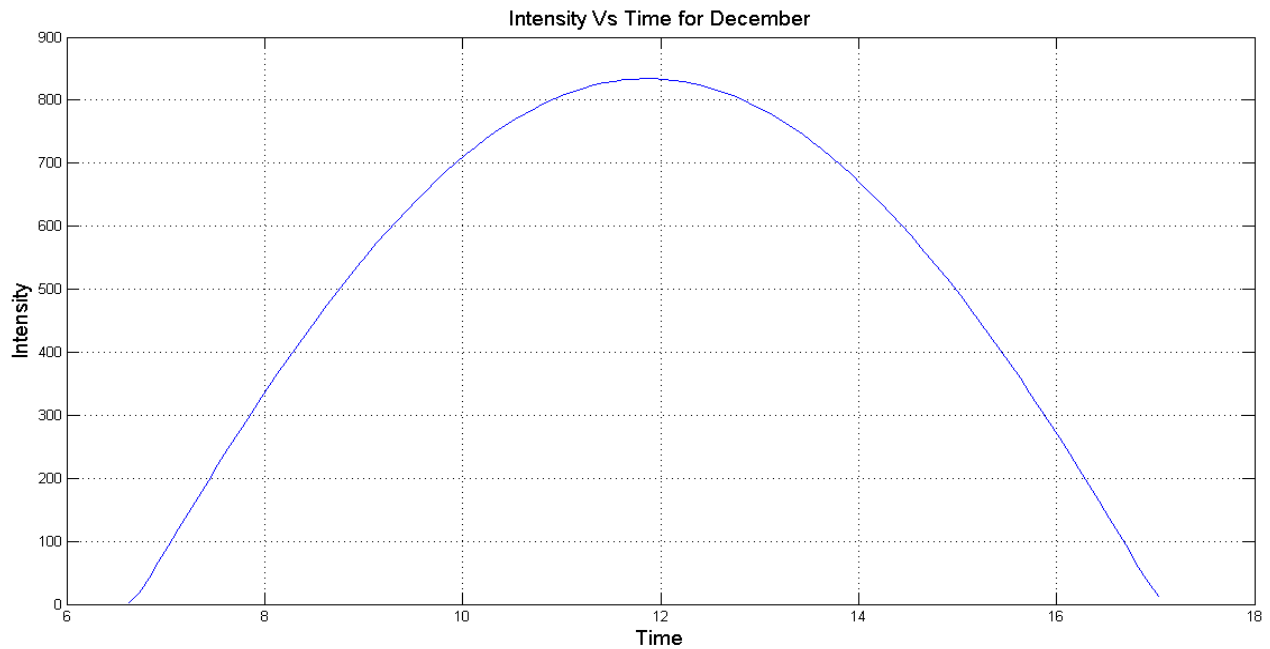


Fig 6.14 Intensity graph for tilt angle optimized for Sep-Apr

The peak value of intensity i.e.  $834 \text{ W/m}^2$  is found from the intensity graph. If  $1000 \text{ W/m}^2$  is considered to deliver  $9587 \text{ W}$  then unitarily we can say that  $7996 \text{ W}$  will be obtained as output and accounting for the environmental and other factors, we can calculate the input power to the motor to be  $5997 \text{ W}$ .

In the next step, from the intensity graph the percentage decrease of intensity from the peak value to the next value in 30 minutes interval is calculated and their corresponding percentage drop (%),  $P_{\text{out}}$ ,  $P_{\text{in}}$ , flow rate(FR) in litres/minute is calculated and shown in the table below:

Time	Intensity (W/m <sup>2</sup> )	%	P <sub>out</sub>	P <sub>in</sub>	FR (litres/min)
12	834	-	7996	5997	680
11.30	830.2	0.46	7959	5969	660
11	808.8	3.02	7755	5816	630
10.30	769.6	7.72	7379	5534	580
10	713.3	14.47	6839	5129	500
9.30	641	23.14	6146	4610	390
9	554	33.57	5312	3984	220
8.30	454	45.56	4353	3265	25
8	342.7	58.91	3286	2465	-
7.30	221.8	73.41	2126	1595	-
7	92.94	88.86	891	668	-

Table 6.9 Flow rate calculation for 28 panels for tilt angle optimized for September-April

By plotting the flow rate (litres/min) versus time (min) graph we get:

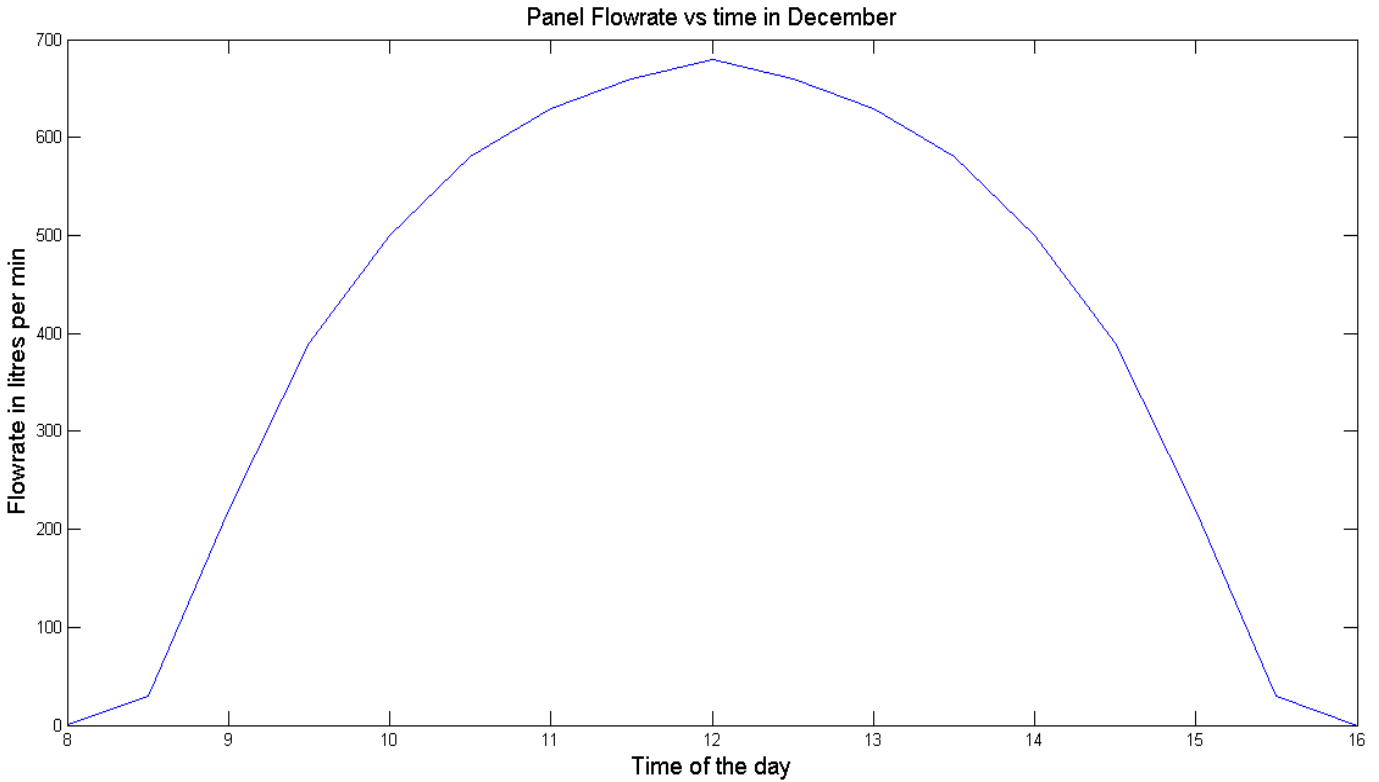


Fig 6.15 Flow rate vs Time for 28 panels for tilt angle optimized for September-April

From this we get the total water obtained to be 2,01,000 litres. This is not fulfilling our requirement of 22,09,59.6 litres. This means we have to increase our panel now.

**For 30 panels:**

Arrangement of 30 panels in total as shown in fig 6.10 will give us a power output of 10271.4 W. As we know, the peak value of intensity i.e. 834 W/m<sup>2</sup> is found from the intensity graph from Fig 6.14 and if 1000 W/m<sup>2</sup> is considered to deliver 10271.4 W then unitarily we can say that 8566 W will be obtained as output and accounting for the environmental and other factors, we can calculate the input power to the motor to be 6425 W.

Percentage drop (%), P<sub>out</sub>, P<sub>in</sub>, flow rate (FR) in litres/minute is again calculated and shown below:

Time	Intensity (W/m <sup>2</sup> )	%	P <sub>out</sub>	P <sub>in</sub>	FR (litres/min)
12	834	-	8566	6425	740
11.30	830.2	0.46	8527	6395	720

11	808.8	3.02	8307	6230	700
10.30	769.6	7.72	7904	5928	660
10	713.3	14.47	7327	5495	550
9.30	641	23.14	6584	4938	420
9	554	33.57	5690	4268	240
8.30	454	45.56	4663	3497	75
8	342.7	58.91	3520	2640	-
7.30	221.8	73.41	2278	1709	-
7	92.94	88.86	954	716	-

Table 6.10: Flow rate calculation for 30 panels for tilt angle optimized for September-April

By plotting the flowrate (litres/min) versus time (min) graph we get:

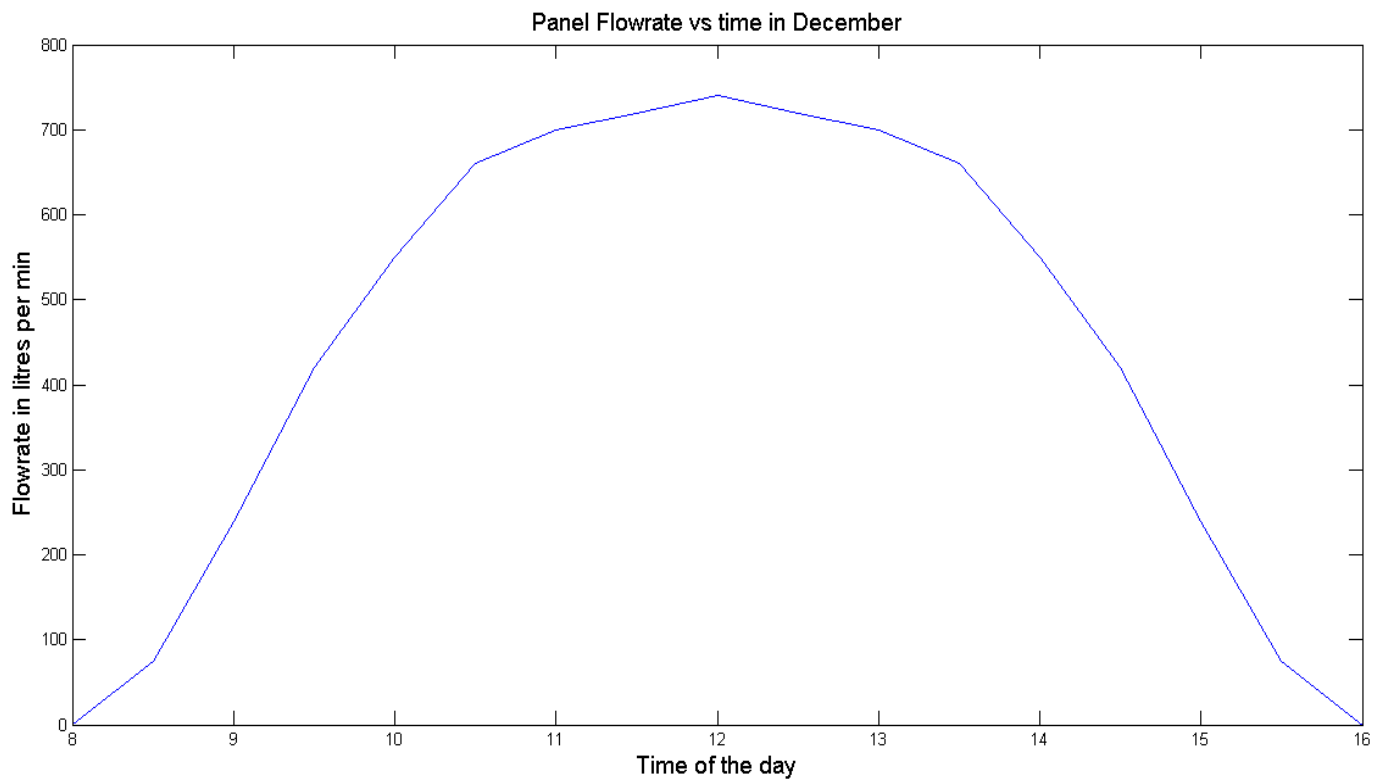


Fig 6.16 Flow rate vs time for 30 panels for tilt angle optimized for September-April

From this we get the total water obtained to be 2,24,100 litres. This meets our requirement of 220959.6 litres. This meets our desired amount of water from this system. For further checking, we increase the number of panels again.

**For 32 panels:**

If we arrange the solar panels of our system such that 16 panels stay in series in one group and other 16 in another one, as shown in fig 6.12, we will obtain an output that can be used to calculate the total water obtained by that arrangement.

The peak value of intensity found from the intensity graph from Fig 6.14 is 834 W/m<sup>2</sup> and if 1000 W/m<sup>2</sup> is considered to deliver 10956.16 W then unitarily we can say that 9096 W will be obtained as output and accounting for the environmental and other factors, we can calculate the input power to the motor to be 6822 W.

Percentage drop (%), P<sub>out</sub>, P<sub>in</sub>, flow rate(FR) in litres/minute is again calculated and shown below:

Time	Intensity (W/m <sup>2</sup> )	%	P <sub>out</sub>	P <sub>in</sub>	FR (litres/min)
12	834	-	9096	6822	825
11.30	830.2	0.46	9054	6791	810
11	808.8	3.02	8821	6616	770
10.30	769.6	7.72	8394	6296	710
10	713.3	14.47	7780	5835	630
9.30	641	23.14	6991	5243	500
9	554	33.57	6042	4532	320
8.30	454	45.56	4951	3713	100
8	342.7	58.91	3738	2804	-
7.30	221.8	73.41	2418	1814	-
7	92.94	88.86	1013	760	-

Table 6.11 Flow rate calculation for 32 panels for tilt angle optimized for September-April

By plotting the flowrate (litres/min) versus time (min) graph we get:

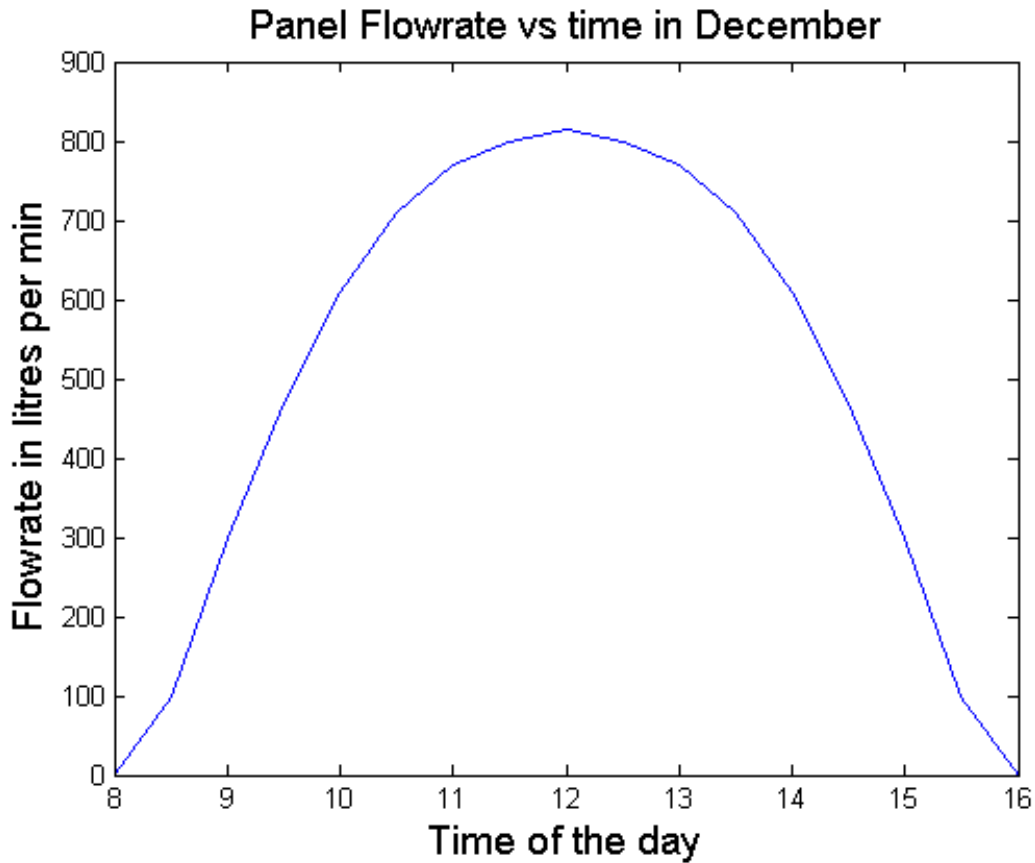


Fig 6.17 Flow rate vs time for 32 panels for tilt angle optimized for September-April

From this we get the total water obtained to be 2,50,050 litres. This meets our requirement of 2,20,959.6 litres. This system gives more water than our required amount.

### **6.3.3 Calculation for total water obtained for tilt angle optimized for December**

#### **For 28 panels**

If we arrange the solar panels of our system such that 14 panels stay in series in one group and other 14 in another one, as shown in fig 6.7, we will obtain an output that can be used to calculate the total water obtained by that arrangement.

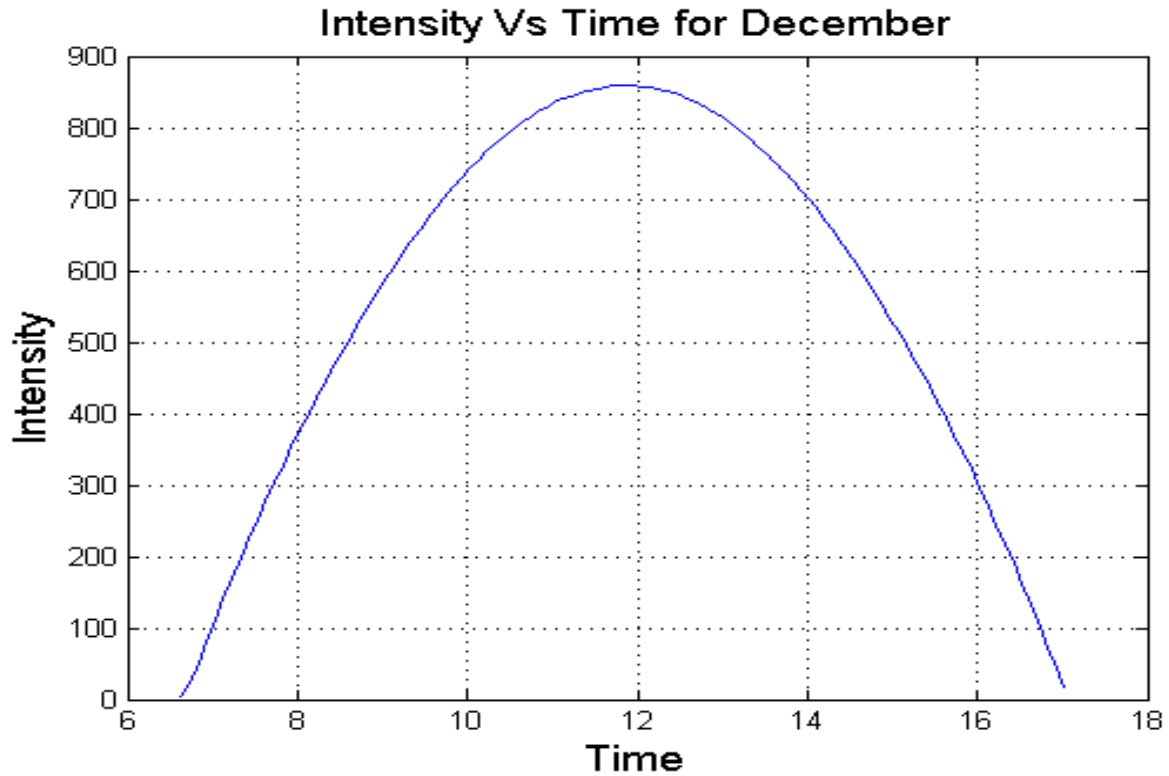


Fig 6.18 Intensity graph for tilt angle optimized for December

The peak value of intensity found from the intensity graph is  $834858.7 \text{ W/m}^2$ . If  $1000 \text{ W/m}^2$  is considered to deliver  $9587 \text{ W}$  then unitarily we can say that  $8232.4 \text{ W}$  will be obtained as output and accounting for the environmental and other factors, we can calculate the input power to the motor to be  $6174 \text{ W}$ .

Percentage drop (%),  $P_{\text{out}}$ ,  $P_{\text{in}}$ , flow rate(FR) in litres/minute is calculated and shown in the table below:

Time	Intensity ( $\text{W/m}^2$ )	%	$P_{\text{out}}$	$P_{\text{in}}$	FR (litres/min)
12	858.7	-	8232.4	6174	700
11.30	854.9	0.44	8196.2	6147	690
11	834.3	2.84	7998.6	5999	680
10.30	769.6	7.24	7636.4	5727	650
10	742.1	13.58	7114.4	5336	570



9.30	672	21.74	6442.7	4832	420
9	587.1	31.63	5628.5	4221	280
8.30	488.4	43.12	4682.6	3512	100
8	376.8	56.12	3612.4	2709	-
7.30	252	70.65	2416.2	1812	-
7	111.4	87.03	1067.7	801	-

Table 6.12: Flow rate calculation for 28 panels for tilt angle optimized for December

By plotting the flowrate (litres/min) versus time (min) graph we get:

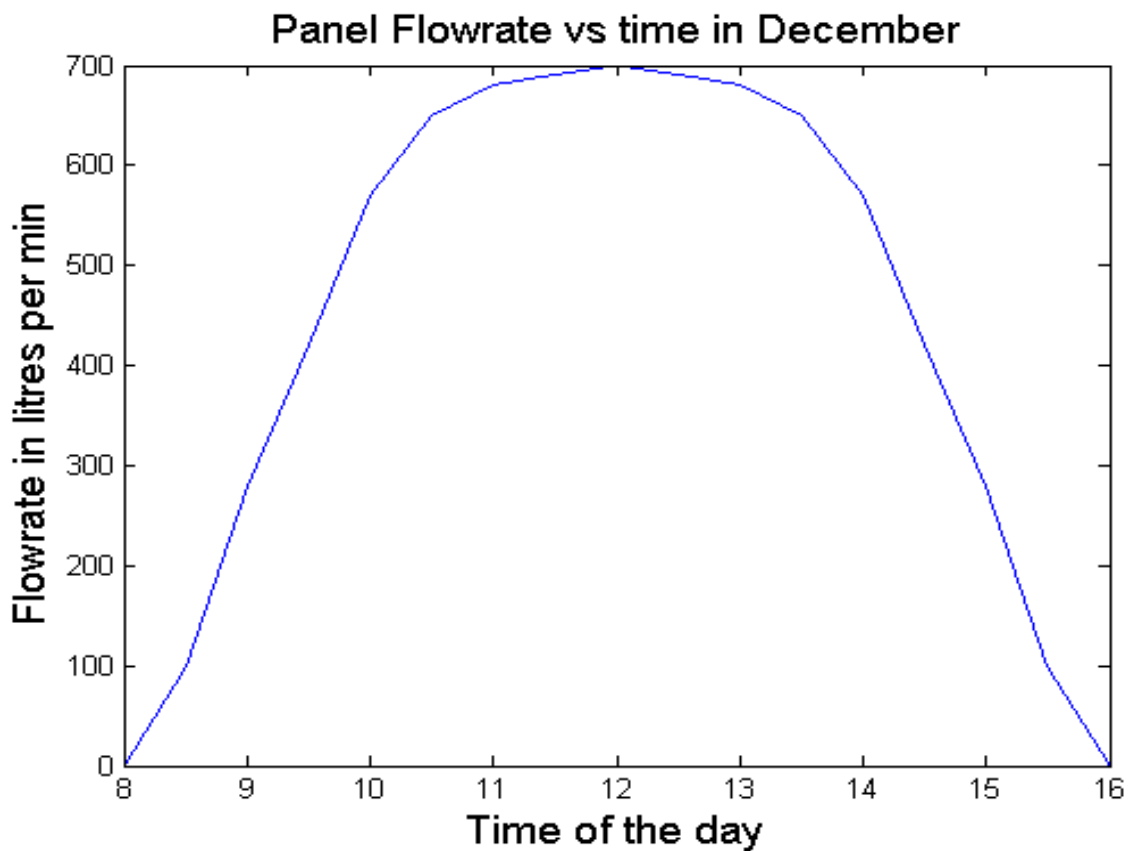


Fig 6.19 Flow rate vs time for 28 panels for tilt angle optimized for December

From this we get the total water obtained to be 2,24,400 litres. This is fulfilling our requirement of 22,09,59.6 litres. For further comparison, we take more number of panels.

### **For 30 panels:**

Arrangement of 30 panels in total as shown in fig 6.10 will give a total power output of 10271.4 W. As we know, the peak value of intensity i.e. 858.7 W/m<sup>2</sup> is found from the intensity graph from Fig 6.18 and if 1000 W/m<sup>2</sup> is considered to deliver 10271.4 W then unitarily we can say that 8820.1 W will be obtained as output and accounting for the environmental and other factors, we can calculate the input power to the motor to be 6615 W.

Percentage drop (%), P<sub>out</sub>, P<sub>in</sub>, flow rate (FR) in litres/minute is again calculated and shown below:

Time	Intensity (W/m <sup>2</sup> )	%	P <sub>out</sub>	P <sub>in</sub>	FR (litres/min)
12	858.7	-	8820.1	6615	740
11.30	854.9	0.44	8781.3	6586	720
11	834.3	2.84	8569.6	6427	700
10.30	769.6	7.24	8181.5	6136	660
10	742.1	13.58	7622.3	5717	550
9.30	672	21.74	6902.6	5177	420
9	587.1	31.63	6060.3	4523	240
8.30	488.4	43.12	5016.9	3763	75
8	376.8	56.12	3870.3	2903	-
7.30	252	70.65	2588.7	1942	-
7	111.4	87.03	1144	858	-

Table 6.13: Flow rate calculation for 30 panels for tilt angle optimized for December

By plotting the flowrate (litres/min) versus time (min) graph we get:

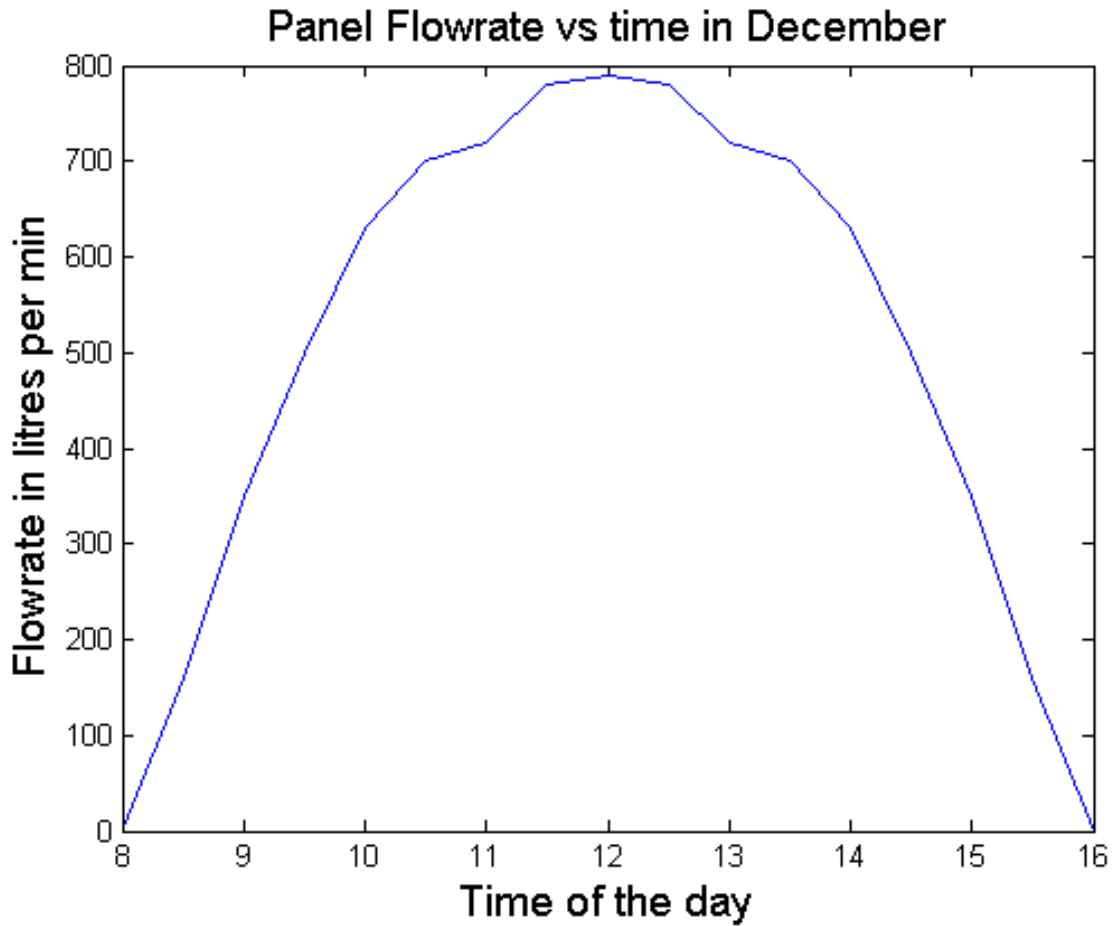


Fig 6.20 Flow rate vs time for 30 panels for tilt angle optimized for December

From this we get the total water obtained to be 2,54,100 litres. This meets our requirement of 220959.6 litres. This is more than our required amount.

Therefore, if we use 28 panels for tilt angle optimized for December, we get the water requirement. For tilt angle optimized for September to April we need 30 panels and for tilt angle for latitude we need 32 panels as shown highlighted in the table below:

Tilt Angles ( $\lambda$ )	Water Obtained (litres)		
	28 Panels	30 Panels	32 Panels
Latitude (24.04°)	1,64,700	1,93,200	2,25,300
Sep-Apr (33.68°)	2,01,000	2,24,100	2,50,050
Dec (47.19°)	2,24,400	2,54,100	-

Table 6.14: Summary of total water obtained for different solar panels arrangements according to different tilt angles

# Chapter-7

## **7.1 Conclusion**

From the calculations done in the previous chapter, we can summarize the results obtained for the three different scenarios i.e. three different tilt angles. For tilt angle as latitude we do not get our required water by using 28 or 30 panels. By using the 32 panels, only then the water requirement is fulfilled. For optimization for the period of September to April, we do not get the water required for 28 panels but it is obtained if we use 30 or 32 panels.

Therefore, optimization for the month of December gives us the tilt angle, i.e.  $47.19^\circ$ , for which we can get the water required for the overall period including our two cultivation and crop growing periods. With 28 solar panels arrangement, for the month of December which has the lowest intensity, we can get the necessary power that helps us fulfill our water demand. Hence, we can assume that it will also fulfill that requirement for the whole year around.

To conclude, this thesis presents how in irrigation we can integrate solar photovoltaic technology without the use of batteries, generators, etc. In other words, providing necessary energy by cutting cost and other factors effectively which is very essential to a developing country like Bangladesh. Though the initial costs of the solar panels and the pump is comparatively high, in the long run it is a simple, good investment.

## **7.2 Future aspects**

Most of the global energy uses are dependent on non-renewable sources, especially fossil fuel like diesel, which is supposed to end up soon. Demand for energy is increasing day by day because of industrialization and population growth. Also, most of the fossil fuel sources are highly polluting and produce Green House Gases. Solar energy helps us overcome this future energy crisis. It would provide reliable source of energy and would not cause destruction or serious harm to our global or local environments. Moreover, it would help ensure the future generations inherit a quality environment with a fair share of the earth's resources. In the near future, panel efficiency will have a considerable improvement with increased research work and the cost will significantly decrease with the growth in demand and the usage of PV technology.

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# Appendix

## Appendix A

### 1. Solar energy bar graphs for different optimized tilt angles

#### 1.1 Energy bar graph for Latitude Tilt Angle

clc;

close all;

clear all;

latitudeD=24;

latitudeM=2;

latitudeS=25.61;

sunrise=[5.733 5.917 6.2 6.53 6.7 6.52 6.117 5.617];

sunset=[17.983 17.5 17.06 17.2 17.5 17.85 18.083 18.283];

ntotal=[258 288 319 349 15 46 74 105]; %15th of every month identification Sep-Apr

lambda=0; %tilt angle

%Choosing sunrise and sunset times for given n



```

panelenergy=zeros(8,1);

inew=1;

for day=1:8

    Tsr=sunrise(1,day);

    Tss=sunset(1,day);

    i=1;

    time=zeros(1,length((Tsr+0.1):0.1:(Tss-0.1)));

    ti=1;

    panelintensity=zeros(1,length((Tsr+0.1):0.1:(Tss-0.1)));

    declination=(23.45*sind((360*(ntotal(1,day)-80))/365));

    for t=(Tsr+0.1):0.1:(Tss-0.1)

        phi=angtodeg(latitudeD,latitudeM,latitudeS);

        SRangle= acosd(-tand(phi)*tand(declination));

        diffSRangle=2*SRangle;

        diffT=Tss-Tsr;

```

```

hourangle=(-SRangle)+(((2*SRangle)/diffT)*(t-Tsr));

theta=acosd(((sind(phi-lambda))*sind(declination))+((cosd(phi-
lambda))*cosd(declination)*cosd(hourangle)));

alpha=asind((sind(declination)*sind(phi))+((cosd(declination)*cosd(phi)*cosd(hourangle))));

AM=(1/(sind(alpha)));

I=1367*((0.7)^(AM^0.678));

incidentIntensity=((I)*(cosd(theta)));

panelintensity(1,i)=incidentIntensity;

time(1,ti)=t;

ti=ti+1;

i=i+1;

end

disp(diffT)

energy=trapz(time,panelintensity);

energy=real(energy);

panelenergy(inew)=energy;

inew=inew+1;

end

```

```

monthnames={'September';                                     'October';
'November';'December';'January';'February';'March';'April' };

h=bar(panelenergy/1000);xlabel('Months','fontsize',14),ylabel('Average Daily Solar Energy
(kWh/m ^2/day)','fontsize',14),title('Energy for Latitude Tilt Angle','fontsize',14);

set(gca,'xticklabel',monthnames,'fontsize',14)

disp(panelenergy/1000)

```

## **1.2 Energy bar graph for tilt angle optimized for September-November**

```

clc;

close all;

clear all;

latitudeD=24;

latitudeM=2;

latitudeS=25.61;

sunrise=[5.733 5.917 6.2 6.53 6.7 6.52 6.117 5.617];

sunset=[17.983 17.5 17.06 17.2 17.5 17.85 18.083 18.283];

ntotal=[258 288 319 349 15 46 74 105]; %15th of every month identification Sep-Apr

lambda=35.8427; %tilt angle

```

```

%Choosing sunrise and sunset times for given n

panelenergy=zeros(8,1);

inew=1;

for day=1:8

    Tsr=sunrise(1,day);

    Tss=sunset(1,day);

    i=1;

    time=zeros(1,length((Tsr+0.1):0.1:(Tss-0.1)));

    ti=1;

    panelintensity=zeros(1,length((Tsr+0.1):0.1:(Tss-0.1)));

    declination=(23.45*sind((360*(ntotal(1,day)-80))/365));

    for t=(Tsr+0.1):0.1:(Tss-0.1)

        phi=angtodeg(latitudeD,latitudeM,latitudeS);

        SRangle= acosd(-tand(phi)*tand(declination));

        diffSRangle=2*SRangle;

        diffT=Tss-Tsr;

```

```

hourangle=(-SRangle)+(((2*SRangle)/diffT)*(t-Tsr));

theta=acosd(((sind(phi-lambda))*sind(declination))+((cosd(phi-
lambda))*cosd(declination)*cosd(hourangle)));

alpha=asind((sind(declination)*sind(phi))+((cosd(declination)*cosd(phi)*cosd(hourangle))));

AM=(1/(sind(alpha)));

I=1367*((0.7)^(AM^0.678));

incidentIntensity=((I)*(cosd(theta)));

panelintensity(1,i)=incidentIntensity;

time(1,ti)=t;

ti=ti+1;

i=i+1;

end

disp(diffT)

energy=trapz(time,panelintensity);

energy=real(energy);

panelenergy(inew)=energy;

inew=inew+1;

end

```

```

monthnames={'September';                                     'October';
'November';'December';'January';'February';'March';'April' };

h=bar(panelenergy/1000);xlabel('Months','fontsize',14),ylabel('Average Daily Solar Energy
(kWh/m ^2/day)','fontsize',14),title('Energy for Sep-Nov Optimized Tilt Angle','fontsize',14);

set(gca,'xticklabel',monthnames,fontsize',14)

disp(panelenergy/1000)

```

### **1.3 Energy bar graph for tilt angle optimized for February-April**

```

clc;

close all;

clear all;

latitudeD=24;

latitudeM=2;

latitudeS=25.61;

sunrise=[5.733 5.917 6.2 6.53 6.7 6.52 6.117 5.617];

sunset=[17.983 17.5 17.06 17.2 17.5 17.85 18.083 18.283];

ntotal=[258 288 319 349 15 46 74 105]; %15th of every month identification Sep-Apr

lambda=25.5002; %tilt angle

```

```

%Choosing sunrise and sunset times for given n

panelenergy=zeros(8,1);

inew=1;

for day=1:8

    Tsr=sunrise(1,day);

    Tss=sunset(1,day);

    i=1;

    time=zeros(1,length((Tsr+0.1):0.1:(Tss-0.1)));

    ti=1;

    panelintensity=zeros(1,length((Tsr+0.1):0.1:(Tss-0.1)));

    declination=(23.45*sind((360*(ntotal(1,day)-80))/365));

    for t=(Tsr+0.1):0.1:(Tss-0.1)

        phi=angtodeg(latitudeD,latitudeM,latitudeS);

        SRangle= acosd(-tand(phi)*tand(declination));

        diffSRangle=2*SRangle;

        diffT=Tss-Tsr;

```

```

hourangle=(-SRangle)+(((2*SRangle)/diffT)*(t-Tsr));

theta=acosd(((sind(phi-lambda))*sind(declination))+((cosd(phi-
lambda))*cosd(declination)*cosd(hourangle)));

alpha=asind((sind(declination)*sind(phi))+((cosd(declination)*cosd(phi)*cosd(hourangle))));

AM=(1/(sind(alpha)));

I=1367*((0.7)^(AM^0.678));

incidentIntensity=((I)*(cosd(theta)));

panelintensity(1,i)=incidentIntensity;

time(1,ti)=t;

ti=ti+1;

i=i+1;

end

disp(diffT)

energy=trapz(time,panelintensity);

energy=real(energy);

panelenergy(inew)=energy;

inew=inew+1;

end

```



```

monthnames={'September';                                     'October';
'November';'December';'January';'February';'March';'April' };

h=bar(panelenergy/1000);xlabel('Months','fontsize',14),ylabel('Average Daily Solar Energy
(kWh/m ^2/day)','fontsize',14),title('Energy for Feb-Apr Optimized Tilt Angle','fontsize',14);

set(gca,'xticklabel',monthnames,fontsize',14)

disp(panelenergy/1000)

```

#### **1.4 Energy bar graph for tilt angle optimized for September-April**

```

clc;

close all;

clear all;

latitudeD=24;

latitudeM=2;

latitudeS=25.61;

sunrise=[5.733 5.917 6.2 6.53 6.7 6.52 6.117 5.617];

sunset=[17.983 17.5 17.06 17.2 17.5 17.85 18.083 18.283];

ntotal=[258 288 319 349 15 46 74 105]; %15th of every month identification Sep-Apr

lambda=33.6864; %tilt angle

```

```

%Choosing sunrise and sunset times for given n

panelenergy=zeros(8,1);

inew=1;

for day=1:8

    Tsr=sunrise(1,day);

    Tss=sunset(1,day);

    i=1;

    time=zeros(1,length((Tsr+0.1):0.1:(Tss-0.1)));

    ti=1;

    panelintensity=zeros(1,length((Tsr+0.1):0.1:(Tss-0.1)));

    declination=(23.45*sind((360*(ntotal(1,day)-80))/365));

    for t=(Tsr+0.1):0.1:(Tss-0.1)

        phi=angtodeg(latitudeD,latitudeM,latitudeS);

        SRangle= acosd(-tand(phi)*tand(declination));

        diffSRangle=2*SRangle;

        diffT=Tss-Tsr;

```

```

hourangle=(-SRangle)+(((2*SRangle)/diffT)*(t-Tsr));

theta=acosd(((sind(phi-lambda))*sind(declination))+((cosd(phi-
lambda))*cosd(declination)*cosd(hourangle)));

alpha=asind((sind(declination)*sind(phi))+((cosd(declination)*cosd(phi)*cosd(hourangle))));

AM=(1/(sind(alpha)));

I=1367*((0.7)^(AM^0.678));

incidentIntensity=((I)*(cosd(theta)));

panelintensity(1,i)=incidentIntensity;

time(1,ti)=t;

ti=ti+1;

i=i+1;

end

disp(diffT)

energy=trapz(time,panelintensity);

energy=real(energy);

panelenergy(inew)=energy;

inew=inew+1;

end

```

```

monthnames={'September';                                     'October';
'November';'December';'January';'February';'March';'April' };

h=bar(panelenergy/1000);xlabel('Months','fontsize',14),ylabel('Average Daily Solar Energy
(kWh/m ^2/day),title('Energy for Sep-Apr Optimized Tilt Angle','fontsize',14);

set(gca,'xticklabel',monthnames,fontsize',14)

disp(panelenergy/1000)

```

### **1.5 Energy bar graph for tilt angle optimized for December**

```

clc;

close all;

clear all;

latitudeD=24;

latitudeM=2;

latitudeS=25.61;

sunrise=[5.733 5.917 6.2 6.53 6.7 6.52 6.117 5.617];

sunset=[17.983 17.5 17.06 17.2 17.5 17.85 18.083 18.283];

ntotal=[258 288 319 349 15 46 74 105]; %15th of every month identification Sep-Apr

lambda=47.1943; %tilt angle

```

```

%Choosing sunrise and sunset times for given n

panelenergy=zeros(8,1);

inew=1;

for day=1:8

    Tsr=sunrise(1,day);

    Tss=sunset(1,day);

    i=1;

    time=zeros(1,length((Tsr+0.1):0.1:(Tss-0.1)));

    ti=1;

    panelintensity=zeros(1,length((Tsr+0.1):0.1:(Tss-0.1)));

    declination=(23.45*sind((360*(ntotal(1,day)-80))/365));

    for t=(Tsr+0.1):0.1:(Tss-0.1)

        phi=angtodeg(latitudeD,latitudeM,latitudeS);

        SRangle= acosd(-tand(phi)*tand(declination));

        diffSRangle=2*SRangle;

        diffT=Tss-Tsr;

```

```

hourangle=(-SRangle)+(((2*SRangle)/diffT)*(t-Tsr));

theta=acosd(((sind(phi-lambda))*sind(declination))+((cosd(phi-
lambda))*cosd(declination)*cosd(hourangle)));

alpha=asind((sind(declination)*sind(phi))+((cosd(declination)*cosd(phi)*cosd(hourangle))));

AM=(1/(sind(alpha)));

I=1367*((0.7)^(AM^0.678));

incidentIntensity=((I)*(cosd(theta)));

panelintensity(1,i)=incidentIntensity;

time(1,ti)=t;

ti=ti+1;

i=i+1;

end

disp(diffT)

energy=trapz(time,panelintensity);

energy=real(energy);

panelenergy(inew)=energy;

inew=inew+1;

end

```

```

monthnames={'September';                                     'October';
'November';'December';'January';'February';'March';'April' };

h=bar(panelenergy/1000);xlabel('Months','fontsize',14),ylabel('Average Daily Solar Energy
(kWh/m ^2/day','fontsize',14),title('Energy for Dec Optimized Tilt Angle','fontsize',14);

set(gca,'xticklabel',monthnames,fontsize',14)

disp(panelenergy/1000)

```

## **1.6 All the bar graphs combined to show a 5 bar average daily solar energy graph**

```
clc;
```

```
close all;
```

```
clear all;
```

```
latitudeD=24;
```

```
latitudeM=2;
```

```
latitudeS=25.61;
```

```
sunrise=[5.733 5.917 6.2 6.53 6.7 6.52 6.117 5.617];
```

```
sunset=[17.983 17.5 17.06 17.2 17.5 17.85 18.083 18.283];
```

```
ntotal=[258 288 319 349 15 46 74 105]; %15th of every month identification Sep-Apr
```

```
lambda=[0 35.8427 25.5002 33.6864 47.1943]; %tilt angle
```

```
%Choosing sunrise and sunset times for given n
```

```
panelenergy=zeros(8,5);
```

```
inew=1;
```

```
for day=1:8
```

```
    Tsr=sunrise(1,day);
```

```
    Tss=sunset(1,day);
```

```
    ienergy=1;
```

```
    i=1;
```

```
    time=zeros(1,length((Tsr+0.1):0.1:(Tss-0.1)));
```

```
    ti=1;
```

```
    panelintensity=zeros(1,length((Tsr+0.1):0.1:(Tss-0.1)));
```

```
    declination=(23.45*sind((360*(ntotal(1,day)-80))/365));
```

```
    for idec=1:5
```



```

for t=(Tsr+0.1):0.1:(Tss-0.1)

    phi=angtodeg(latitudeD,latitudeM,latitudeS);

    SRangle= acosd(-tand(phi)*tand(declination));

    diffSRangle=2*SRangle;

    diffT=Tss-Tsr;

    hourangle=(-SRangle)+(((2*SRangle)/diffT)*(t-Tsr));

    theta=acosd(((sind(phi-lambda(idec)))*sind(declination))+((cosd(phi-
lambda(idec)))*cosd(declination)*cosd(hourangle)));

alpha=asind((sind(declination)*sind(phi))+cosd(declination)*cosd(phi)*cosd(hourangle));

    AM=(1/(sind(alpha)));

    I=1367*((0.7)^(AM^0.678));

    incidentIntensity=((I)*(cosd(theta)));

    panelintensity(1,i)=incidentIntensity;

    time(1,ti)=t;

    ti=ti+1;

    i=i+1;

end

disp(diffT)

energy=trapz(time,panelintensity);

```

```

energy=real(energy);

panelenergy(inew,ienergy)=energy;

ienergy=ienergy+1;

panelintensity=panelintensity.*0;

end

inew=inew+1;

end

monthnames={'September'; 'October'; 'November'; 'December'; 'January'; 'February'; 'March';
'April' };

h=bar(panelenergy/1000);xlabel('Months','fontsize',14),ylabel('Average Daily Solar Energy
(kWh/m ^2/day)','fontsize',14),title('September to April','fontsize',14);

set(gca,'xticklabel',monthnames)

l = cell(1,5);

l{1}='Latitude'; l{2}='Optimized for Sep-Nov'; l{3}='Optimized for Feb-Apr'; l{4}='Optimized
for Sep-Apr';l{5}='Optimized for Dec' ;

legend(h,l);

disp(panelenergy/1000)

```

## **2. Latitude tilt angle**

### **2.1 Panel Intensity**

```

clc;

clear all;

```

```
close all;

%inputs

latitudeD=24;

latitudeM=2;

latitudeS=25.61;

Tsr=6.53;

Tss=17.2;

n=349;

lambda=23.685;

%intensity calculation loop

intensity=zeros(1,length(Tsr+0.1:0.1:Tss-0.1));

i=1;

time=zeros(1,length((Tsr+0.1):0.1:(Tss-0.1)));

ti=1;

for t=(Tsr+0.1):0.1:(Tss-0.1)

    phi=angtodeg(latitudeD,latitudeM,latitudeS);

    declination=(23.45*sind((360*(n-80))/365));
```

```

SRangle= acosd(-tand(phi)*tand(declination));

diffSRangle=2*SRangle;

diffT=Tss-Tsr;

hourangle=(-SRangle)+(((2*SRangle)/diffT)*(t-Tsr));

theta=acosd(((sind(phi-lambda))*sind(declination))+((cosd(phi-
lambda))*cosd(declination)*cosd(hourangle)));

alpha=asind((sind(declination)*sind(phi))+((cosd(declination)*cosd(phi)*cosd(hourangle))));

AM=(1/(sind(alpha)));

I=1367*((0.7)^(AM^0.678));

incidentIntensity=((I)*(cosd(theta)));

intensity(1,i)=incidentIntensity;

time(1,ti)=t;

ti=ti+1;

i=i+1;

end

plot(time,intensity),xlabel('Time','fontsize',14),ylabel('Intensity','fontsize',14),title('Intensity Vs
Time for December','fontsize',14)

```

```
grid on;
```

## **2.2 Flow Rate**

### **For 28 panels**

```
clc;
```

```
clear all;
```

```
close all;
```

```
flowrate=[ 0 0 130 250 400 500 570 590 610 590 570 500 400 250 130 0 0];
```

```
time=[ 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15 15.5 16 ];
```

```
plot(time,flowrate),xlabel('Time of the day'),ylabel('Flowrate in litres per min'),title('Panel  
Flowrate vs time in December')
```

```
flowrate=flowrate*60;
```

```
amount=trapz(time,flowrate);
```

```
disp(amount)
```

### **For 30 panels**

```
clc;
```

```
clear all;
```

```
close all;
```

```
flowrate=[ 0 0 190 320 490 570 630 670 700 670 630 570 490 320 190 0 0];
```

```
time=[ 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15 15.5 16 ];
```

```
plot(time,flowrate),xlabel('Time of the day','fontsize',14),ylabel('Flowrate in litres per  
min','fontsize',14),title('Panel Flowrate vs time in December','fontsize',14)
```

```
flowrate=flowrate*60;
```

```
amount=trapz(time,flowrate);
```

```
disp(amount)
```

### **For 32 panels**

```
clc;
```

```
clear all;
```

```
close all;
```

```
flowrate=[ 0 0 290 440 580 640 700 730 750 730 700 640 580 440 290 0 0];
```

```
time=[ 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15 15.5 16 ];
```

```
plot(time,flowrate),xlabel('Time of the day','fontsize',14),ylabel('Flowrate in litres per  
min','fontsize',14),title('Panel Flowrate vs time in December','fontsize',14)
```

```
flowrate=flowrate*60;
```

```
amount=trapz(time,flowrate);
```

```
disp(amount)
```

### **3. Sep-Apr Optimized tilt angle**

#### **3.1 Panel Intensity**

```
clc;
```

```
clear all;
```

```
close all;
```

```
%inputs
```

```
latitudeD=24;
```

```
latitudeM=2;
```

```
latitudeS=25.61;
```

```
Tsr=6.53;
```

```
Tss=17.2;
```

```
n=349;
```

```
lambda=33.6864;
```

```
%intensity calculation loop
```

```
intensity=zeros(1,length(Tsr+0.1:0.1:Tss-0.1));
```

```
i=1;
```

```

time=zeros(1,length((Tsr+0.1):0.1:(Tss-0.1)));

ti=1;

for t=(Tsr+0.1):0.1:(Tss-0.1)

    phi=angtodeg(latitudeD,latitudeM,latitudeS);

    declination=(23.45*sind((360*(n-80))/365));

    SRangle= acosd(-tand(phi)*tand(declination));

    diffSRangle=2*SRangle;

    diffT=Tss-Tsr;

    hourangle=(-SRangle)+(((2*SRangle)/diffT)*(t-Tsr));

    theta=acosd(((sind(phi-lambda))*sind(declination))+((cosd(phi-
lambda))*cosd(declination)*cosd(hourangle)));

    alpha=asind((sind(declination)*sind(phi))+((cosd(declination)*cosd(phi)*cosd(hourangle))));

    AM=(1/(sind(alpha)));

    I=1367*((0.7)^(AM^0.678));

    incidentIntensity=((I)*(cosd(theta)));

    intensity(1,i)=incidentIntensity;

    time(1,ti)=t;

    ti=ti+1;

    i=i+1;

end

plot(time,intensity),xlabel('Time','fontsize',14),ylabel('Intensity','fontsize',14),title('Intensity Vs
Time for December','fontsize',14)

```



```
grid on;
```

### **3.2 Flow Rate**

#### **For 28 panels**

```
clc;
```

```
clear all;
```

```
close all;
```

```
flowrate=[ 0 30 220 390 500 580 630 660 680 660 630 580 500 390 220 30 0];
```

```
time=[ 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15 15.5 16 ];
```

```
plot(time,flowrate),xlabel('Time of the day','fontsize',14),ylabel('Flowrate in litres per  
min','fontsize',14),title('Panel Flowrate vs time in December','fontsize',14)
```

```
flowrate=flowrate*60;
```

```
amount=trapz(time,flowrate);
```

```
disp(amount)
```

#### **For 30 panels**

```
clc;
```

```
clear all;
```

```
close all;
```

```
flowrate=[ 0 75 240 420 550 660 700 720 740 720 700 660 550 420 240 75 0];
```

```
time=[ 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15 15.5 16 ];
```

```
plot(time,flowrate),xlabel('Time of the day','fontsize',14),ylabel('Flowrate in litres per  
min','fontsize',14),title('Panel Flowrate vs time in December','fontsize',14)
```

```
flowrate=flowrate*60;
```

```
amount=trapz(time,flowrate);
```

```
disp(amount)
```

### **For 32 panels**

```
clc;
```

```
clear all;
```

```
close all;
```

```
flowrate=[ 0 100 300 470 610 710 770 800 815 800 770 710 610 470 300 100 0];
```

```
time=[ 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15 15.5 16 ];
```

```
plot(time,flowrate),xlabel('Time of the day','fontsize',14),ylabel('Flowrate in litres per  
min','fontsize',14),title('Panel Flowrate vs time in December','fontsize',14)
```

```
flowrate=flowrate*60;
```

```
amount=trapz(time,flowrate);
```

```
disp(amount)
```

## **4. December Optimized tilt angle**

### **4.1 Panel Intensity**

```
clc;
```

```
clear all;
```

```
close all;
```

```
%inputs
```

```
latitudeD=24;
```

```
latitudeM=2;
```

```
latitudeS=25.61;
```

```
Tsr=6.53;
```

```
Tss=17.2;
```

```
n=349;
```

```
lambda=47.1943;
```

```

%intensity calculation loop

intensity=zeros(1,length(Tsr+0.1:0.1:Tss-0.1));

i=1;

time=zeros(1,length((Tsr+0.1):0.1:(Tss-0.1)));

ti=1;

for t=(Tsr+0.1):0.1:(Tss-0.1)

    phi=angtodeg(latitudeD,latitudeM,latitudeS);

    declination=(23.45*sind((360*(n-80))/365));

    SRangle= acosd(-tand(phi)*tand(declination));

    diffSRangle=2*SRangle;

    diffT=Tss-Tsr;

    hourangle=(-SRangle)+(((2*SRangle)/diffT)*(t-Tsr));

    theta=acosd(((sind(phi-lambda))*sind(declination))+((cosd(phi-
lambda))*cosd(declination)*cosd(hourangle)));

    alpha=asind((sind(declination)*sind(phi))+((cosd(declination)*cosd(phi)*cosd(hourangle))));

    AM=(1/(sind(alpha)));

    I=1367*((0.7)^(AM^0.678));

    incidentIntensity=((I)*(cosd(theta)));

    intensity(1,i)=incidentIntensity;

    time(1,ti)=t;

    ti=ti+1;

```

```

    i=i+1;

end

plot(time,intensity),xlabel('Time','fontsize',14),ylabel('Intensity','fontsize',14),title('Intensity Vs
Time for December','fontsize',14)

grid on;

```

## **4.2 Flow Rate**

### **For 28 Panels**

```

clc;

clear all;

close all;

flowrate=[ 0 100 280 420 570 650 680 690 700 690 680 650 570 420 280 100 0];

time=[ 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15 15.5 16 ];

plot(time,flowrate),xlabel('Time of the day','fontsize',14),ylabel('Flowrate in litres per
min','fontsize',14),title('Panel Flowrate vs time in December','fontsize',14)

```

```

flowrate=flowrate*60;

```

```

amount=trapz(time,flowrate);

```

```

disp(amount)

```

### **For 30 Panels**

```
clc;
```

```
clear all;
```

```
close all;
```

```
flowrate=[ 0 160 350 500 630 700 720 780 790 780 720 700 630 500 350 160 0];
```

```
time=[ 8 8.5 9 9.5 10 10.5 11 11.5 12 12.5 13 13.5 14 14.5 15 15.5 16 ];
```

```
plot(time,flowrate),xlabel('Time of the day','fontsize',14),ylabel('Flowrate in litres per  
min','fontsize',14),title('Panel Flowrate vs time in December','fontsize',14)
```

```
flowrate=flowrate*60;
```

```
amount=trapz(time,flowrate);
```

```
disp(amount)
```

## **Appendix B**

### **Datasheets**

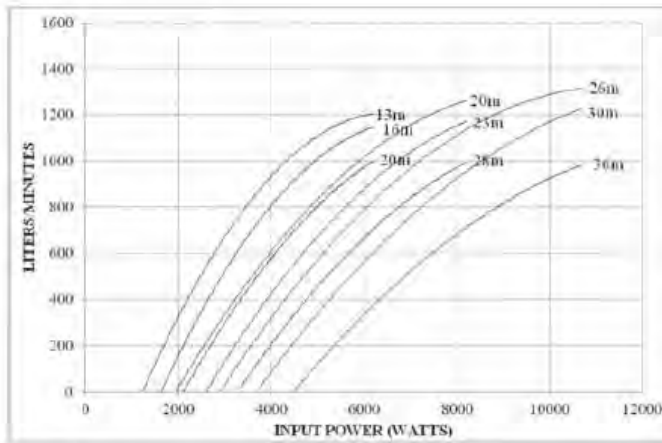
- A. Pump characteristics curve showing change in flow rate with variable input power
- B. Data sheet of the solar panel Sunmodule model number SW340

A:

**INTRODUCTION OF SOLAR MOTOR - HIGH EFFICIENT SYSTEM**

**60 DCSSP 6200/8200/10700**

Pumpset Code : 850000872  
 BSP 100 mm (6X6)  
 (A) VFD 17 A Code : 9000021159  
 (B) VFD 17 A Code : 9000021159  
 (C) VFD 25 A Code : 9000023553  
 Chock code : Not Required



(A)	INPUT POWER(WATT)						
	6200	5300	4600	3900	2100	1600	1400
HEAD(M)	FLOW IN LPM						
20	1000	861	773	545	0		
16	1160	1002	904	786	293	0	
13	1220	1133	1028	924	385	220	0

(B)	INPUT POWER(WATT)						
	8200	7200	6200	5200	3300	2600	2100
HEAD(M)	FLOW IN LPM						
28	1000	878	665	540	0		
23	1185	1060	865	724	271	0	
20	1280	1158	1052	861	425	240	0

(C)	INPUT POWER(WATT)						
	10700	9500	8500	6500	4500	3700	3100
HEAD(M)	FLOW IN LPM						
36	1000	842	768	442	0		
30	1245	1102	990	672	268	0	
26	1345	1190	1142	895	510	330	0



B:

# Sunmodule® SW 340 - 350 XL MONO



## PERFORMANCE UNDER STANDARD TEST CONDITIONS (STC)\*

		SW 340	SW 345	SW 350
Maximum power	$P_{max}$	340 Wp	345 Wp	350 Wp
Open circuit voltage	$V_{oc}$	47.0 V	47.2 V	47.3 V
Maximum power point voltage	$V_{mpp}$	37.1 V	37.5 V	37.8 V
Short circuit current	$I_{sc}$	9.81 A	9.82 A	9.82 A
Maximum power point current	$I_{mpp}$	9.26 A	9.28 A	9.29 A
Module efficiency	$\eta_m$	17.04 %	17.29 %	17.54 %

Measuring tolerance ( $P_{max}$ ) traceable to TUV Rheinland: +/- 2% (TUV Power controlled, ID 0000039351)

\*STC: 1000W/m<sup>2</sup>, 25°C, AM 1.5

## PERFORMANCE AT 800 W/m<sup>2</sup>, NOCT, AM 1.5

		SW 340	SW 345	SW 350
Maximum power	$P_{max}$	257.3 Wp	260.4 Wp	262.2 Wp
Open circuit voltage	$V_{oc}$	43.6 V	43.6 V	43.7 V
Maximum power point voltage	$V_{mpp}$	34.4 V	34.7 V	34.9 V
Short circuit current	$I_{sc}$	7.97 A	7.98 A	7.98 A
Maximum power point current	$I_{mpp}$	7.49 A	7.50 A	7.56 A

Minor reduction in efficiency under partial load conditions at 25°C: at 200 W/m<sup>2</sup>, 97% (+/-3%) of the STC efficiency (1000 W/m<sup>2</sup>) is achieved.

## PARAMETERS FOR OPTIMAL SYSTEM INTEGRATION

Power sorting	-0 Wp / +5 Wp
Maximum system voltage SC II / NEC	1000 / 1500 V
Maximum reverse current	25 A
Number of bypass diodes	3
Operating temperature	-40 to +85 °C
Maximum design loads (Two rail system)*	113 psf downward, 64 psf upward

\*Please refer to the Sunmodule Installation Instructions for the details associated with these load cases.

## COMPONENT MATERIALS

Cells per module	72
Cell type	Monocrystalline PERC
Cell dimensions	6 in x 6 in (156 mm x 156 mm)
Front	Tempered safety glass with ARC (EN 12150)
Back	Multi-layer polymer backsheet, white
Frame	Clear anodized aluminum
J-Box	IP65
Connector	PV wire (UL4703) with Amphenol UTX connectors
Module fire performance	(UL 1703) Type 1

## DIMENSIONS / WEIGHT

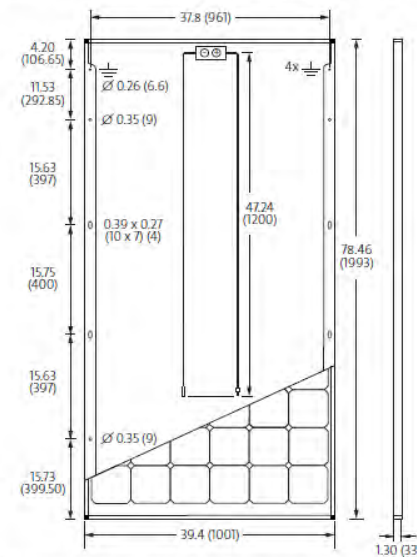
Length	78.46 in (1993 mm)
Width	39.40 in (1001 mm)
Height	1.30 in (33 mm)
Weight	47.6 lb (21.6 kg)

## THERMAL CHARACTERISTICS

NOCT	46 °C
TC $I_{sc}$	0.03 % / °C
TC $V_{oc}$	-0.29 % / °C
TC $P_{mpp}$	-0.42 % / °C

## ORDERING INFORMATION

Order number	Description
82000664	Sunmodule Plus SW 340 XL mono
82000561	Sunmodule Plus SW 345 XL mono
82000563	Sunmodule Plus SW 350 XL mono



All units provided are Imperial. SI units provided in parentheses.

## CERTIFICATES AND WARRANTIES

Certificates	IEC 61730	IEC 61215	UL 1703
	IEC 62716	IEC 60068-2-68	IEC 61701
Warranties	Product Warranty	20 years	
	Linear Performance Guarantee	25 years	

SolarWorld AG reserves the right to make specification changes without notice. This data sheet complies with the requirements of EN 50380.

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