Introduction

to Solar Energy & Solar Water Pumping Systems

FOUNDATION
Building Sustainable Enterprises and Ecosystems

Established in 2008, Environment Conservation Society (SwitchON Foundation) is a multiple award winner, registered non-governmental organisation dedicated to work towards equitable and sustainable development. Over the past decade we have completed multiple projects with bilateral organisations and government agencies , incubated 3 social enterprises, 5 farmer producer companies and over 500 micro enterprises in pursuit of fulfilling our mission.

SwitchON Foundation has worked extensively across Eastern India. Our reach ranges from West Bengal, Jharkhand, Maharashtra, Madhya Pradesh, Orissa to North East Indian states. We have positively impacted more than 10,00,000 lives of people in these regions and reached out to more than 5000 villages through our work.

Environment Conservation Society (SwitchON Foundation) has prepared this Handbook for Solar Water Pumping System Technical Training to promote technical education in renewable energy sector.

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TOPICS COVERED

Solar Energy

The energy from the sun can be converted directly in the form of heat or converted into electrical energy and then utilized. **Accordingly the solar energy is classified into solar thermal and solar photovoltaic (PV).** Solar PV can be considered the only form of electricity that can be generated **anytime and anywhere** provided sunshine is available.

Solar photovoltaic (PV)

Solar thermal

The earth receives more energy from the sun in just one hour than the world uses in a whole year. **Photovoltaic (PV) Technology** is a process of generating electrical energy from solar radiation. The principle of conversion of solar energy into electrical energy is based on the effect called **photovoltaic effect.**

Solar thermal has multiple applications like water heating, drying vegetables and agricultural products, cooking, etc.

Water heating

Drying vegetables

Agricultural drying

Solar Water Pumping Systems

The Solar Pumping System harnesses the abundantly available **solar energy to power the pumps to draw water** from water bodies. The longer life span gives an edge to promote use of this system.

The principal means of water lifting in the developing world are presently the hand pump for smaller demands and the diesel or electric-driven pump for larger quantities. Solar PV pumping can be more appropriate than these technologies in many applications. Spare parts and fuel can be difficult or expensive to obtain, and the quality of fuel is often poor due to adulteration, which leads to frequent maintenance requirements.

Solar water pumps are **cost-effective** in the long run and **dependable** method for drawing water. It is a **highly effective** and **smarter solution** in situations where electric supply is unreliable or unavailable; or fuel cost & maintenance costs are considerably high. **A solar pump is often the best option for reducing the cost and labor** which is required in arranging the diesel.

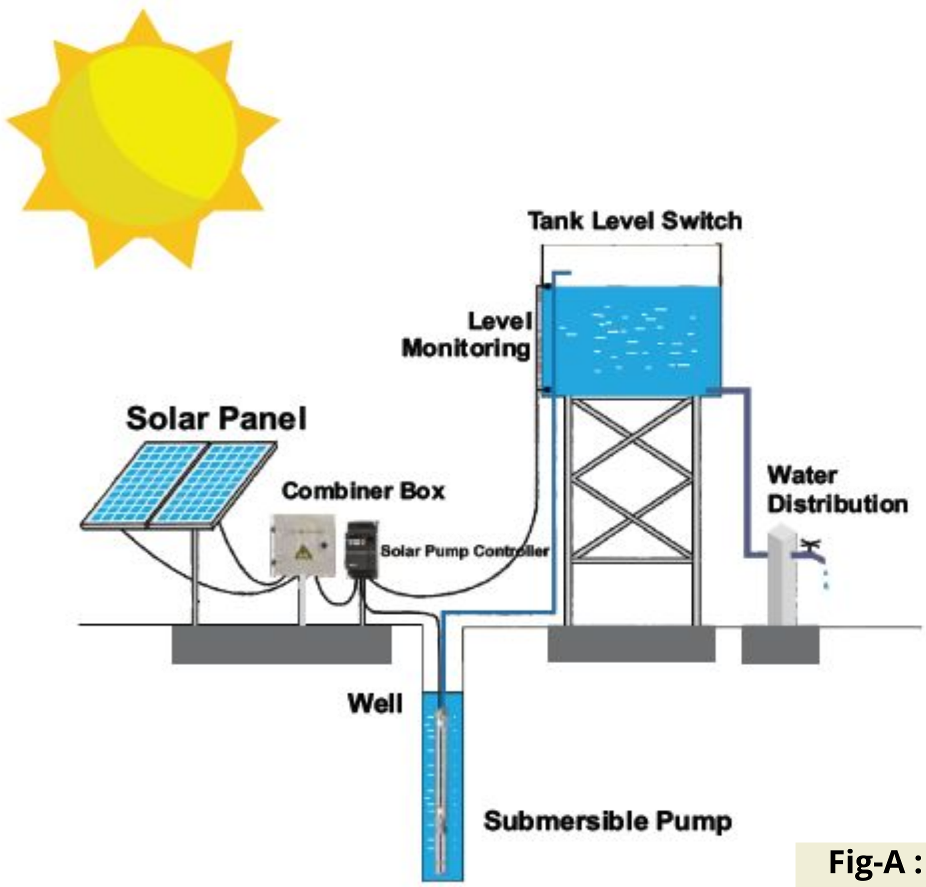
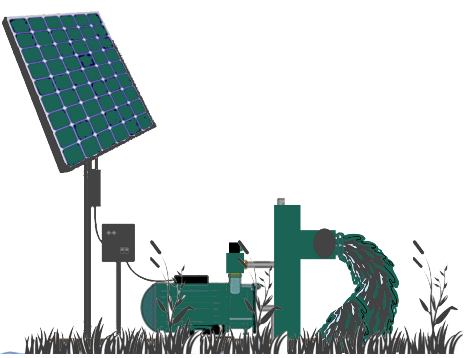


Fig-A : Diagrammatic representation of solar water pumping system



DID YOU KNOW?

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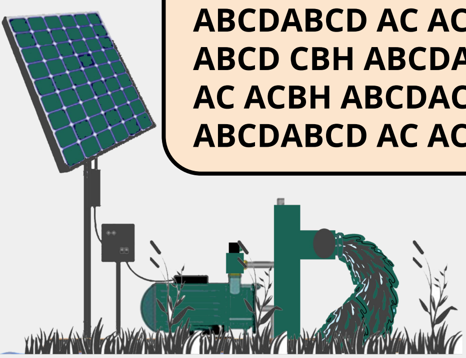


Applications of Solar Pumps

The potential applications of solar pumps include:

Irrigation
(individual farmers or cooperatives)

Potable water supply for institutions
(traditional niche market for schools and health clinics)

Community-scale water supply schemes
(larger village schemes)

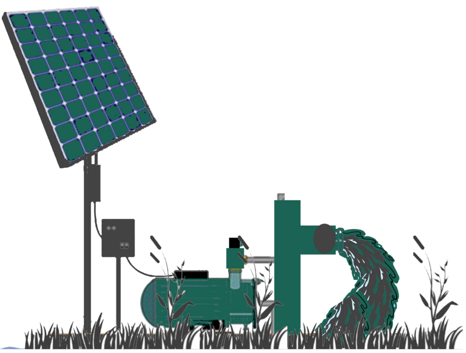
Livestock water supply
(individual or communal)

Water pumped for irrigation can be used as drinking water also if it is free from impurities and is potable. Therefore, PV systems for irrigation and drinking water will be described together.

Access to a safe and clean water supply is one of the primary factors in improving the **health** and **quality of life in rural communities**. In the developing world, especially in Africa, Asia, and Latin America a lot of people do not have the option of using clean water for drinking. These remote regions are not connected to a centralized system for supplying drinking water.

A water pump does not necessary require batteries. To save costs, the majority of solar powered water pumps can run directly from the solar panels. Electricity aimed at running the water pump is not stored in batteries, but the water is instead stored in a water tank or pond. This way the water is stored and can be used anytime required.

In terms of automation, developed wireless technologies, researches focused on automatic irrigation with sensors in agricultural systems. The advantages of using wireless sensor is to reduce wiring and piping costs, and easier to install and maintenance especially large areas.



Efficiency

The **solar pump efficiency** as we know is the ratio of output vs input and if represented in percentage it is known as percentage efficiency. In the case of a solar pump, the overall efficiency can be split into three parts

- The efficiency of conversion of solar energy into electrical energy.
- The efficiency of the motor drives the pump.
- The efficiency of a pump or the pumping efficiency.

A very narrow band in solar energy spectrum gets converted into electrical energy, Therefore the efficiency of conversion is very low of order of 12 to 20% which mainly depends upon the design of the solar panel and the ambient conditions like temperature, etc.

The motor efficiency is of the order of 80 to 90% again mainly dependent upon the design and rating of the motor. Finally, we come to pump efficiency which normally is of the order of 50 to 65%. Adding up all the three efficiencies we come to the overall efficiency of 47 to 58%.

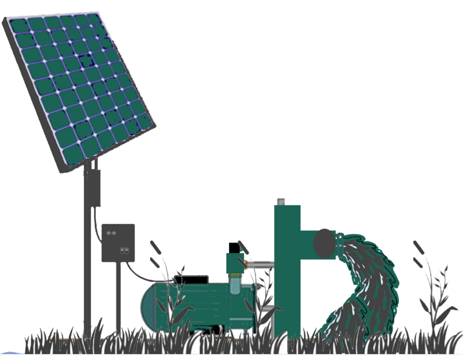
Area Required and Lifespan of SWP

The area required by the solar pump depends on its size. **For every 1 HP of the solar pump size, the area required is 100 square feet**. Therefore, a 2 HP solar pump required about 200 square feet area to be installed and 5 HP solar pump requires about 500 square feet area. Relocation of a solar pump is not advisable.

The minimum lifespan of solar panel is 25 years

Lifetime of pump is 10-15 years.

The Pump, solar modules and pump controller have a warranty for 5 years.



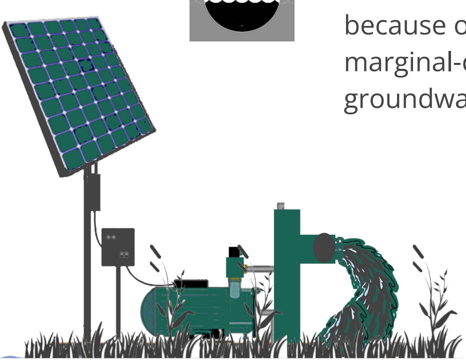
Advantages and Limitations

One of the major milestones in solar water pumping is the elimination of dependency on an external power source. The solar panels in the pumping system coalesce solar irradiation to provide the electricity required to pump up groundwater from beneath the ground. With a surge in the means of production, the **prices of solar water pumps have gone down favorably for users in recent years**. This has propelled users to recover their investments faster and use the pump for free water harvesting for a longer period of time.

Nevertheless, **solar water pumps are a one-time investment opportunity with guaranteed rich dividends** in store. One of the major factors why it is promoted on large scale India is because it significantly reduces the financial burden of electricity distribution companies who provide subsidized power to its agriculture consumers.

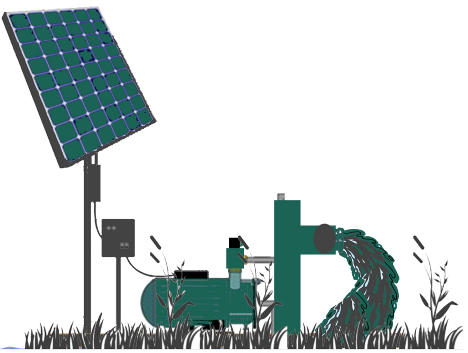
The limitations of solar pumps and their corresponding solutions are

Limitations	Solutions
High initial investment cost	Government subsidies and easy bank finances are available
Output fluctuation due to varying solar isolation (weather dependent)	Use of VFD and battery can ensure a constant supply without voltage fluctuations Grid connected solar pumps use grid energy to run the pump when solar energy is not available
Vandalism and theft	Anti-theft technology used in panels and pump controller Bank insurance is available at minimum premium
Excessive groundwater extraction because operators face near zero marginal-cost of pumping groundwater	Creation of groundwater recharging structures and judicious use of solar pumps



The advantages of solar pumps are

1	Operation is independent of grid power and reduces dependency on electric grid
2	Negligible maintenance cost
3	Highly cost-effective in long run against diesel and electric
4	Environment Friendly - No Carbon emissions
5	No fuel cost - uses available free sunlight
6	Helps to increase in agricultural productivity due to consistent water supply
7	Ease of operation as it is highly automatic
8	Reduces the electricity distribution companies' (DISCOM) financial burden in long term even after providing subsidized pump sets to farmers
9	Properly installed solar systems are safe and low risk due to low system voltage
10	Solar pumping systems are modular so can be tailored to current power needs and easily expanded by adding PV panels and accessories



Revolution of Solar Pumps over last decade

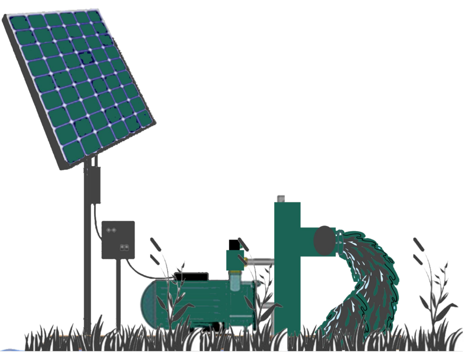
Solar water pumping systems capacity and ability have expanded. New pump and motor designs have increased water outputs over the entire pump range.

Prices of photovoltaic (PV) panels have dropped exponentially: High demand for PV modules for grid tied applications has resulted in massive economies of scale in production as well as competition among vendors. The commodity price of silicon, the key material, has also dropped substantially

The number of SWP manufacturers and suppliers has increased: Old monopolies have been broken, and although the technology leaders continue to innovate, competition is fierce on price, performance, and quality.

SWP is being mainstreamed and awareness is growing: Further opportunities are rising as intensive awareness campaigns support and elaborate on the details of system performance and savings.

The investment costs associated with buying solar water pumps has come down in the past few years.



However, the factors which influence the deployment of a solar water pump are numerous and include:

- Economic viability
- Access to capital subsidy
- Standardization and quality control of products and service
- Water management
- Environmental regulation at local level

Considering these factors, we can say that solar water pumping can provide significant environmental and socio-economic benefits at the local and national levels. At the local level, the technology can present a reliable source of energy in remote areas, especially areas that are not connected to the electricity grid or lacking a regular supply of costly liquid fuels. On a national level, solar water pumping can help stabilize, increase and diversify agricultural production and stabilize the electricity grid.

Many governments and institutions have realized that Solar Water Pumping can act as a catalyst to increase farmers' income and is an extremely viable way to expand energy access across developing countries and communities. Additionally, this creates a strong resistance to changes in rainfall patterns. This is the reason many governments have opted to subsidize the cost of solar pumping, increasing the pool of shared learning for this emerging technology.

Basic Definitions

Current (I):

Current is the rate of flow of electric charge particles. These charge particles are present in the current. It is defined as the number of charges per unit time passing through a point. Current is represented with the letter 'I'.

SI Unit: Ampere (A)

Voltage (V):

Voltage is the potential energy difference between two points. It is the pressure that pushes the charged particles from one point to another. Voltage is represented with the letter 'V'.

SI Unit: Volt (V)

Resistance (R):

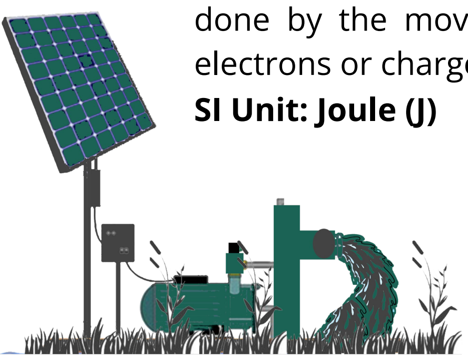
Resistance is the measure of the difficulty of passing an electric current through a substance. It explains the relationship between voltage and current. With more resistance, less electricity will flow through the circuit.

Formula: R = V/I
SI Unit: Ohm (Ω)

Energy (E):

The energy which is caused by the movement of the electrons from one place to another such type of energy is called electrical energy. In other words, electrical energy is the work done by the moving streams of the electrons or charges.

SI Unit: Joule (J)



Power (P):

Power is the rate of electrical energy transferred by an electric circuit per unit time. It is the product of Current and Voltage. Power is represented with the letter 'P'.

Formula: P = V x I
SI Unit: Watt (W)

Solar Irradiance or Insolation:

Solar irradiance is the power per unit area received from the Sun in the form of electromagnetic radiation as measured in the wavelength range of the measuring instrument.

SI Unit: Watt per square metre (W/m^2)

Photovoltaic (PV) array:

An interconnected system of PV modules that function as a single electricity-producing unit. The modules are assembled as a discrete structure, with common support or mounting. In smaller systems, an array can consist of a single module.

Photovoltaic (PV) cell:

The smallest semiconductor element within a PV module to perform the immediate conversion of light into electrical energy (direct current voltage and current). Also called a solar cell.

Photovoltaic (PV)

conversion efficiency: The ratio of the electric power produced by a photovoltaic device to the power of the sunlight incident on the device.

Did you KNOW?

Evaluation

1 **What is the drawback of diesel generators is**

a. High capital cost
b. Availability of fuel
c. Pollution
d. Both b & c

2 **Solar Pumps are**

a. Eco-friendly
b. Releases pollution
c. High maintenance
d. Both a & c

3 **__________ requires high investment amount**

a. Diesel
b. Solar
c. Grid Connected
d. Both a & c

4 **What are the parts that require replacement in Solar PV Pumping system before the end of 25 years?**

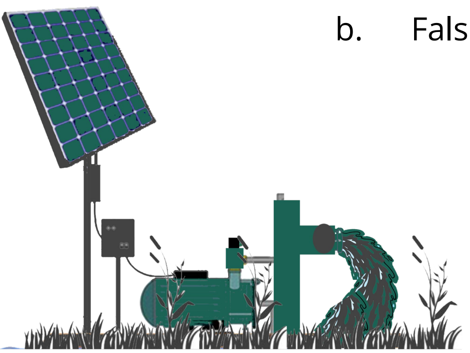
a. Controller
b. Inverter
c. AC pump
d. Solar Panel
e. Both b & c

5 **The life cycle cost of Diesel pumping system is ___________ than Solar PV Pumping system**

a. more
b. less
c. Almost same

6 **Maintenance cost of diesel pump is less as compared to solar pump**

a. True
b. False



Evaluation

7 **The Solar PV is used to generate electricity anytime and anywhere provided _________ is available.**

a. Wind
b. Water
c. Sunshine
d. Silicon

8 **The conversion of Solar Energy into Electrical Energy is based on the principle of**

a. Photosynthesis
b. Photovoltaic effect
c. Radiation
d. Heat

9 **Thin Film Solar Panels have _______ efficiency than crystalline modules.**

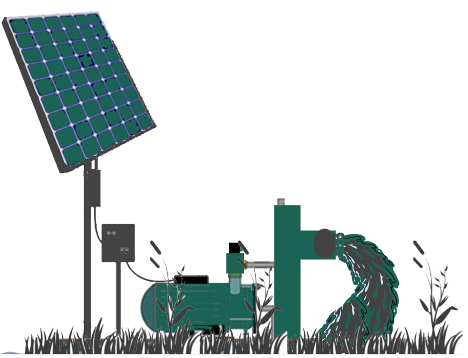
a. More
b. Less
c. Almost equal
d. Cannot compare

10 **Which silicon cells are made from an ingot of melted and recrystallised silicon?**

a. Thin film
b. Monocrystalline
c. Polycrystalline
d. None

11 **The manufacturing process of _________ cells is complicated compared to other technologies.**

a. Polycrystalline
b. Monocrystalline
c. Thin film
d. None



Evaluation

12 **The most commonly used material for manufacture solar cells is**

a. Silicon
b. Iron
c. Wood
d. Glass

13 **Traditional solar panels produce _________ electricity as output.**

a. Alternating current
b. Direct current
c. Both a and b
d. None

14 **When two cells are connected in series, ________ of the two cells is added.**

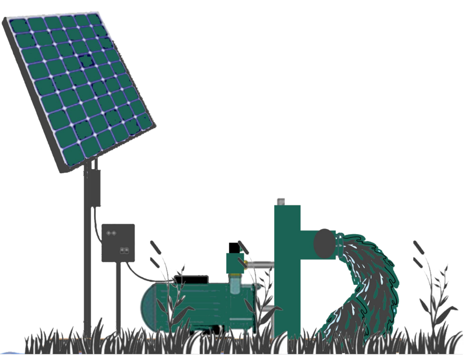
a. Power
b. Current
c. Voltage
d. Energy

15 **The current of the two cells is added when they are connected in**

a. Series
b. Parallel
c. Combination of series and parallel
d. None

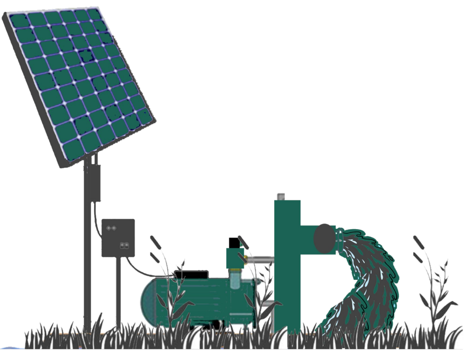
16 **Higher power can be obtained using low power solar cells by making _______ Connection of cells.**

a. Parallel
b. Series
c. Combination of series and parallel both
d. None



Answers

1	d.	5	a.	9	b.	13	b.
2	a.	6	b.	10	b.	14	c.
3	b.	7	c.	11	c.	15	b.
4	e.	8	b.	12	a.	16	c.

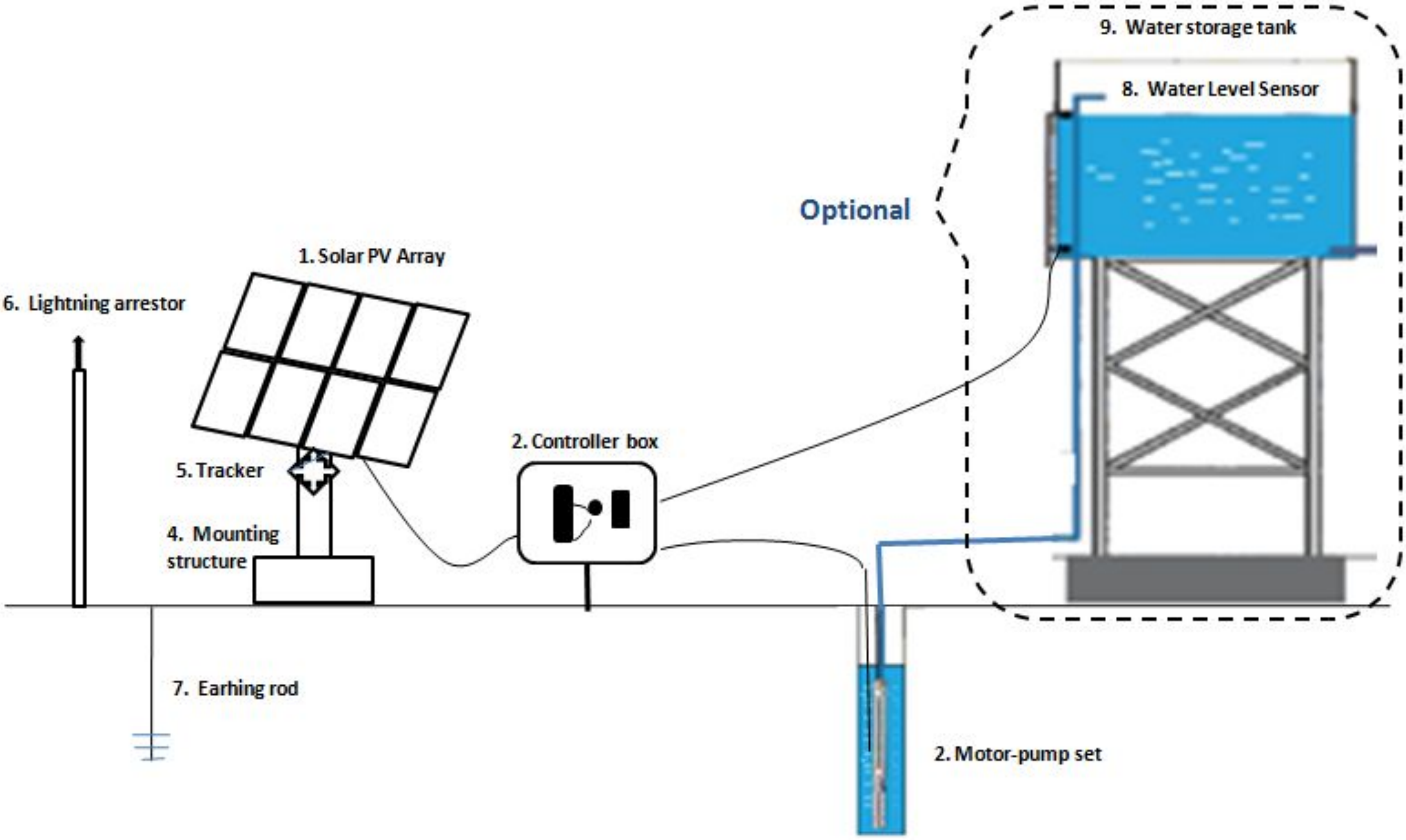


Components of the Solar Pumping System

TOPICS COVERED

Introduction

A Solar pumping system consists mainly of Solar Panels, Motor-pump set and a Controller, interconnected cables, earthing rod and lightning arrester. Sometimes a water storage tank is also provided depending upon the requirement. This chapter describes in more detail the major components used in solar pumping systems.



Solar PV Cells and Solar Array

Solar Cells

The smallest part of the device that converts solar energy into electrical energy is called a solar cell. Solar cells are in fact large area semiconductor diodes, which are made by combining silicon material with different impurities. Sand, a base material for semiconductors, is the most abundantly available raw material in the world. The ordinary sand (SiO2) is the raw form of silicone.

All photovoltaic (PV) cells consist of two or more thin layers of semiconducting material, most commonly silicon. When the semiconductor is exposed to light, electrical charges are generated and these charges are conducted away by metal contacts as Direct Current (DC). The electrical output from a single cell is small, so multiple cells are connected together to form a 'string', which produces a higher direct current.

Power generated by a solar cell depends on its efficiency.

The power generated per unit area is usually in the range of 10 milliWatt/cm^2 to 25 milliWatt/cm^2 which corresponds to 10% to 25% cell efficiency.

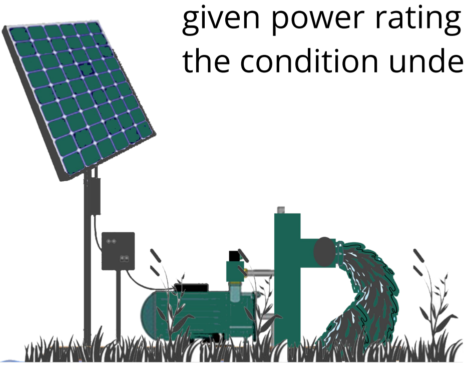
The maximum area of a single, typical wafer based solar cell is 15 × 15 = 225 cm^2.

With 15% efficiency peak power generated by the solar cells would be
225 cm^2 × 15 milliWatt/cm^2 = 3.37 Watt.

Nowadays solar panels with efficiency of over 18% are also commercially available.

Solar PV modules

It is not solar cells alone, but PV modules that are installed in the field to supply the power. Solar PV modules are made of solar cells by connecting many cells in series and/or parallel. The solar PV modules are encapsulated properly so that they can work in outdoor conditions for a very long period of time. The module power output depends on the power output of individual cells. By choosing appropriately sized cells, modules of given power rating can be obtained. The power output of the module depends on the condition under which module is working (radiation, temperature, etc).



Solar PV Modules can be considered as a big solar cell (array of several solar cells connected in series and parallel) with larger voltage and current output than a single solar cell.

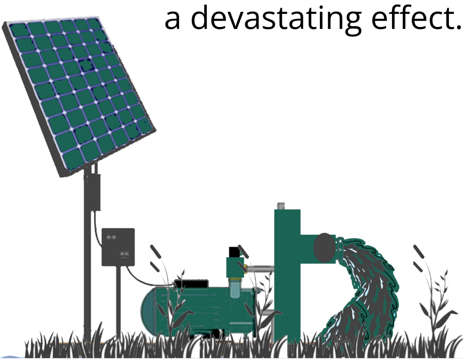
In the first level of interconnection to increase the power output, cells are connected to form solar PV modules. These days solar PV modules are available with power ratings ranging from 3 Watts to 400 Watts. In the second level of interconnection solar PV modules are connected together in the form of an array to get the power which is more than a single PV module power output. A PV array can provide us with power ranging from few Watts to several megawatts.

Higher power can be obtained using low power solar cells by making series and parallel connections of cells. Series connection is done in order to increase the output voltage while parallel connection is done in order to increase the current output. While making a series and parallel connection of cells it is assumed that all cells have the same characteristics, i.e. they are identical in all aspects like size, material and efficiency.

PV modules are rated according to their power output, based on a solar irradiance of 1,000 W/m^2 at a specified module temperature. Panel output data includes the peak power (maximum power generated by the panel referred to as watt-peak or Wp), voltage (volts or V), and current (amps or A). In addition to irradiance, PV module temperature affects the amount of power produced, with higher temperatures decreasing power output.

The main global standard for crystalline silicon modules is IEC 61215, which, like similar standards, is awarded largely based on tests administered to samples of modules produced. Since modules cannot be tested throughout their 25-year lifetime, accelerated stress testing is performed. One of the main tests is the verification of the nominal peak power that a PV module can deliver under standard testing conditions (STC), which include 1 kW/m^2 of solar irradiation perpendicular to the panels and 25°C of PV cell temperature.

Quality of solar modules, and matching of solar module performance is especially important in solar pumping systems consisting of large arrays of modules connected in series, where array performance, hence system performance, depends on the performance of the weakest module. Even one module with inferior output can have a devastating effect.

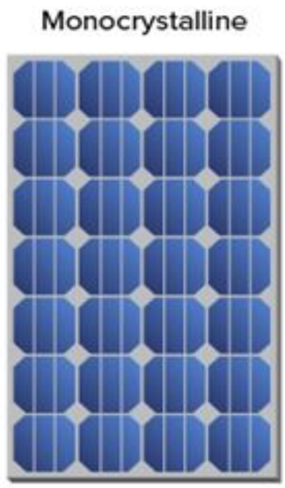


Classification of Solar Panels

Solar panels are broadly classified based on solar cell technology which is being used. The ways in which interconnection of solar cells is obtained in the thin film technology and in a wafer-based technology (Crystalline) are different. In thin film technology, cells are interconnected during the process of manufacturing of solar cells. While in wafer-based technology solar cells are manufactured first and then interconnected to make PV modules.

Thin-film

Wafer based (Crystalline)

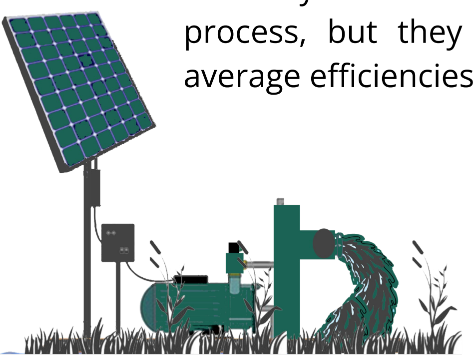


Monocrystalline silicon PV panels

These panels are made using cells sliced from a single cylindrical crystal of silicon. This is the most efficient photovoltaic technology, typically converting around 15% of the sun's energy into electricity. The manufacturing process required to produce monocrystalline silicon is complicated, resulting in slightly higher costs than other technologies.

Polycrystalline silicon PV panels

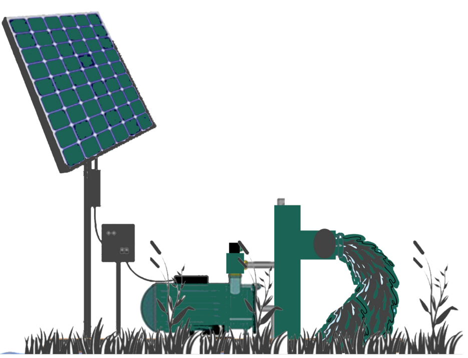
Also sometimes known as multicrystalline cells, polycrystalline silicon cells are made from cells cut from an ingot of melted and recrystallised silicon. The ingots are then saw-cut into very thin wafers and assembled into complete cells. They are generally cheaper to produce than monocrystalline cells, due to the simpler manufacturing process, but they tend to be slightly less efficient, with average efficiencies of around 12%.



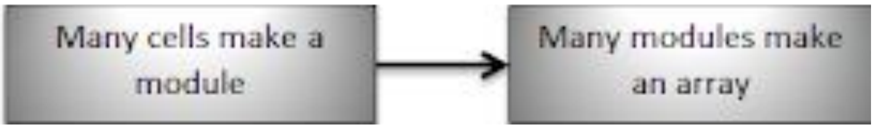
Thin-film based solar panels

It basically uses less silicon, hence named thin film. It tends to be less expensive but also has lower efficiency than crystalline modules. A thin-film solar cell is a second generation solar cell that is made by depositing one or more thin layers, or thin film (TF) of photovoltaic material on a substrate, such as glass, plastic or metal.

Type	Advantage	Disadvantage
Monocrystalline	• Highest efficiency (upto 22%) • Takes lesser space • Higher durability • More efficient in warm weather	Higher Cost
Polycrystalline	• Relatively easier to make • Cost-effective as compared to Monocrystalline panels • Higher temperature coefficient, therefore impact of temperature on power output is less	Efficiency of panels is around 15%
Thin-film based solar panels	• Mass production is easier • High temperature and shading have lesser impact on power output	• Lowest space efficiency • Faster degradation as compare to mono & poly panels



Solar PV system

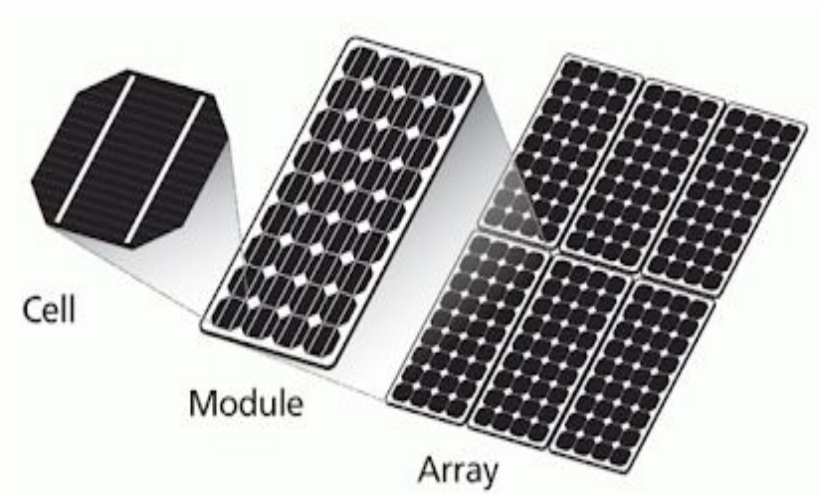


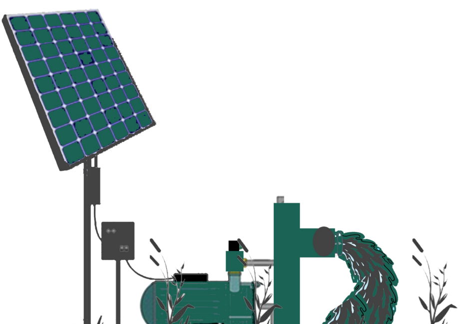
Harnessing power from the sun, the PV system consists of a systematic arrangement of components designed to supply usable electric power for a variety of applications. Photovoltaic power capacity is measured in watts peak (Wp). When the PV modules are exposed to sunlight, they generate direct current (DC). An inverter then converts the DC into alternating current (AC). A small PV system has capability to power a single home or even an isolated AC or DC based device.

Solar PV systems can be classified based on the end-use application of the technology. There are two main types of solar PV systems:

- Grid-connected (or grid-tied) solar PV systems
- Off grid (or stand alone) solar PV systems

Off-grid solar PV systems are applicable for areas without a utility grid. Currently, such solar PV systems are usually installed at isolated sites where the power grid is far away, such as rural areas or off-shore islands. But they may also be installed within the city in situations where it is inconvenient or too costly to tap electricity from the utility grid.





Did you KNOW?

Module Mounting Structures

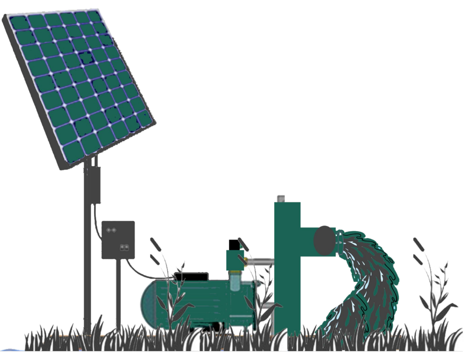
Various module mounting structure solutions are available as per requirement of site / project / customer. They are designed in order to maximize yield within a minimum area. Tailor made structures are also available to suit project requirements, which maximize the generation from solar modules. Most commonly used are Galvanized Iron structures which can withstand wind speed upto 150 kmph or as per requirement of site. Aluminium structures are also seen, however they are not as strong as GI structures. Structure designed to facilitate replacement of modules if required. Common theft-prevention measures include:

- use of lock tie nuts
- spraying the owner's ID with non removable spray paint onto the back of the panels;
- integrating the solar panels into the mounting structure (non detachable)
- placing the mounting structure out of easy reach by using elevated structures, fences or floating PV systems.

There are two basic types of mounting structures

- Ground mounted structures which can be single pole mounting or multiple leg mounted structures
- Rooftop mounting structures. These are installed where ground space is not available
- Apart from this, floating structures are also noted in various location where land area is inadequate

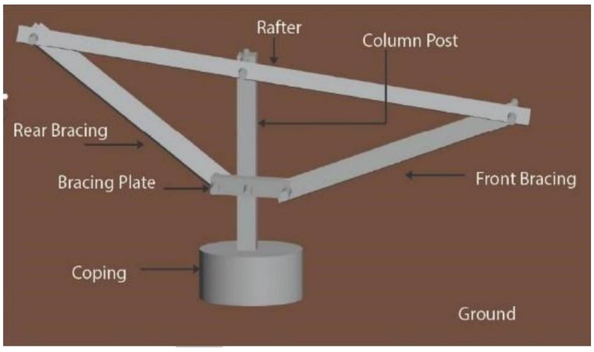
Additionally, tracker based mounting structures are installed that rotate the solar modules in the direction of maximum solar irradiation



Common Features of Module Mounting Structure

Irrespective of various MMS designs, certain components are common in all designs.

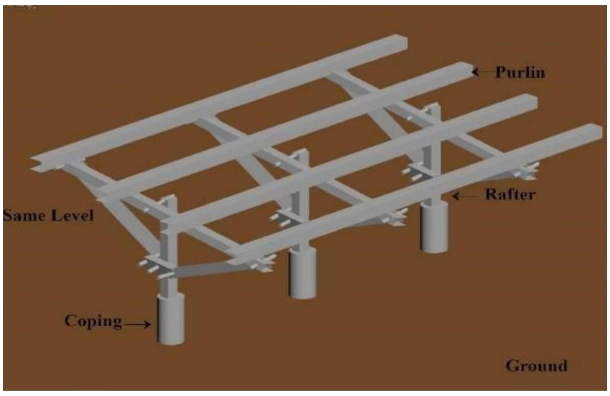
- There will be legs driven into the ground usually concreted to support the weight of the entire mounting structure. They are called column posts
- There will be rafters which are tilted at an angle suitable to utilize solar power in the most optimal manner as per design. Usually, the tilt is facing the equator at an angle equal to the latitude.



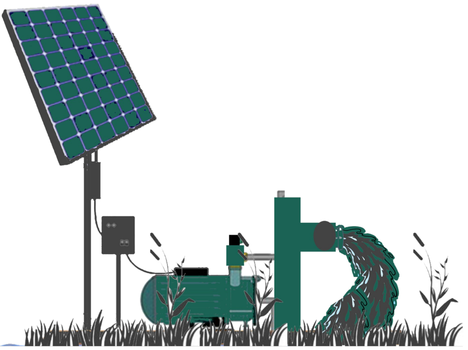
Load Carrying Components of Module Mounting Structure - Column and Rafter

- Rafter will be connected to column post either directly or using Front and Rear bracings with cleats
- There will be purlins placed on the rafter perpendicular to it. Based on the number of rows of modules, the number of purlins required are decided. Modules are placed over the purlins and clamped to the purlins
- Long Bracings - These are supporting GI arms provided for strength and stability of the structure at various places.

MMS are specified by the number of rows and columns. 4×3 MMS means there are 4 modules in a row and 3 such rows



Purlin over rafter for module housing



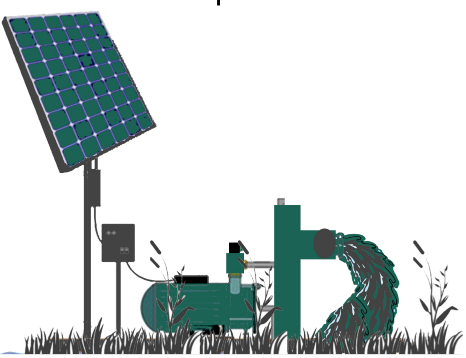
Ground Mounted structure 	Ground-mounted array can be positioned for best exposure to sunlight. This option requires a suitable ground area and type of soil, however. Typically, ground-mounted arrays get high exposure to sun, and they are a comparatively cheap option. The main advantage of this structure is ease of installation. Also it is easier to clean the panels.

Pole-mounted structure 	This is one of the most popular installation methods for solar PV power in areas where ground- or roof mounting is not suitable is to mount the array on poles. To increase the number of panels, more poles shall be created adjacent to the solar pump. Installing a pole-mounted solar PV array is a more detailed operation than other forms of mounting, and the structural loading on a pole-mounted array must be determined in advance. Every manufacturer has different designs and sizes available.

Roof Mounted structure 	A roof-mounted array can be installed on a suitable existing structure (such as a shed). This is the standard mounting option for urban grid-connected solar PV systems. The size of the array that’s possible is limited by the available installation area on the roof. This is not very popular in solar pumping systems, but can save cost of mounting structures, if the roof is readily available adjacent to the solar pump. Again, cleaning of panels can become challenging if access to the roof is difficult.

Overhead Tank structure 	This is popularly used in drinking water applications where the fewer number of solar panels are available. Storage tank is to be mounted on height to create water pressure. Existing structure of overhead tanks can be utilized to support the panels, this reduces the space requirement. But it becomes challenging to clean the solar panels.

The fixed installation of solar panels on a rigid structure is the cheapest, most reliable and most common method. Metal supports that are pile-driven into the ground are generally recommended for larger systems. They make the utilization of concrete foundations redundant and save labor and material cost. However, in developing countries, simple concrete foundations are often used for smaller installations and represent an appropriate solution, provided that static requirements are met.



Fixed Tilt single column MMS

A single supporting column concreted to the ground holds the entire MMS. Hence the rafters need to be supported like a grid from beneath and the entire rafter grid will have to be fastened to the column post.

Seasonal Tilt single column MMS

In seasonal tilt the only difference is that instead of fastening the rafter grid to column post, a semi-circular GI plate with holes are provided to fasten the rafter at multiple angles with column based on seasons.

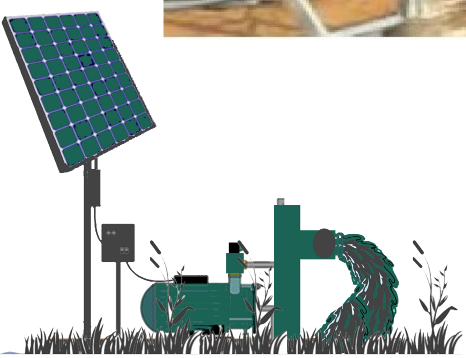
Usually, the seasonal tilting is done manually

Fixed Tilt multi column MMS

In multi-column MMS there is one column leg to support each rafter (or two column legs to support each rafter if the number of rows are higher). Since legs support individual rafters, rafters need not be interconnected as a grid. Purlins can be placed perpendicular to the rafters over it.

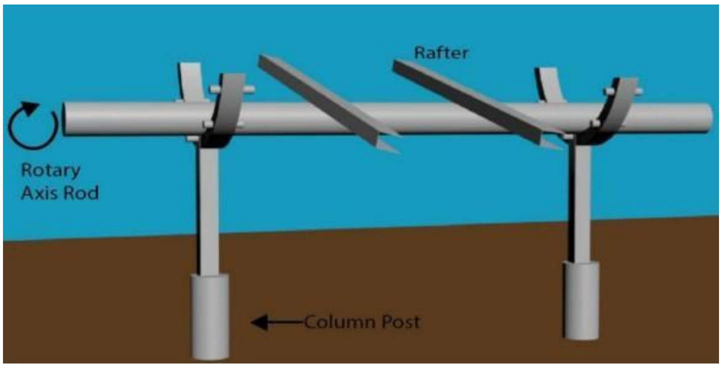
Seasonal tilt multi column MMS

In each rafter the seasonal tilt option is provided with a GI semi-circular plate with holes for specific angles.



Single Axis Tracker

These rotate the array in the east-west axis only, following the sun at a fixed angle of elevation from the time it rises in the east until it sets in the west. Installing a single-axis tracker for your solar PV array results in higher power output in the mornings and evenings. Decision to install tracker is purely economic based on the trade-off of additional energy available Vs cost of tracker.

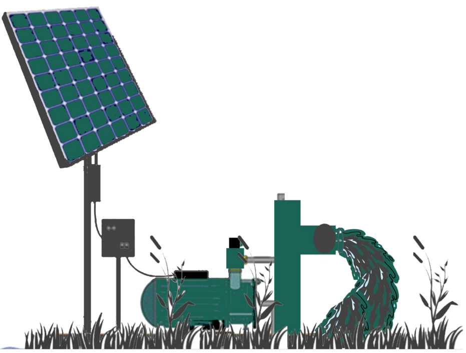


One of the single axis mechanisms

Double Axis Tracker

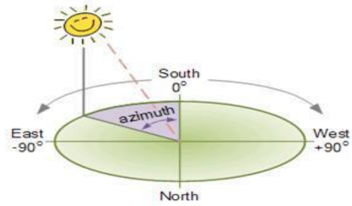
These rotate the array on an east-west axis and also can tilt it on a second axis in south-north direction, so that it is angled directly towards the sun at all parts of the day. The strength of dual-axis trackers is their ability to maximize energy production. A motor controlled by a programmed microcontroller, which actuates a pneumatic actuator that can move the entire rafter-purlin grid mounted on a single column, in both axes.

Since they have a higher degree of mechanical complexity, they are expensive and require more maintenance during their lifetime. Hence they are seldom used in Solar pump installations.



Azimuth Angle

The angle between true south and the point on the horizon directly below the sun. Azimuth angle of the solar module is an indicator of alignment of the module with respect to (true) south. For modules facing (true) south this angle is 0° and for module facing (true) north this angle is +/- 180

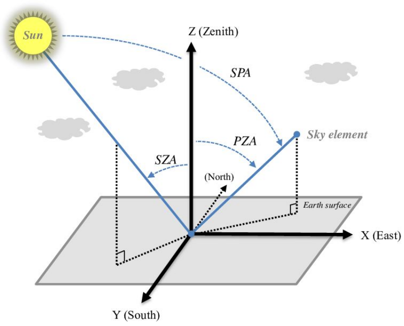


The sun's apparent location east and west of true south is called azimuth, which is measured in degrees in east or west of true south. Since there are 360° and 24 hours, sun appears to move 15° in azimuth each hour. When the sun is true south in the sky at 0 degrees azimuth, it will be at its highest altitude for that day. This time is called solar noon.

On fall and spring equinoxes, the sun rises at the due east of south and sets at the due west of south. Whereas in winter months it rises at the south of true east and sets at the south of true west; in summer months it appears to rise north of true east and set north of true west. In winter, the sun appears to be at its lowest in the southern sky. So, they must be tilted up from horizontal at an angle 15° greater than the latitude. Conversely, if a PV system is going to be used mostly in summer, where the sun will be highest in the southern sky, it may be most advantageous to optimize the performance of the panel by tilting it 15° less than the latitude.

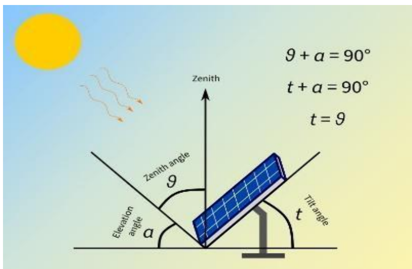
Zenith Angle

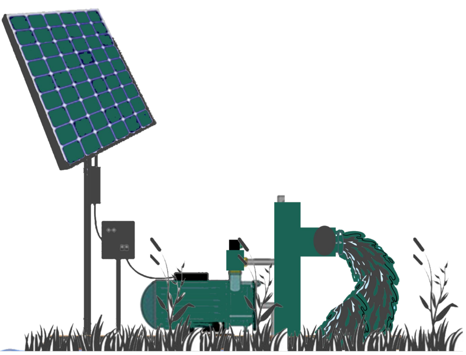
Zenith Angle is the angle between the sun's rays and the vertical. The Zenith angle is calculated based on the angle of incidence of the sun with the perpendicular line from the round surface. The zenith angle varies throughout the day.



Tilt Angle

Tilt Angle is also known as Elevation Angle is the angle between the horizontal ground and the solar panel. As the sun changes its position every hour due to the rotation of earth, there is no exact direction towards which the panels can always be faced. So, the system design should be in such a way that solar collection is optimised by positioning the array to take full advantage of the maximum amount of sunlight available at a particular region.





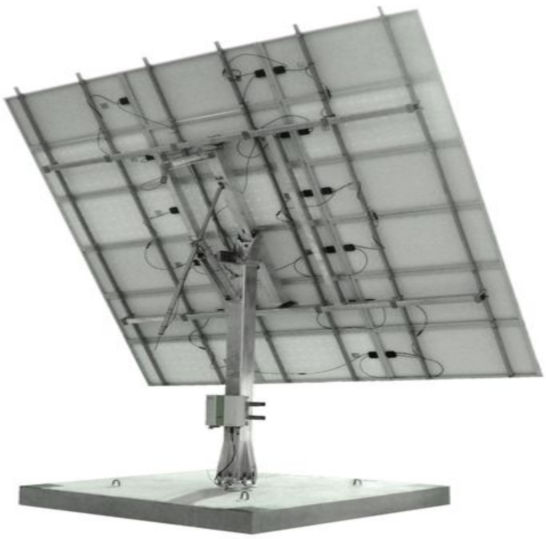
The panels need to be facing south since the installation is being done in the northern hemisphere. In case of the southern hemisphere, the solar modules should be installed facing the north direction.

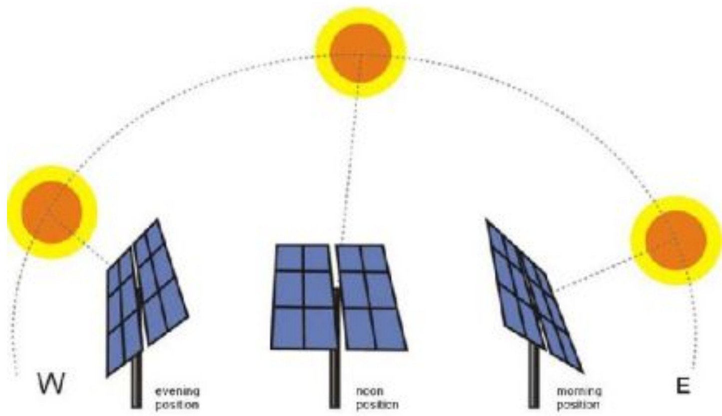
Due to the rotation of earth about the tilted axis, the sun appears at different altitudes above the horizon at solar-noon throughout the year. The latitude of the location tells us about the altitude at which the sun appears above the horizon. When the tilt angle or the angle at which the panels are elevated is equal to latitude, the insolation is optimized. In the northern hemisphere, the sun travels towards the southern sky.

In India, the tilt angle usually varies between 17° to 23°, based on the latitude of the installation location.

Trackers for solar panels *(Optional component)*

A solar tracker is a device that orients solar panels toward the Sun. Trackers are used to minimize the angle of incidence between the sunlight and a solar panel. The purpose of a tracking mechanism is to follow the Sun as it moves across the sky. The amount of solar energy available for collection from the direct beam is the amount of light intercepted by the panel. Or to put it in another way, the energy intercepted is equivalent to the area of the panel surface which receives perpendicular direct beams of sunlight.





Motor-Pump Set

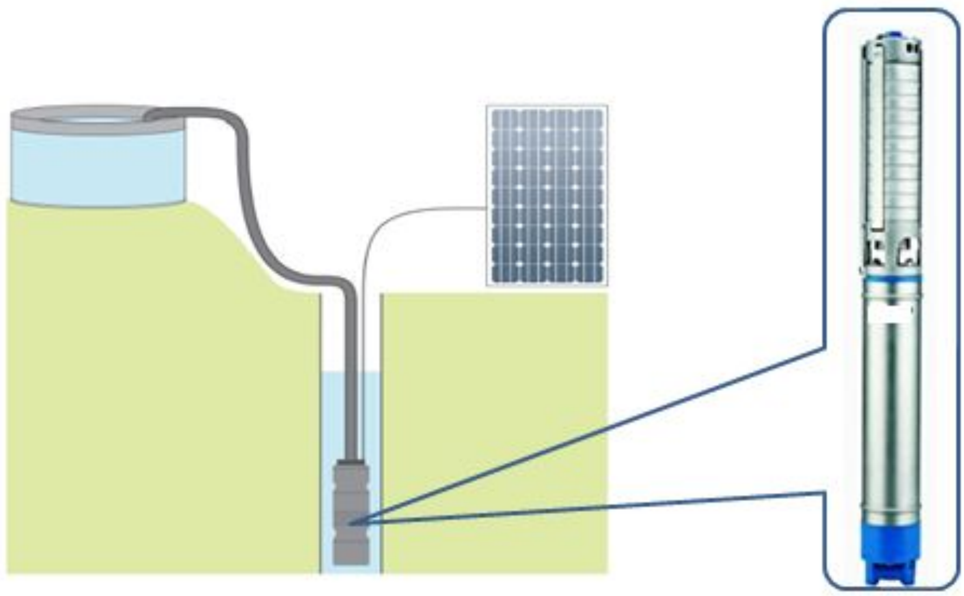
Water pumps are driven by electrical motors, which convert electrical energy (produced, in the case of solar pumps, by PV panels) into mechanical energy.

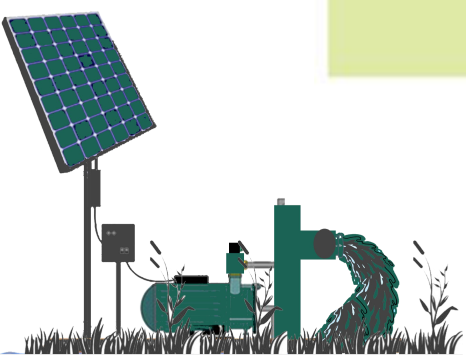
We can say that the pump is the heart of the Solar Pumping system. Primarily they are classified based on their placement (underwater and above the water). These pumps are surface and submersible pumps. These pumps can be further classified into categories depending upon the type of motor used in the pump. Most motors typically run on either direct current (DC), where the electrical flow does not switch direction periodically in the wires; or alternating current (AC), where it does. In solar pumping systems it is advisable to use the term 'Motor-Pump set' instead of calling it only pump or motor.

Based on various applications and parameters appropriate motor pump sets can be selected for the solar pumping system. But before studying these combinations it is important to understand the concepts which broadly classify the pumps and motors to avoid any confusion.

Submersible Pumps

A solar submersible pump is located deep below the ground level; whenever the suction head is beyond a depth of 10 metres. In a region where the water table keeps on dipping radically, installation of the submersible pump within the water table in a bore well is more practical. The pump remains submerged under the water.





The installation of a submersible pump often requires that a bore-well is dug which can be a costly undertaking but without which the water cannot be taken out. Sometimes, a submersible pump can also be located inside water bodies like lakes, canals, etc.

- Submersible pumps as their name portrays, are completely submerged in the water source.
- One important thing is the efficiency of submersible pumps as water pressure naturally forces water into a submerged pump rather than utilizing energy to do so.
- Being submerged all the time, submersible pumps do not require manual priming, which can easily become a very time consuming chore.
- Surface mounted pumps are also known to be much louder, and since it is on the surface, it just looks out of place

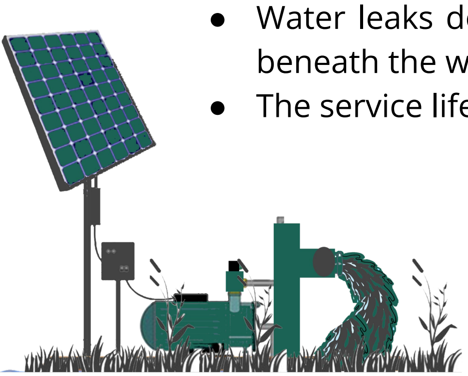
When the pump is immersed into the water, air won't be available around the motor to provide cooling. Therefore, oil and water are used as coolants.

Oil filled Motors

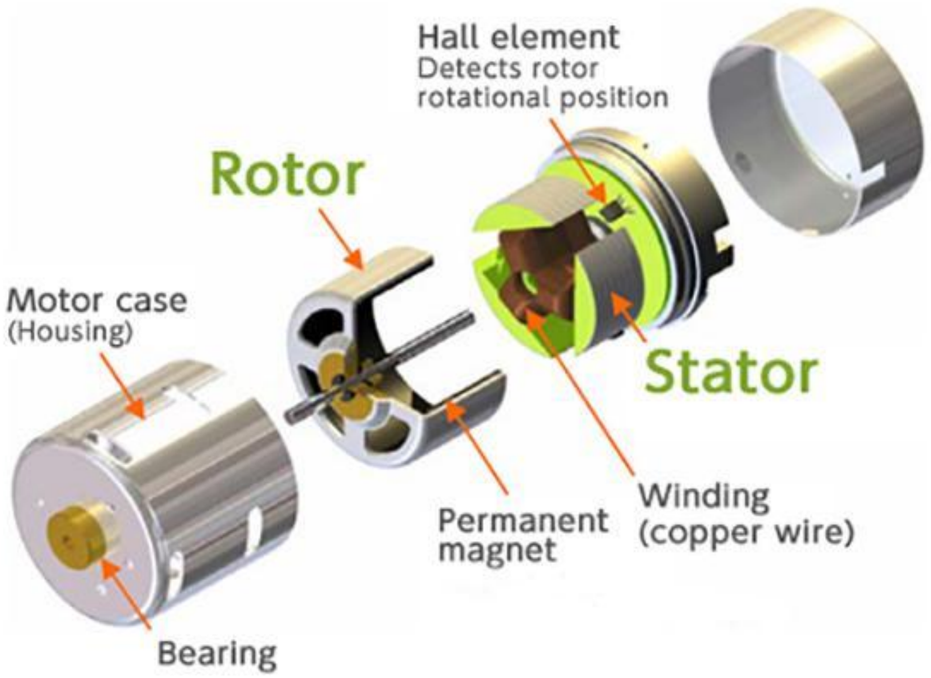
- Oil is served as a coolant in oil filled motors.
- Oil filled submersible pumps are mostly used in water lifting in wells, irrigation in farmland, hills, residential etc.
- These can be very advantageous if used in cool areas as oil cannot be frozen.
- They also have better lubricating conditions and give long service life.
- These are to be avoided where the quality of water pumped is important, as the oil may leak sometimes.

Water Filled Motors

- Water filled motors use water as cooling material and is mostly used in industrial, residential, farming etc.
- Water leaks do not pollute the water source and can be fixed for operating beneath the water.
- The service life of water filled pumps is shorter than oil filled pumps.

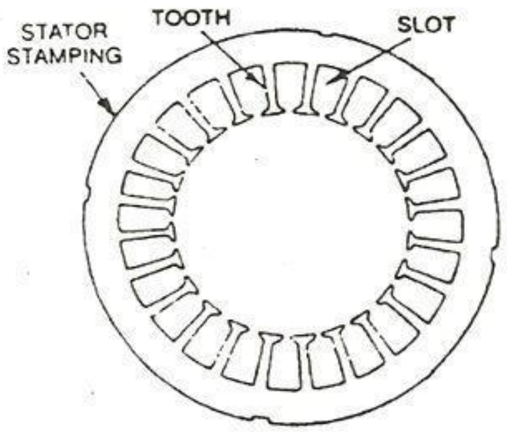


Components of Submersible Pumps



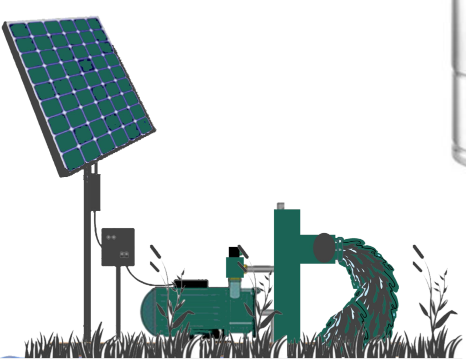
1. Stator

In a submersible pump, the stator is a stainless steel cylindrical metal tube with stampings on the internal side acting as the outer frame. The main function is to carry an alternating magnetic field. Slots are punched on the inner side of the stampings. The stator is wound with either single phase or three phase coil windings. When power is supplied through the stator, it generates a magnetic field around the stator to drive the rotor.



2. Rotor

The rotor is the rotating electrical component; consisting of a group of electromagnets aligned around a cylinder with the poles facing towards the stator poles. The rotor is located within the stator and is mounted to the motor's shaft, which is connected to the pump shaft.



3. Air gap

The space between the rotor magnets and stator magnets is called the *air gap*. The air gap is an annular space to permit the magnetic lines of force to transmit back and forth between the rotor and stator. The air gap is maintained on both ends of the rotor by an inboard bearing and outboard bearing.

4. Bearings

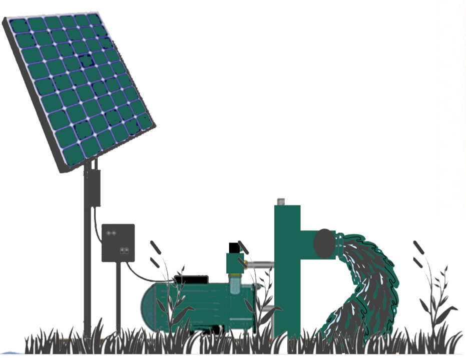
The function of the bearing is to reduce friction between the moving parts and allow smoother rotation, reducing the energy consumption. Submersible pumps use thrust bearings instead of ball and roller bearings. There are no moving parts within the bearing, so if the motor is controlled correctly there are fewer risks of parts failure. They transmit the rotating shaft's axial load to the frame of the motor.

5. Seals

Mechanical seals improve the efficiency of submersible pumps. In a submersible pump, the motor is hermetically sealed and close-coupled onto the pump body. It protects the bearings and the motor with a vertical shaft that is submerged in the pumped liquid. Water and oil seals are also used for submersible pumps.

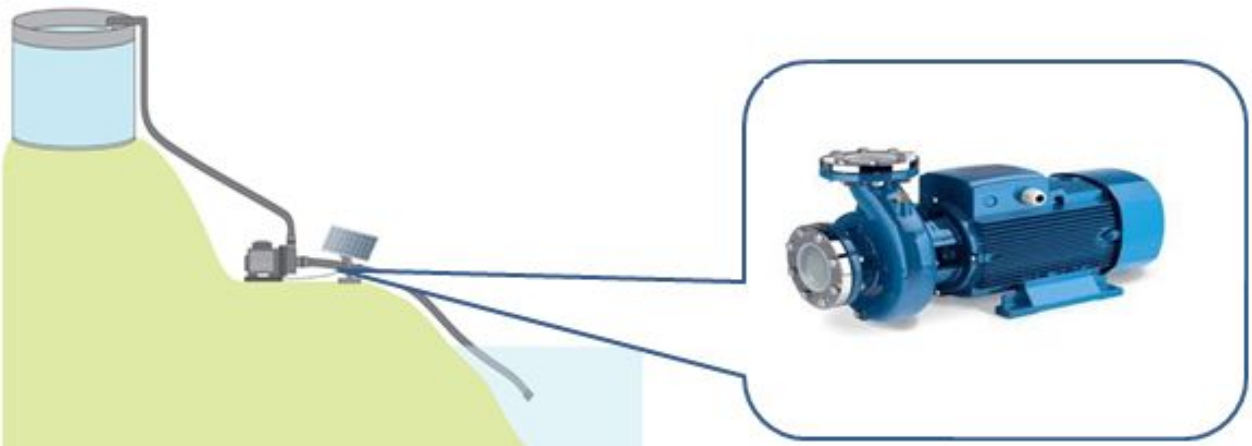
6. Impellers

An impeller is a rotating iron or steel disc with vanes that transfer energy from the motor that drives the pump to the fluid being pumped by accelerating the fluid radially outwards from the centre of rotation. Submersible pumps are multistage pumps, where a series of impellers are connected to the rotating shaft which is driven by the motor.



The water is pulled in through the intake, and as it enters the eye of the impeller, they are thrown out due to the action due to centrifugal force. As a result, water gains both kinetic and pressure energy. The water is carried to the next impeller efficiently with the help of a stationary device called a diffuser, connected right next to the impeller. The diffuser deflects the impeller water and makes it ready for the next impeller stage. This series connection of impellers multiplies the pressure. This is why submersible pumps can pump water to greater heights.

Surface Pumps

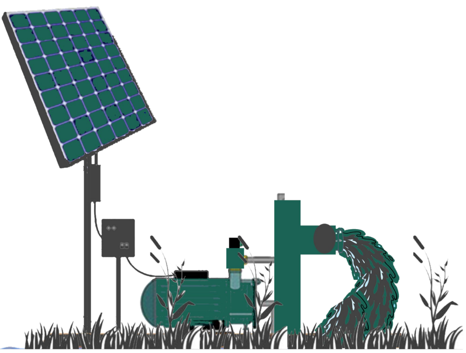


A surface pump is located in the open by the side of a water source, for example an open well, lake or canal. The pump remains out of the water, and generally the motor and the pump can be seen separately. Surface pumps are usually easy to install and maintain.

Surface pumps can also be feasible options in cases where the water table is within a depth of up to 10 meters and an open well is available.

These pumps are not they're not situated in the water, meaning they are very easily accessible if anything were to fail or need replacing. The pumps are usually contained within a pump housing to protect them from the elements. The pumps have filter baskets and an inspection cover.

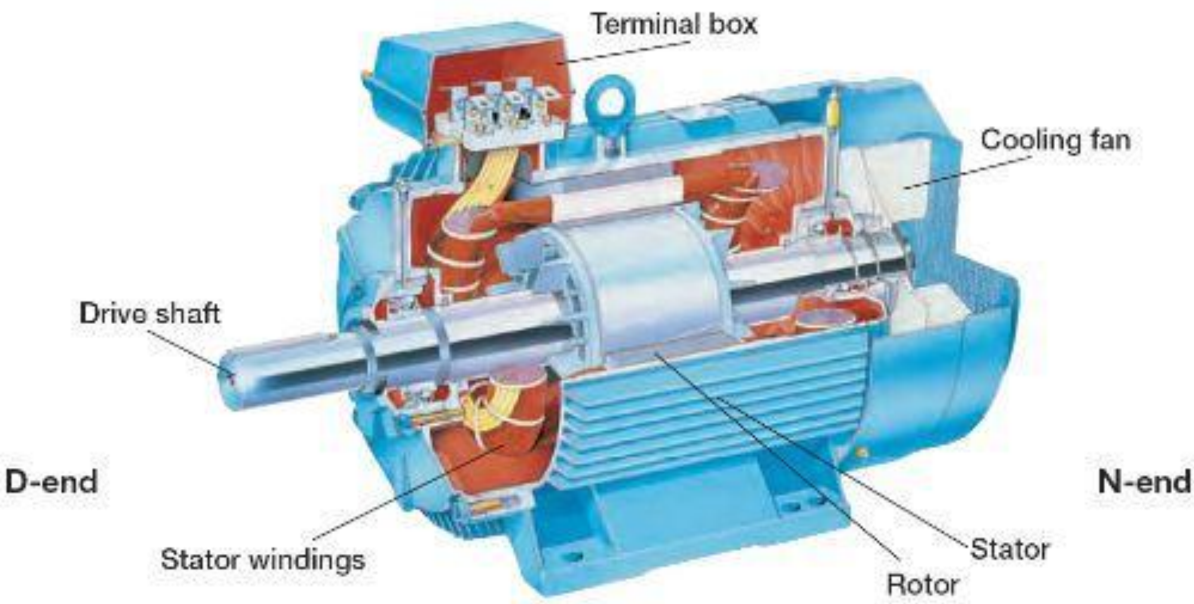
Solar water pumping is becoming increasingly relevant in many applications, especially for livestock watering, drip irrigation, remote houses and where water is needed but no AC power is available. Pumping from remote bores or dams can become very expensive using generators, and the cost of running power lines is sometimes not feasible. In such situations, solar power is ideal comparing to diesel generators.

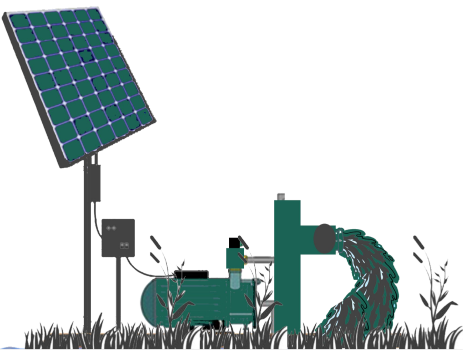


- Allows easy access to the pump itself, but because of the environment, they may require access more often. Winter storms can really affect the productivity and results of a surface pump because it is not below the freezing line, which can cause trapped water to expand inside the pump which could lead to several problems like freezing.
- Flash floods, wildlife, and thunderstorms can also be a great risk because surface mounted pumps are not as shielded from their surroundings, unlike submersible pumps.

- Another disadvantage is the amount of energy surface pumps use; the water must first be moved up out of a water source by a suction force before it can actually reach the pump, this process requires a lot more power than an apparatus that already has the water readily available.

Components of Surface Pumps

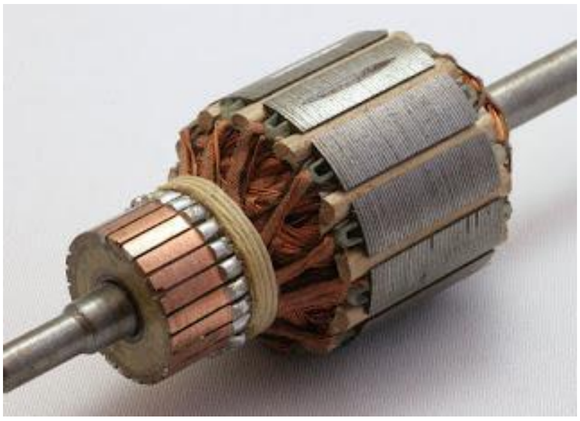




1. Stator / Armature Coil

The stator is composed of iron plates wrapped by copper winding located around the main axis. This copper is connected to a current source. The function of the stator is to generate a magnetic field around the rotor. When the current is passed through the winding, a magnetic force is induced in the stator. A motor generally has three stator coils. The more the number of coils, the greater the magnetism generated, and faster the pump rotates and faster water is pumped out. For simple electric motors, the stator is replaced using a permanent magnet.

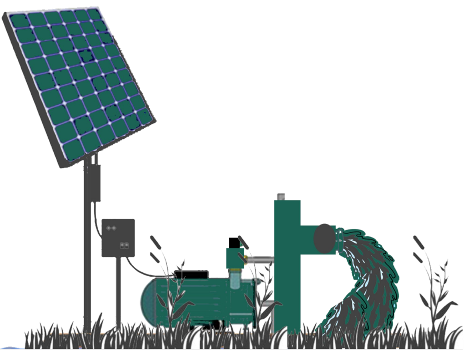
2. Rotor Coil



Rotor resembles a stator, except that the rotor is a dynamic copper wire as the coil is attached with the main shaft or main axle of the motor that will rotate. The more the number of turns on the rotor the greater the resulting spin. Commonly, a chopper with a small diameter. It aims to make the number of windings more even if it requires a large wire length. The wound end will be connected to another rotor located at the end of the main shaft.

3. Main Shaft

The main shaft is a rust-proof, durable and temperature resistant aluminium rod that extends to provide attachment for the rotor coil and a drive pulley.



4.Brush

A copper brush connects the current source with a coil rotor. This brush is attached to a small rotor located at the end of the main shaft. The flow of current is maintained in the same direction using the brushes, even though the rotor rotates, thus the rotation is synchronous and continuous. The structure is supported by a spring located behind the copper brush, which ensures it always hits the brush even when spinning at high speed. A simple electric motor should be equipped with two brushes. The brushes need to be checked regularly for wear and tear, and replaced during servicing if required.

5 . Bearing

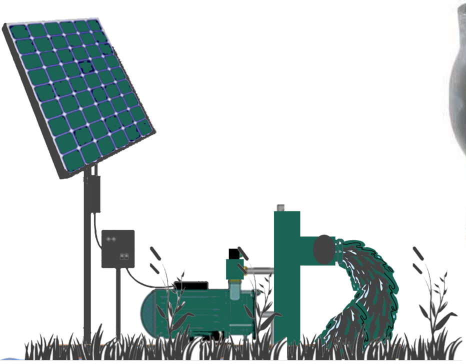
The function of the bearing is to produce rotation. A bearing between the shaft surface and the motor housing reduces friction and ensures free movement. Bearings are generally made from aluminum, which has less friction and does not inhibit motor rotation.

6 . Pulley Drive

The pulley drive is located at the outer end of the main shaft, and transfers motor rotation to other components. This acts like a gear, conducting the rotation through the pump.

7 . Motor Housing

The electric motor is covered by an iron plate that protects the parts of the electric motor. In addition, motor housing also controls the trembling effect of the motor which is rotating at very high speed.



Classification of pump-motor set based on current

AC Pumps and Motors

An AC pump has a motor which operates on alternating current (AC). Direct current generated by solar panels or batteries is converted to AC by an inverter-cum-controller, and is then passed on to the AC pump motor. The conversion from DC to AC leads to small losses in power between the points of generation and consumption.

Advantages

- Low upfront cost compared to DC pumps.
- Easy to set up, installation and availability of maintenance and repair services locally.

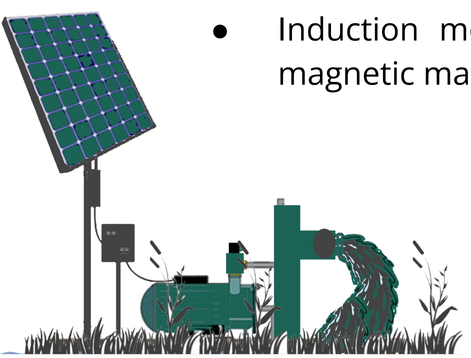
Disadvantages

- Low efficiency and water output compared with a DC pump.
- Additional inverter is required.

An AC electric motor is a type of electric motor operating with an alternating current (AC) voltage source. This AC electric motor can be distinguished by its resources as follows:

- Synchronous motor, is an AC motor working at a fixed speed at a certain frequency system. This motor has a low initial torque, and therefore synchronous motors are suitable for low-load initial use, such as air compressors, frequency changes and motor generators. Synchronous motors are able to improve the system power factor, so it is often used on systems that use a lot of electricity.

- Induction motor is an AC powered motor that works based on induction magnetic material between rotor and stator.



DC Pumps and Motors

A DC Pump has a motor which operates on direct current (DC). Solar Panels generate DC current, which is then passed on to the DC pump motor through a controller. Since the current from solar panels or batteries is directly used, and no conversion to AC is required, there is no/little loss of power between generation and consumption. However, it should be noted that the current should not have to travel a long distance before being fed to the pump in order to minimize the losses.

Advantages

- Approximately 10% higher water discharge as compared to an AC pump.
- No need for an inverter between the solar PV panels and the pump

Disadvantages

- High upfront costs.
- Lack of repair and maintenance services in rural and remote locations.

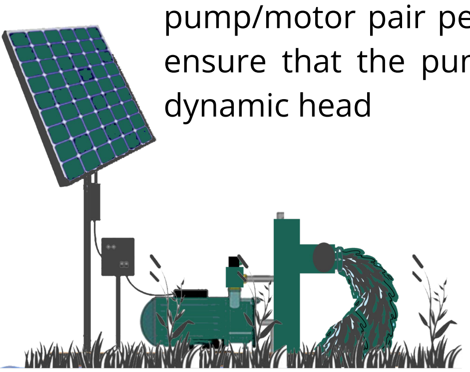
Direct current electric motor is a type of electric motor that operates with a direct current DC voltage source (DC). DC motors can be distinguished again based on the following resources.

- Separately Excited Motor is a type of DC motor where the field current source is supplied from a separate source other than the electric motor coil, so the DC electric motor is called a separate DC power source (separately excited).

- Self Excited motor is a type of DC motor where the field current source is supplied from the same source as the electric motor coil, so the DC electric motor is called a self-excited DC power motor.

DC motors are appealing for solar pumping because PV modules producing direct current can be directly coupled to the motor with limited power conditioning. This makes them an economical option for systems with low water demand and a short cable distance between the PV panel array and the motor. For long-distance cabling, however, low-voltage DC motors are not suitable because of power loss in the cable. AC motors can be used in larger solar pumping systems, although they require a DC/AC inverter.

The most suitable pump and motor type for any situation should be determined based on manufacturers' catalogues and motor pump manuals, and specifically on pump/motor pair performance curves (characterized to the IEC 62253 standard) to ensure that the pump/motor pair can deliver the required flow against the total dynamic head



Standalone (off-grid) and Grid-connected (on-grid) solar pumps

Standalone pumps are not connected to the main electrical grid, and the pump completely runs on the energy harnessed from the solar panels connected to the pump. A battery might be used to store the energy generated and pump out the water when sunlight is not available.

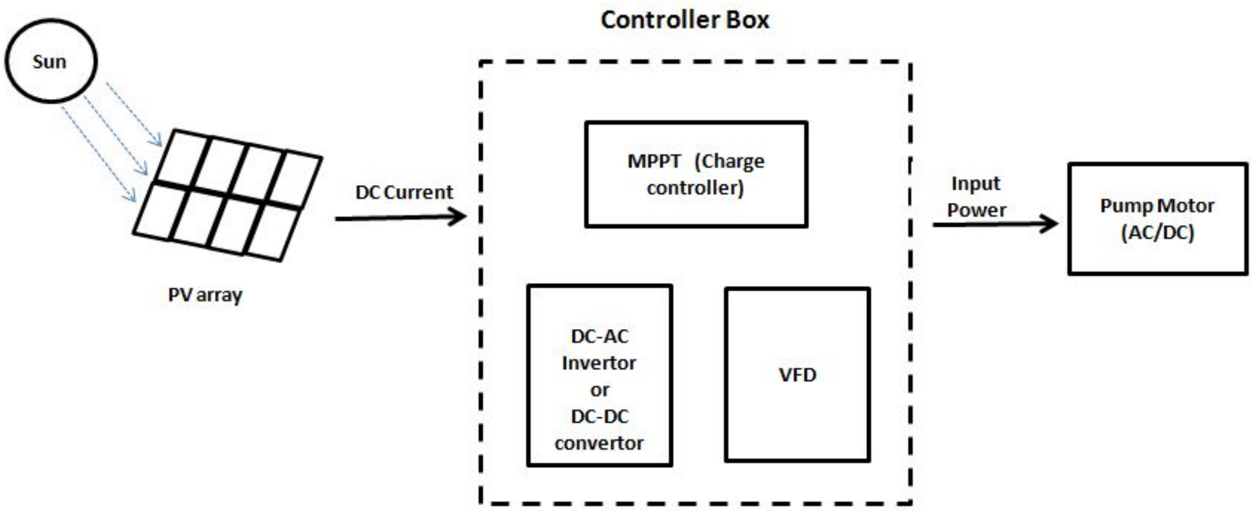
Grid connected solar pumps are becoming popular gradually. Here, the pump can switch it's source of power from solar energy to grid connected electricity in the absence of sunlight. Also, excess energy produced by the solar panels during the day can be directed to the grid, which is sold and acts as a source of extra income for the pump owners.

Pump Controller

Solar pump controller is a device installed between the panels and the pump that allows the solar pump to regulate the intermittent sunshine to provide desired output. The controller box contains the pump controller as well as various electronic components, which provide electronic protection against dry run operation, over and under voltage, short circuit and reverse polarity. The electronics normally include an inverter, power conditioner or pump controller, controls/protections and water sensors.

The main function of the pump controller are:

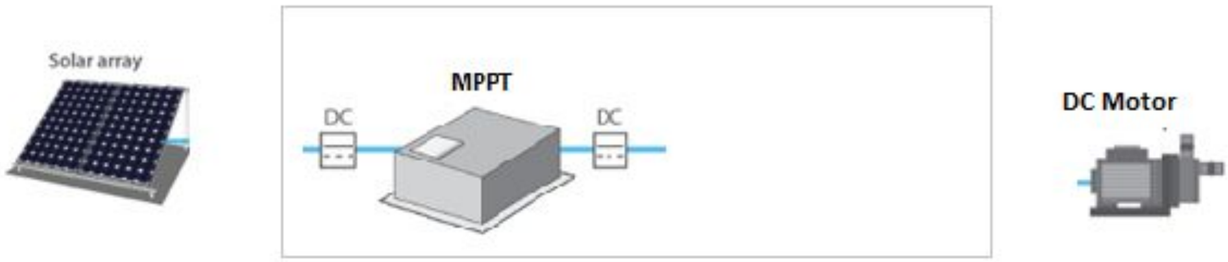
1. to match the output power that the pump receives with the input power available from the solar panels.
2. to protect the pump against various faults which may damage the pump, thus increasing its lifetime and reducing the need for maintenance.
3. to control the water level sensor and remote monitoring system.

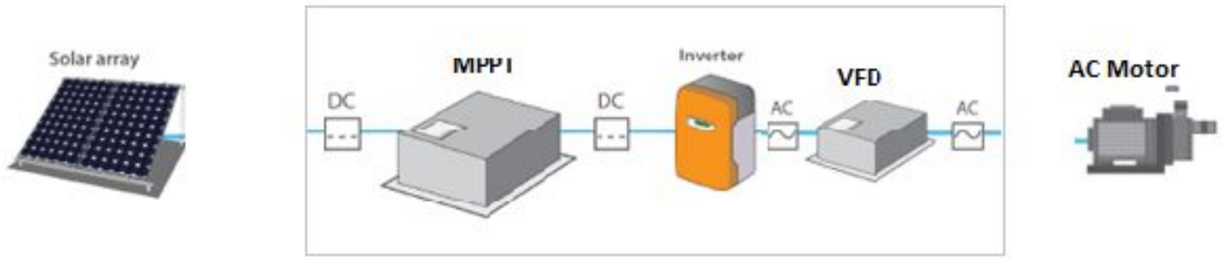


Input voltage of the solar pump motors can be AC (alternating current) or DC (direct current). If an AC pump is used, the direct current from the solar panels is converted into alternating current using an inverter. The supported power range of inverters can be adjusted according to size of irrigation systems. However, the panel and inverters must be sized accordingly to accommodate the inrush characteristic of an AC motor.

The "pump controller" in the DC powered pump system would typically include a maximum power point tracker (MPPT) to ensure that the solar array is delivering power at its peak power point. The "pump controller" in the AC powered pump system would include an MPPT as well as a DC to AC inverter in order to operate the ac electric motor which is part of the water pump. In larger systems these should be three-phase inverters to operate three-phase motors.

A DC-DC Convertor is used to match the voltage output from the solar PV modules with that of the voltage required for operating the pump, preventing overvoltage.





The inverter and controller must have IP54 protection or must be housed in a cabinet having IP54 protection to protect the controller from dust and water.

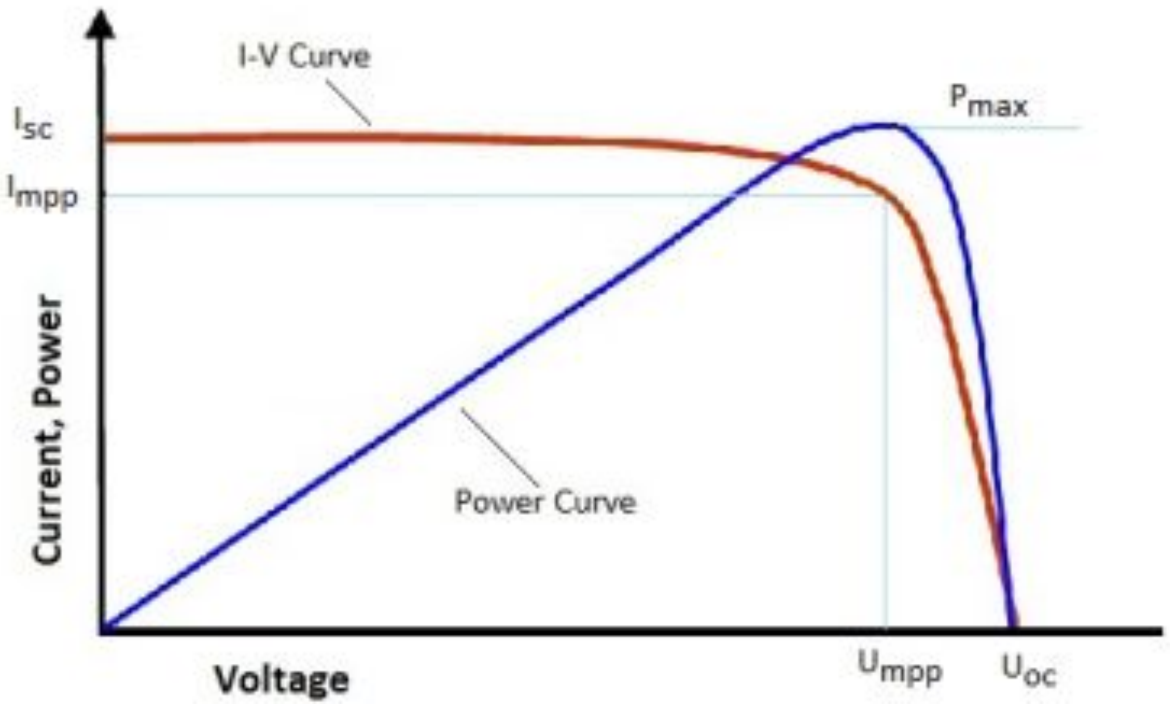
Hybrid controllers are used sometimes too, when grid connected solar pumps are used. These controllers switch between solar power and prid power intelligently.

The following Parameters are noted in the controller by the manufacturer

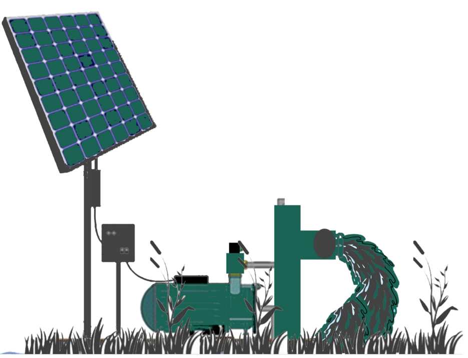
- Manufacturer's name, logo or trade-mark;
- Model and Serial Number;
- Voltage Range;
- Power Range in kW for Controller; and
- Current rating (A)

Maximum Power Point Tracker (MPPT)

The output of the Solar panel is variable as it depends on the temperature and irradiance. The MPPT charge controller is a smart device that compares the panel output with the pump voltage and then determines the most optimum panel output in order to maximize the water output. The use of these solar charge controllers increases the efficiency of the whole system. The MPPT tracks the I_{mpp} and V_{mpp} every 5 seconds and forces the PV modules to operate at those voltages to get the maximum power output.



The pump rotational speed can be regulated according to the variation of solar irradiation: When the solar radiation intensity reaches the peak, the pump runs at its rated speed, and the output power is close to the maximum power of the PV array. When the solar radiation intensity is relatively weak, the pump runs with a lower speed based on the MPPT algorithm. When the pump speed is so low that no water flow can be available, the system stops working.



Variable Frequency Drive (VFD)

A solar pump controller matches the variable power provided by the solar array. Variable speed control ensures there is no in-rush or surge of energy during the pump/motor start-up, helping to eliminate wear on the motor and pumping system.

Normally, when there is a demand for water and when solar power is available. Whenever the solar pump controller detects a need for water, the controller always "ramps up" the motor speed while gradually increasing motor voltage, resulting in a cooler motor and lower start-up current compared to conventional water systems. Due to the controller's soft-start feature this will not harm the motor. VFD provides constant torque for a wide range of intensity of sunlight - morning till evening. So water will be continuously pumped from morning till evening.

The VFD basically changes the frequency of the system. For a constant frequency, the voltage is also constant. So, if the frequency of the system reduces then the voltage needs to be reduced subsequently as well. The frequency is generally noted in Rotations per Minute or RPM.

In case 3 phase connection is used, VFD is needed as the starting torque is high and the initial voltage needs to be controlled. For single phase connection (for 1 or 2 HP pumps), VFD is not required, instead capacitor is used. In a single phase connection, all the connections need to be disconnected together to prevent oversupply.

Advantages of using a VFD

Reduce energy consumption

A VFD with variable torque load can be used in water pumps to reduce the input energy requirement. As described by the affinity law, the power consumption of the pump can drop significantly with a small drop in the speed of the motor. Provided that the flowrate is acceptable, running a pump at a lower speed over a long period of time can deliver considerable energy saving. The VFD can reduce the operating speed of the motor, allowing a smaller PV array to be installed to deliver the pumping requirement.
The ability of the VFD to control pump operation also means that in case of cloudy conditions or times of reduced solar irradiation, the motor could still run to deliver pumping work.

Reducing surge current at motor start-up

VFD can provide a reduced starting voltage to the motor windings, thus reducing the starting current of the motor and giving it time to gain momentum before the full load is supplied with power. The VFD also allows the user to start and stop the pump at a controlled, programmable rate (e.g. accelerate or decelerate over a time period) while putting minimum strain on the motor. This reduces the mechanical wear of the motor as well as the startup loads on the PV array.

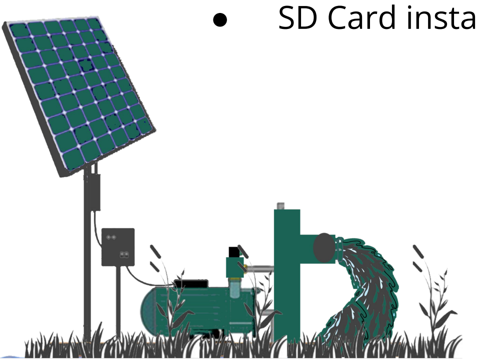
Remote Monitoring System

Remote monitoring system or RMS is installed in the pump controller to record the electricity generated by the solar modules etc and sends it directly online, which is used to monitor the system performance of the solar modules and the pump.

The RMS is placed in the controller box and connected to the pump controller through the wires.

The data can be collected through various methods:

- A recharged SIM card inserted in the RMS
- USB drive inserted in the RMS
- SD Card installed in the RMS



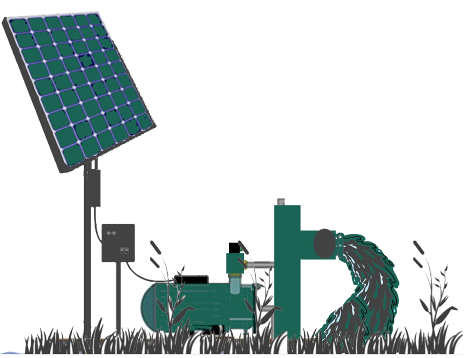
Inverter

Solar generators always provide DC current. Most electric motors of solar water pumps are powered by direct current (DC). Since DC motors usually have a higher efficiency than AC motors of a similar size, they tend to be preferred by solar pump manufacturers

A power inverter or inverter is a system that converts Direct Current (or DC) to an alternating current (or AC). A solar panel produces DC current, batteries also generate DC current, but most systems we use in our daily lives use AC current. Inverters also have transformers to convert DC output voltage to any AC output voltage. Depending on the type of system (grid or off-grid) various types of inverters are available.

Water-filled brushless DC motors in particular are gaining importance because they are maintenance-free and are not affected by frequent starts/stops that are typical of solar-powered systems. Some solar pumps are still equipped with comparably cheap brushed DC motors. The main disadvantage of brushed motors is that brushes are subject to wear and tear and need to be replaced at regular intervals (approximately every two years). DC motors are mainly used for small to medium-sized irrigation schemes, while AC motors are gaining importance in applications where higher output/head combinations are required.

The controller has to have an inverter if the pump is AC. Innovations in DC/AC inverter technology have led to the development of specially designed pump inverters that can drive conventional AC motors. Non-compatible inverter/motor combinations may reduce the expected lifetime of the conventional AC motor. Therefore, well matched and tested controller/motor combinations are recommended to increase system reliability.



Types of Solar Pump Inverters

String Inverters

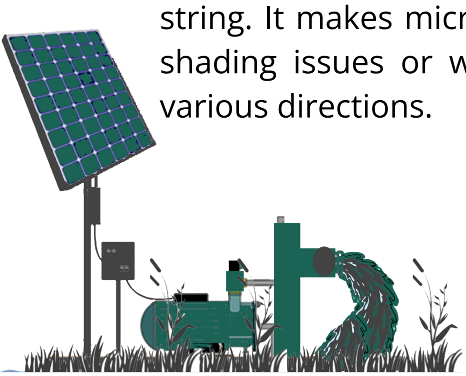
Solar panels are installed in rows, each on a string. And multiple strings are connected to one string inverter. Each string carries the DC power the solar panels produce to the string inverter where it is converted into usable AC power consumed as electricity. And based on the size of the installation, you may have several string inverters each receiving DC from a few strings.

Central Inverters

They are similar to string inverters but they are much larger and are able to support more strings of panels. Instead of string running directly to the inverter, as with string models, the string is connected together in a common combiner box, which runs the DC power to the central inverter where it is the converter to AC power. It requires fewer component connections, but requires a pad and combiner box. And central inverters are also best suited for large installations with consistent production across the array.

Micro Inverters

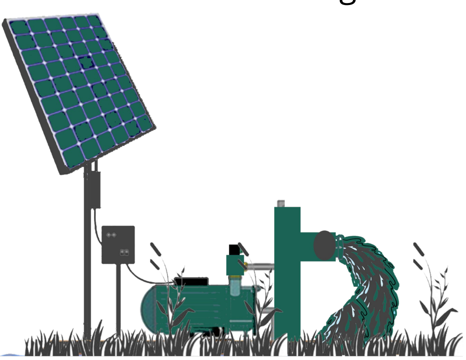
They have also become a popular choice for residential and commercial installations. Like power optimizers, they are module-level electronics so one is installed on each panel. And while, unlike power optimizers which don't convert, micro inverters convert DC power to AC right at the panel and so don't require a string inverter. It also monitors the performance of each individual panel, although string inverters show the performance of each string. It makes micro inverters good for installations with shading issues or with panels on multiple panels facing various directions.



Battery Based Inverter

With the growth of solar and storage, battery-based inverters are becoming increasingly imperative. They are basically directional in nature, including both a battery charger and an inverter. It requires a battery to operate. They may be ground interactive, standalone grid-tied or off-grid, based on their UL rating and design. The main benefit of the inverter is that they provide for continuous operation or critical loads irrespective of the presence or condition of the grid.

1. **Stand-alone inverters,** used in isolated systems where the inverter draws its DC energy from batteries charged by photovoltaic arrays. Many stand-alone inverters also incorporate integral battery chargers to replenish the battery from an AC source, when available. Normally these do not interface in any way with the utility grid, and as such, are not required to have anti-islanding protection.
2. **Grid-tie inverters**, which match phase with a utility-supplied sine wave. Grid-tie inverters are designed to shut down automatically upon loss of utility supply, for safety reasons. They do not provide backup power during utility outages.
3. **Battery backup inverters** are special inverters which are designed to draw energy from a battery, manage the battery charge via an onboard charger, and export excess energy to the utility grid. These inverters are capable of supplying AC energy to selected loads during a utility outage, and are required to have anti-islanding protection.
4. **Intelligent hybrid inverters**, manage photovoltaic arrays, battery storage and utility grid, which are all coupled directly to the unit. These modern all-in-one systems are usually highly versatile and can be used for grid-tie, stand-alone or backup applications but their primary function is self-consumption with the use of storage.



Sizing of Inverter

Sizing of the inverter depends on the wattage of appliances connected to it. The input rating of the inverter should never be lower than the total wattages of the appliances. Also it should have the same nominal input voltage as that of the battery setup. It is always better to have inverter wattage about 20-25% more than that of the appliances connected. This is specifically essential if the appliances connected have compressors or motors (like AC, refrigerator, pumps, etc), which draw high starting current. The minimum continuous watt rating of a solar water pump inverter is required to start off a submersible water pump without additional loads.

Most inverters available in the market are rated in Kilo Volt Ampere/Volt Ampere or kVA/VA.

In ideal situations, (power factor of 1) 1 VA = 1 Watt.
But in real power factor it varies from 0.85 to 0.99.
So one can assume 1.18 VA = 1 Watt.
So if you have a setup where the total wattage of the system = 1000 Watts

It means your inverter size required is more than 1180 VA or 1.18 kVA (add some extra to be on a safer side).

The higher the VA of an inverter, more is the number of appliances it can support, but more costly it would be. So it is important to size it right while buying. Also for a grid-tied system, as there are no batteries connected, the size or VA of the inverter should match the wattage of the PV panel for efficient and safe operation.

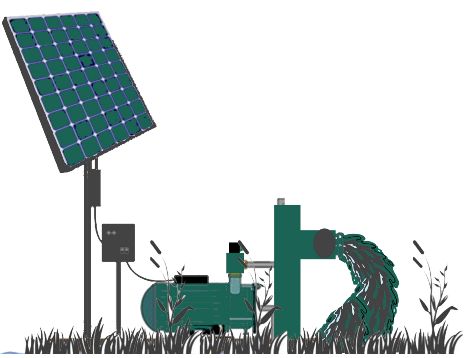
Battery

During optimum sunlight periods (late morning to late afternoon on bright sunny days) the pump operates at or near 100 percent efficiency with maximum water flow. However, during early morning and late afternoon, pump efficiency may drop by as much as 25% or more under these low-light conditions. During cloudy days, pump efficiency will drop off even more.

Batteries can be used to store excess electrical energy produced during the peak sunlight hours and used during the non-peak hours and night to pump out water. The excess energy from the solar panels can be used to charge the battery, and used for running a small appliance like light or charging.

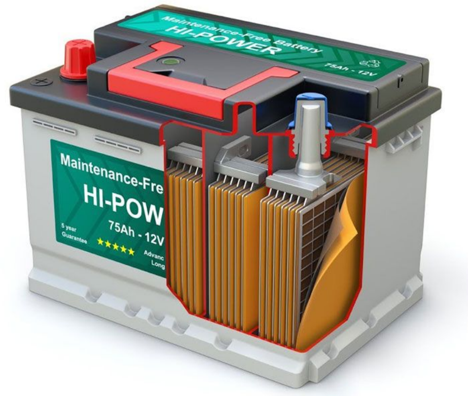
In a battery, two or more electrochemical cells enclosed in a container and electrically interconnected in an appropriate series/parallel arrangement to provide the required operating voltage and current levels. The battery capacity is the maximum total electrical charge, expressed in ampere-hours, which a battery can deliver to a load under a specific set of conditions. The battery available capacity is defined as the total maximum charge, expressed in ampere-hours, that can be withdrawn from a cell or battery under a specific set of operating conditions including discharge rate, temperature, initial state of charge, age, and cut-off voltage. The period during which a cell or battery is capable of operating above a specified capacity or efficiency performance level is known as battery life. Life may be measured in cycles and/or years, depending on the type of service for which the cell or battery is intended.

DC produced by solar panels can be connected either directly to batteries or through solar hybrid inverters. This system includes solar modules, inverters and batteries.



Types of Batteries used in Solar Pump

Lead Acid



The common automobile batteries in which the electrodes are grids of metallic lead-containing lead oxides that change in composition during charging and discharging. The electrolyte is diluted sulfuric acid. The new AGM Battery technology has made a huge impact on lead-acid batteries, making it one of the best batteries to use in solar electric systems.

Industrial-type batteries can last as long as 20 years with moderate care, and even standard deep cycle batteries, such as the golf car type, should last 3-5 years. Intermediate batteries, such as the S460 and other batteries made by Surrette should last 7 to 12 years.

Lithium Ion Based

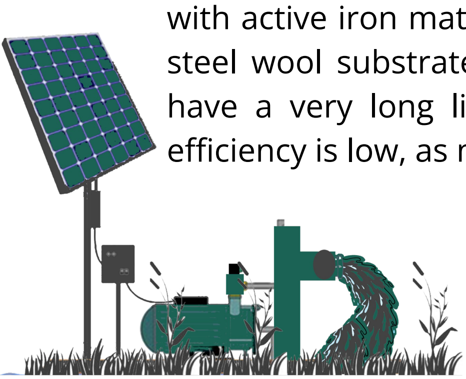
Lithium batteries have many advantages over traditional battery types. They have an extremely long cycle life and high discharge and recharge rates.

Nickel Cadmium

They are alkaline storage batteries in which the positive active material is nickel oxide and the negative contains cadmium. They are very expensive, and even more expensive to dispose of. Their efficiency is 65-80%.

Nickel Iron

Alkaline-type electric cells using potassium hydroxide as the electrolyte and anodes of steel wool substrate with active iron material and cathodes of nickel plated steel wool substrate with active nickel material. They have a very long life, over 10 years, however, their efficiency is low, as much as 50%.



Sizing of PV System Batteries

If you are not going for a grid connected system or a direct connected system, you need batteries to store the energy generated using PV panels. Along with sizing of the PV panel, it is important to size the batteries as well. Because if you purchase more batteries then they will not get fully charged, if you buy fewer batteries, you may not be able to get the maximum benefit out of the solar panel.

Most big PV systems use deep cycle (or deep discharge) batteries that are designed to discharge to low energy levels and also to recharge rapidly. These are typically lead acid batteries that may or may not require maintenance.

Batteries have energy storage ratings mentioned in Amp-hour (Ah) or milli-Amp-hour (mAh). They also have a nominal voltage that they generate (typically deep discharge batteries are 12V batteries). To calculate the total energy a battery can store you can use following formula:

$$\text{Units or kWh} = (\text{Volt} \times \text{Ah}) \div 1000 \text{ or } (\text{Volt} \times \text{mAh}) \div 1000000$$

Batteries should be sized in such a way that the units of energy generated by the PV system should be equal to the number we have calculated above.

Now, you want the battery bank to last three days without recharging and that you use 0.6 kWh per day.

Energy we need from the batteries = 0.6 x 3 = 1.8 kWh

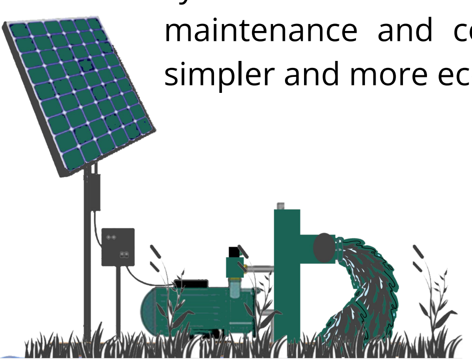
Converting this to Ah we have to divide by the voltage of your system, which can be 12, 24 or 48 V for commercial application.

If we choose to use 48V,

the minimum AH capacity = 1800/48 = 37.5 Ah

Now if you divide by your battery's rating you find the number of batteries you must use.

Batteries are usually not recommended for solar-powered livestock watering systems because they reduce the overall efficiency of the system and add to the maintenance and cost. Instead of storing electricity in batteries, it is generally simpler and more economical to install 3 to 10 days' worth of water storage.



C10 Solar Battery

Let us just take an example of 150 Ah battery

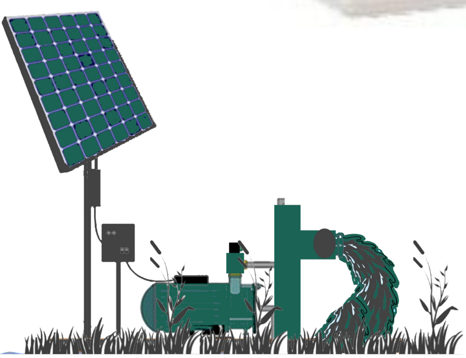
- A 150 Ah battery at C20, will last for 20 hours on a load of 7.5 A.
- A 150 Ah battery at C10 will last for 10 hours on a load of 15 A.
- A 150 Ah battery at C5 will last for 5 hours at a load of 30 A.

C5, C10, C20 all mean the same meaning if it is rated as 150Ah. All batteries are able to supply 150 Amps for 1 hour or 1 Ampere for 150 hours. It should follow the simple rule:

x(hours) × y(Amperes) = 150 if it is mentioned as 150Ah.

The difference is only in the state of charge.
1. A C5 battery means it should not be discharged within 5 hours otherwise the battery life decreases
2. A C10 battery means it should not be discharged within 10 hours otherwise the battery life decreases
3. A C20 battery means it should not be discharged within 20 hours otherwise the battery life decreases

Simply, it means capacity of battery if any battery is rated 12V, 40Ah and C10, it means 10 hours of 4A charging and discharging rate. If the rating changes to C20, then 20 hours of 2A charging and discharging rate is being followed.



Earthing components

Earthing is to ensure safety or protection of electrical equipment and humans by discharging the excess or leaking electrical energy to the earth. The purpose of earthing is to minimize risk of receiving an electric shock if touching metal parts when a fault is present.

The earth rods are inter-connected to structure and lightning arrestor via earth plates. Earthing can be accomplished through bonding of a metallic system to earth. It is normally achieved by inserting ground rods or other electrodes deep inside earth. Normally charcoal and salt are added in earth pits with the rods to improve conductivity. To achieve the required driving depth – the rod couplers provide permanent electrical conductivity and the longer copper earth rods access lower resistivity soils at lower depths.

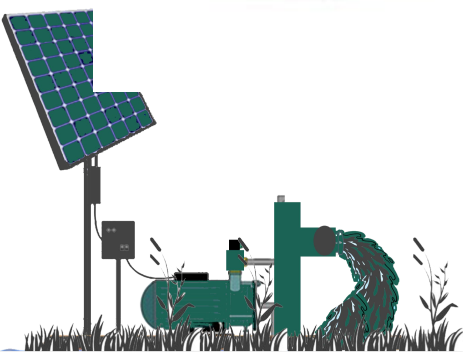
The earthing rod is a 17 cm long structure of 1.5 mm diameter, made generally of copper. In case of a pipe earthing, the earthing rod is a GI rod of 30 mm diameter and 2.5 m length.

Earthing Compound

Earthing compound is a mixture of water retaining clay used to fill around the earthing pit with electrodes to help lower the soil resistivity for the easy conductivity of the electric current. Conventionally, earthing compound is a mixture of wood, coal powder, salt and sand in equal parts. Coal Powder is a good conductor of electricity, anti-corrosive and minimizes the resistivity. Salt is used as electrolyte to form conductivity between the electrode, coal and earth with humidity. Sand lets water flow easily and maintains humidity around the mixture. Coal and salt keep the soil wet as coal absorbs water keeping the soil wet.

Moisture is the controlling factor of earth resistivity. With more than 20% of moisture content, the resistivity is very little but when it is less than 20%, the resistivity increases rapidly. Water also is used to increase the conduction of electricity in soil.

Now-a-days, we have pre-made mixtures like bentonite and marconite in the market. They serve the same purpose but rather more effectively.



Earth meter

Earth meter is the instrument used to test the resistivity of the earth. If resistance of the earth is very low, the fault current through the earth electrode passes to the earth. Thus, protects the system from damage. The Earth meter helps us to keep a check on the resistivity of the earth. Resistivity of the total earthing system should be less than 1 Ohm.

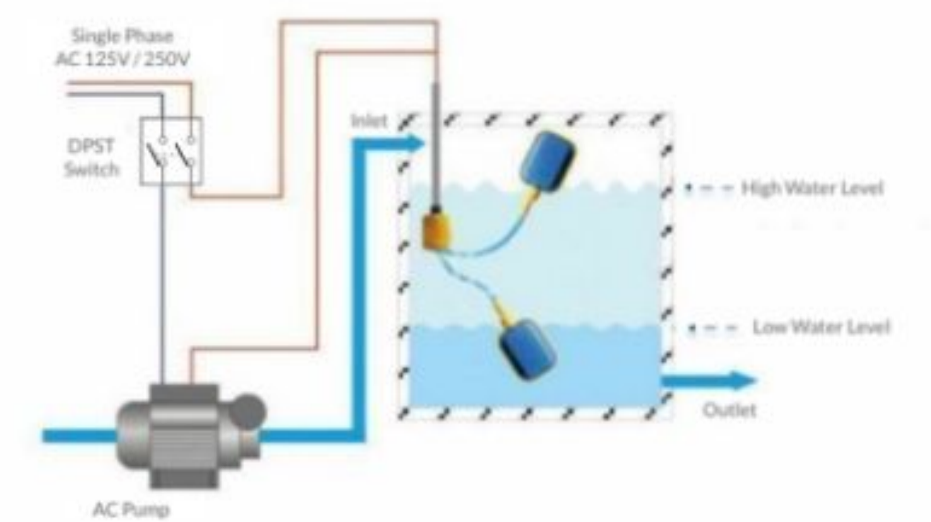
Lightning Arrestor

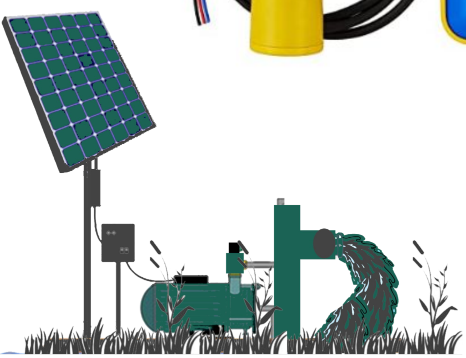
A lightning arrester is a device used on solar power systems to protect the insulation and conductors of the system from the damaging effects of lightning. The typical lightning arrester has a high-voltage terminal and a ground terminal. Ground terminal is connected to the earthing rod. Necessary foundation for holding the Lightning Arrestors is to be arranged keeping in view the wind speed of the site and flexibility in maintenance in future.

The lightning arrester has 4 copper spikes which attract the lightning, and therefore a separate earthing connection is required for the same.

Water-level sensor *(Optional Component)*

Most commonly used water level sensor is a float switch type, which is suspended in the tank at a particular level. When water level rises it floats on the surface and gives a signal to the controller to stop the pump.





Water storage tank *(Optional component)*

Water pumped from the well can be stored in the storage tank. Usually this is used in drinking water applications for communities. These tanks are mostly made up of poly vinyl chloride (PVC) and are available in various shapes and sizes. Sometimes water tanks are made up of cement materials.

Open reservoirs

Open reservoirs are inexpensive and relatively easy to construct, but the big disadvantages are the high evaporation losses of water and easy accumulation of debris and sediments as well as algae growth. These effects can be significantly reduced by covering the tank, e.g. with a plastic foil. Evaporation and algae growth can be reduced when the solar panels are installed on floating mounting structures.

Elevated water tanks

This is the classic configuration of a Solar Powered Irrigation System. The pumped water is stored in an elevated water tank and irrigation functions by gravity. The elevated tank serves as a battery where energy is stored in the form of water. The irrigation system pressure depends on the height of the water level in the storage tank. It also allows for pre-sunrise irrigation. Ready-to-use plastic tanks are available in different sizes, easy to install and do not corrode as metal or cement reservoirs do.

In order to secure a safe system operation, a water level sensor should be installed in the water tank that switches off the pump to avoid overflow. If a submersible pump is installed in a well, a second water level sensor is required to protect the pump from dry running. Such sensors are often integrated into the motor pump by default. As water tanks usually store huge amounts of water, it is important that the foundation and support structure of the water tank meets the static requirements.

Balance of System

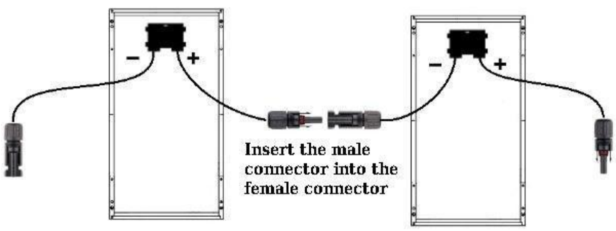
Electrical Equipments

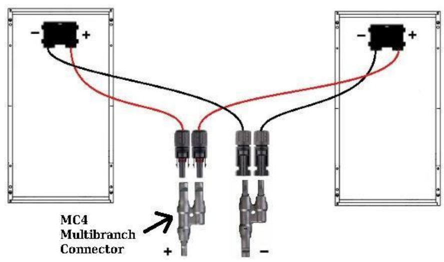
Electrical Equipment including cables and wires that are used for networking in the system. It also includes MC4 connectors, circuit breakers and inverters used in current and voltage management.

MC4 Connectors

MC4 Connectors are single contact electrical connectors used for connecting solar panels. MC stands for manufacturer Multi-Contact and 4 for the 4 mm diameter contact pin. They are used because they make wiring solar arrays much simpler and faster. The connectors come in both male and female types which are designed to be put together. They have a special locking mechanism and need a MC4 unlocking tool to separate the connectors.

For connecting solar modules in series, a female MC4 connector with positive lead of one solar module is connected to a male MC4 connector with negative lead of adjacent solar module.

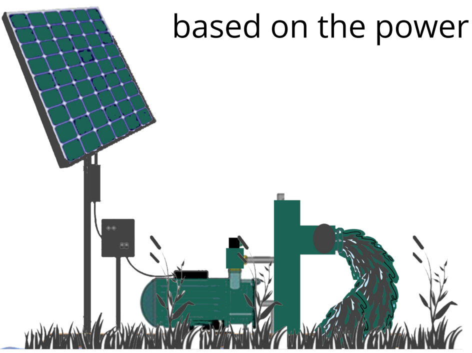




For connecting solar modules in parallel, we need additional equipment called MC4 multi branch connectors. There are two different types of multi branch connectors for both positive and negative leads. When connecting, two male MC4 connectors are connected to a MC4 multi branch connector that suits and has male MC4 connector for its output and two female MC4 connectors are connected to MC4 multi branch connector that takes female MC4 connectors as input and has a female MC4 connector for its output.

Miniature Circuit Breakers

Automatic Circuit Breakers are used in the pump controller to protect from overload or short circuit. The regulated current of the circuit breakers are chosen based on the power and size of the pump.



Distribution Board

A distribution board (also known as panel board, breaker panel, or electric panel) is a component of an electricity supply system that divides an electrical power feed into subsidiary circuits. ACDB / DCDB are an important part of the Solar PV system to provide extra electrical protection to the system during failures.

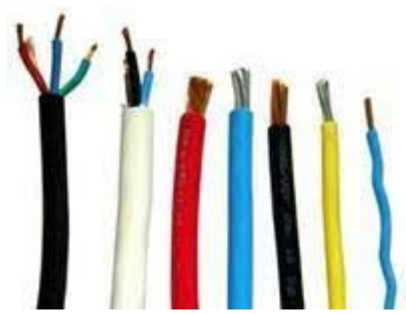
- **Solar DCDB (Direct Current Distribution Box)**, is used to protect the system if there is any fault during failure on the DC side. Here the electricity supply system divides an electrical power feed into subsidiary circuits. It contains a protective fuse or circuit breaker to switch the system off during fault. DCDB controls the DC power from Solar Panels and has a necessary surge protection device (SPD) and fuses to protect the solar panels strings and solar inverter from any type of damage.
- **Solar ACDB (Alternative Current Distribution Box)**, receives the AC power from the solar inverter and directs it to AC loads through the distribution board. ACDB includes necessary surge protection devices (SPD), Voltage, Current monitoring and MCCB to protect the solar inverter from any type of damage or heavy voltage.
- **Array junction box (AJB)**, is referred to as solar PV junction box or combiner box. It collects DC power from PV strings and then transfers either directly or through a main junction box (MJB) to the power inverter. The power inverter converts the DC power to AC which after metering is used to measure the power consumption in ON-Grid/OFF-Grid/Hybrid system.

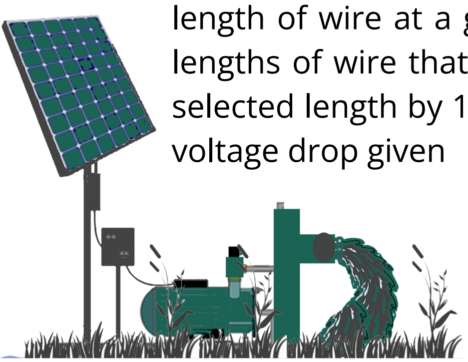
Wires and Wiring Size

Solar water pumping systems are typically provided with all wiring appropriate for the installation. This is why it is important to determine the distances between the solar array and water pump during the site visits. This is particularly important for borehole/well pumps because of the water-resistant cable that must be used to connect the pump.

A properly designed wiring system should have a voltage drop of not more than 5%, and, therefore, on a 12V system, voltage loss should not be more than 0.6V.

The wire-sizing chart below should be used to select the correct wire cross section for a given current and length of wire. The voltage loss values given in the table are for 100m length of wire at a given current. The table can be used for lengths of wire that are less than 100m by first dividing the selected length by 100 and multiplying by the corresponding voltage drop given





2 % Voltage drop chart

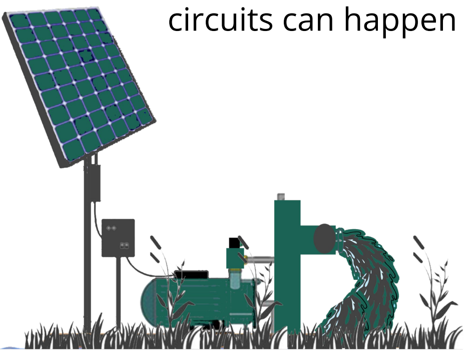
	In sq mm									
	2.5	4	6	10	16	25	35	55	70	
	AWG									
Nominal Ampacity (Amps)	#14	#12	#10	#8	#6	#4	#2	#1/0	#2/0	#4/0
1	45	70	115	180	290	456	720	–	–	–
2	22.5	35	57.5	90	145	228	360	580	720	1060
4	10	17.5	27.5	45	72.5	114	180	290	360	580
6	7.5	12	17.5	30	47.5	75	120	193	243	380
8	5.5	8.5	11.5	22.5	35.5	57	90	145	180	290
10	4.5	7	11.5	18	28.5	45.5	72.5	115	145	230
15	3	4.5	7	12	19	30	48	76.5	96	150
20	2	3.5	5.5	9	14.5	22.5	36	57.5	72.5	116
25	1.8	2.8	4.5	7	11.5	18	29	46	58	92
30	1.5	2.4	3.5	6	9.5	15	24	38.5	48.5	77
40	–	–	2.8	4.5	7	11.5	18	29	36	56
50	–	–	2.3	3.6	5.5	9	14.5	23	29	46
100	–	–	–	–	2.9	4.6	7.2	11.5	14.5	23
150	–	–	–	–	–	–	4.8	7.7	9.7	15
200	–	–	–	–	–	–	3.6	5.8	7.3	11

Source http://www.affordable-solar.com/Learning-Center/Solar-Tools/wire-sizing

It must be noted that voltage losses in the table are theoretical, calculated using Ohm's Law. As such the state of wires must be considered.

Generally insulated copper wires of 2 mm diameter are used for connections in the solar arrays, pumps and controllers. Also, for long distance transmission 9in case the pump is located far from the location of the solar array, aluminium wires are used.

The pump controller is connected to the pump and solar array using a 3-phase connection and lug. The lug is opened, wires are inserted in the live neutral and earth wire positions on either side. The colour coding is followed, and crimped and connected. The colour coding followed in 3-phase conductor is red, yellow and blue wiring, along with black wire for neutral and green wire for earthing. Once repacked, the connection is sealed with waterproof covering using a compound rubber strip. Splice kit is used to waterproof the connection, for otherwise short circuits can happen during heavy rains.



Mechanical Equipments

Mechanical equipment consists of pipes and other plumbing gears. The selection of pipes is done by checking their pressure and temperature rating, ease of fabrication and Suitability for outdoor application. PVC pipes are generally used, and the diameter of the pipes vary according to the size and head (in case of submersible pump).

Safety Equipments

Safety equipment including earthing materials and personal protection gears. For full protection against open circuit, accidental short circuit and reverse polarity, the components need to be Earthed using an earthing rod. For personal protection, rubber gloves, boots and insulated tools are to be used when working on the system.

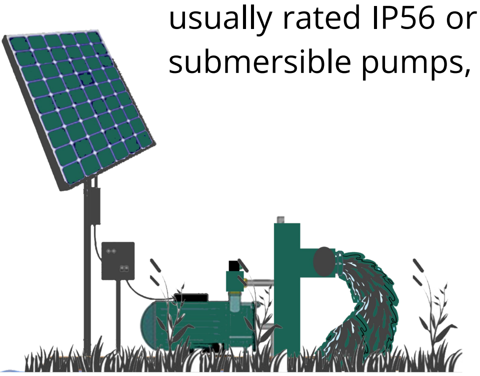
				
Safety Helmet	Safety goggles, preferably with side shields	Protective safety shoes	Protective Gloves	Hearing Protection

A first aid kit needs to be carried by the installation team in case of any mishaps.

The Solar water pumping system should be provided with overvoltage protection. The aim is to reduce the over-voltage to a tolerable value before it reaches the PV or other subsystem components. The source of over voltage can be lightning or another atmospheric disturbance.

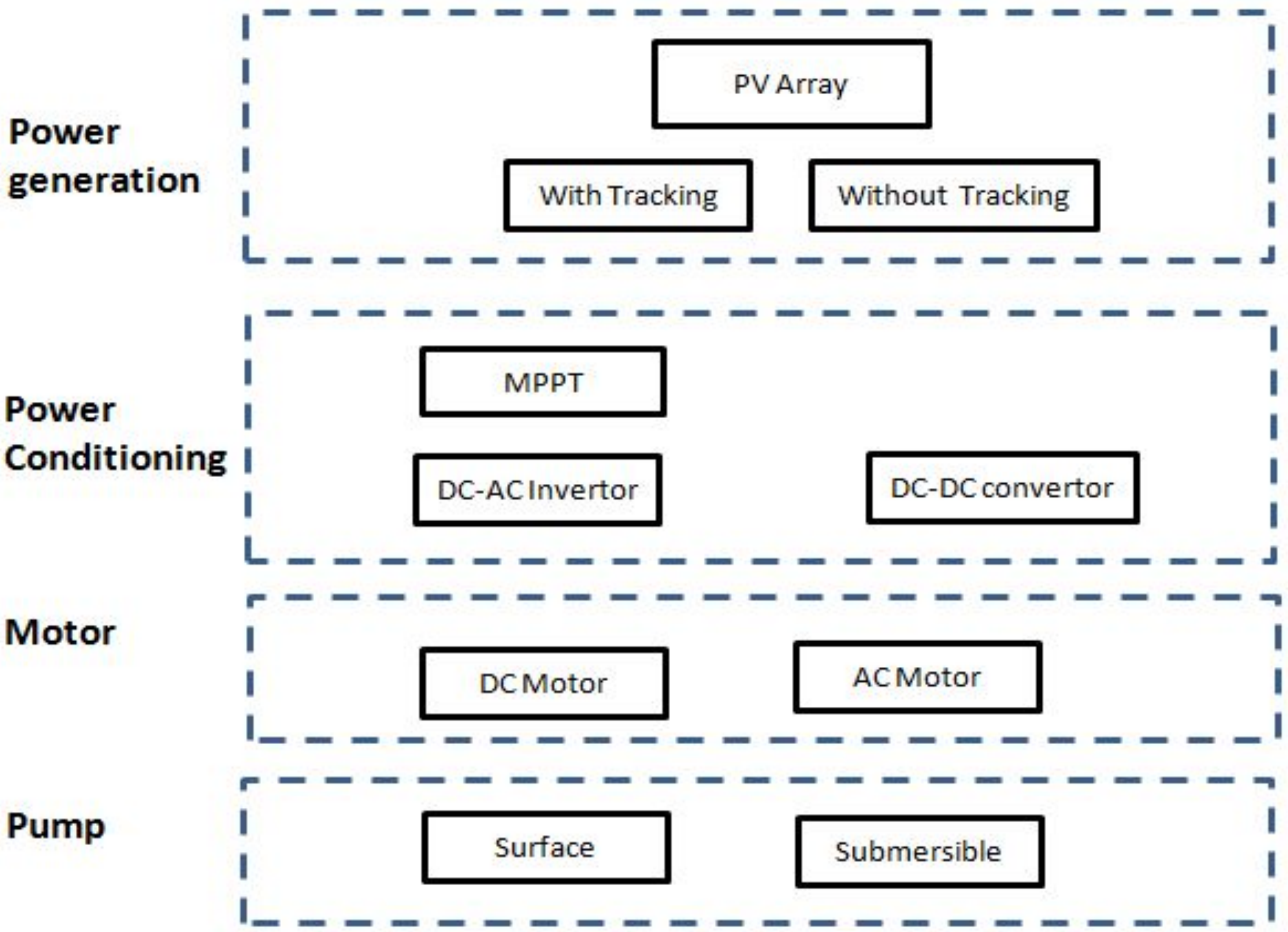
IP Rating of Exposed Components

The Ingress Protection or IP is a rating system designed to check the protection of the components of the pumping system from solid and liquid damage. The first digit in the rating represents the protection level against solids and the second digit indicates protection level against liquid damage. The submersible pumps are usually rated IP56 or above (the liquid protection rating needs to be 6 or higher for submersible pumps, since the pump is submerged in water constantly).

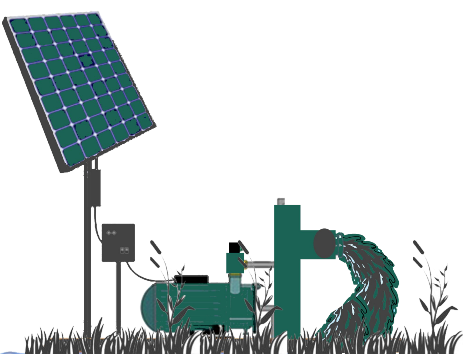


System Configuration

There is a range of possible components and configurations for photovoltaic water pumping systems, as shown in figure. Selection of the most suitable components and configurations for each specific application and site is critical to the economic viability and the long-term performance of the system.



Paired with the right environmental conditions, the right amount of PV panels and controllers and the right installation setup of energy storages, converters, inverters, pumps and motors — the solar water pumping system can present a farm and a nation with numerous benefits.



Evaluation

1 **PV modules are rated according to their**

a. Input
b. Power Output
c. Temperature
d. Solar cells

2 **When AC motors are used in solar pumping system they require**

a. Capacitor
b. Inverter
c. Battery
d. None

3 **For long distance cabling, it is not suitable due to power loss in cable.**

a. True
b. False

4 **The mounting structure is designed for solar modules to optimize**

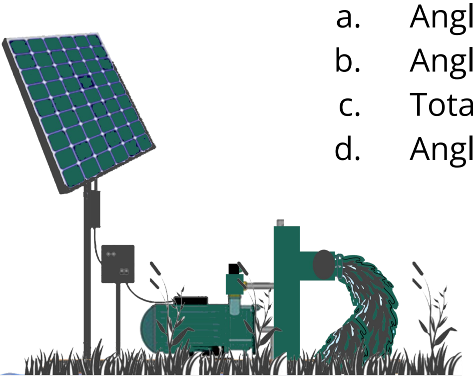
a. Maximum yield within minimum area
b. Minimum yield within large area
c. Maximum yield within maximum area
d. Minimum area

5 **What is the device that orients solar panels towards the sun?**

a. Maximum Power Point Tracker
b. Solar tracker
c. Controller
d. Inverter

6 **Solar tracker is used to minimize _________ between the sunlight and solar panel.**

a. Angle of reflection
b. Angle of incidence
c. Total Angle
d. Angle of irradiance



Evaluation

7 **The ground terminal of lightning arrester is connected to**

a. Battery
b. Solar Modules
c. Earthing rod
d. None

8 **What is the purpose of earthing?**

a. Maximize the output of the system
b. To protect system from lightning
c. To minimize the risk of electric shocks
d. Both b & c

9 **Water storage tank in solar pump system is useful when**

a. There is no sunlight to generate electricity
b. System doesn't work due to technical issue
c. Both a & b
d. When there is excessive sunlight

10 **MPPT will help the system to increase**

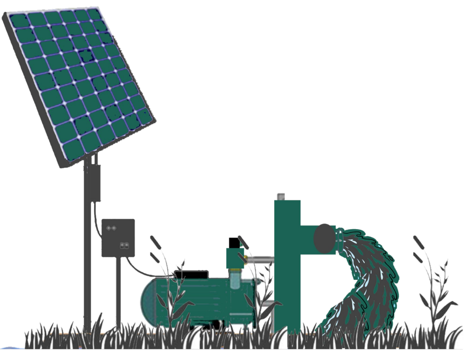
a. Decrease heat generated in the system
b. Increase Efficiency
c. Decrease Efficiency
d. None

11 **________ are used to send signals to controller to stop the flow of water when tank is full.**

a. Inverter
b. MPPT
c. Water level sensors
d. None

12 **Power output of solar PV panels is ___________**

a. AC
b. DC



Evaluation

13 **Thin Film Solar Panels have _______ efficiency than crystalline modules.**

a. More
b. Less
c. Almost equal
d. Cannot compare

14 **Which silicon cells are made from an ingot of melted and recrystallised silicon?**

a. Thin film
b. Monocrystalline
c. Polycrystalline
d. None

15 **The manufacturing process of _________ cells is complicated compared to other technologies.**

a. Polycrystalline
b. Monocrystalline
c. Thin film
d. None

16 **The most commonly used material for manufacture solar cells is**

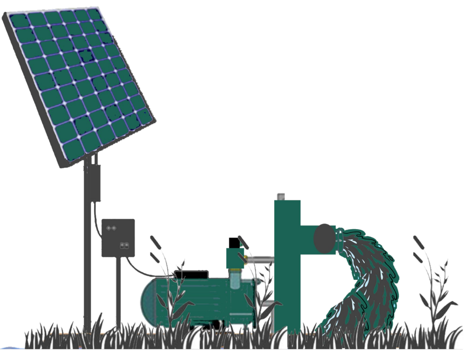
a. Silicon
b. Iron
c. Wood
d. Glass

17 **Controller box should be placed far away from the PV Panels**

a. True
b. False

18 **VFD is used**

a. AC Pumps
b. DC Pumps
c. In both AC and DC pumps



Evaluation

19 **The water output of the Solar panel is variable as it depends on the**

a. Ambient temperature
b. Irradiance
c. Capacity of motor-pump set
d. All of the above

20 **Controller box is used in solar pumping system**

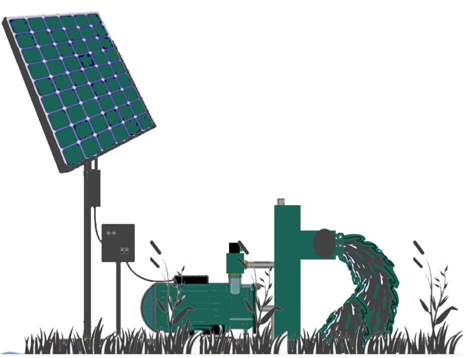
a. To increase the water output
b. To store energy from the solar panels
c. Fault protection
d. Matching of input and output power

21 **On non cloudy day, water output of solar pumping system is more in morning hours as compared to afternoon**

a. True
b. False

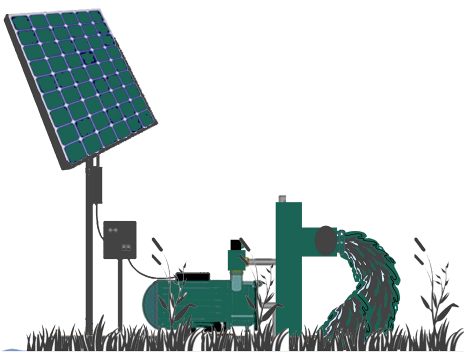
22 **Inverters are used to convert AC current into DC current**

a. True
b. False



Answers

1	b.	2	b.	3	a.	4	a.
5	b.	6	b.	7	c.	8	d.
9	a.	10	b.	11	c.	12	b.
13	b.	14	b.	15	c.	16	a.
17	b.	18	a.	19	d.	20	c & d.
21	a.	22	b.				



Chapter 3

Theory of Pumping Technology

SWITCH ON FOUNDATION
Building Sustainable Enterprises and Ecosystems

10 YEARS OF IMPACT AND INNOVATION

TOPICS COVERED

Introduction to Water Pumping

Theoretical Pump Equation

Real pump equation

Head determination

Flow rate determination

System Curve

NPSHr and NPSHa

Tagging of Pump

Introduction to Water Pumping

Various methods can be used to lift water against gravity. One such method is to shift water into a bucket and lift the bucket with a rope. In electric pumps there are two ways in which this can be achieved - Dynamic and Displacement methods. In both cases, an electrical motor driven pump is required to achieve water lifting. Let's see the principle in both cases. The two principles are explained here:

Dynamic and Positive displacement Pumps

Dynamic pump makes use of the simple fact that any fluid or gas moves from higher pressure to lower pressure. It creates pressure difference with the help of a fast-rotating blade called impeller in a controlled and specially designed chamber called volute. Most popular Dynamic pump used is Centrifugal pump.

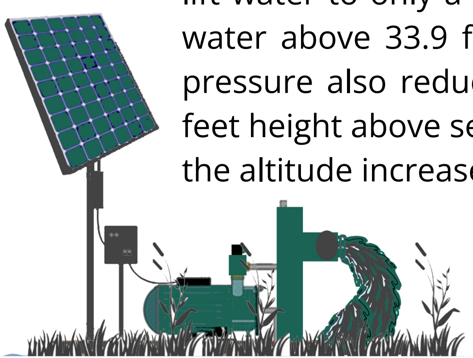
A Positive Displacement pump uses the technique of trapping a fixed volume of water and moving it up without letting it fall back to source. Drawing water from a well in a bucket is positive displacement, wherein a certain volume of water is trapped in the bucket and slowly it is pulled up. Most commonly used Positive displacement pump is the Helical Rotor Pump. Water is trapped in small helical screw threads and every time it rotates, water moves

A dynamic pump does two things to lift water: Suction and Delivery.

Suction

From the water source, the pump sucks water in the same manner we suck water through a straw into our mouth. This phenomenon is called suction. When we suck water using a straw, a temporary vacuum (or low pressure) is created near the mouth which causes atmospheric air to push the water through the straw into our mouth. This happens because the atmospheric pressure around is higher than the low pressure created in our mouth.

Similarly in a centrifugal pump, the rotating vanes create a low pressure in the suction inlet causing flow of water into the inlet of the pump. But there is a limitation. The maximum atmospheric pressure available on earth is 14.7 pSi (pounds per square inch) near sea level. This atmospheric pressure is enough to lift water to only a maximum of 33.9 feet against vacuum. So no pump can suck water above 33.9 feet with the help of atmospheric pressure. The atmospheric pressure also reduces with increase in altitude (2 feet reduction for every 1000 feet height above sea level), thus reducing the maximum suction height further, as the altitude increases.

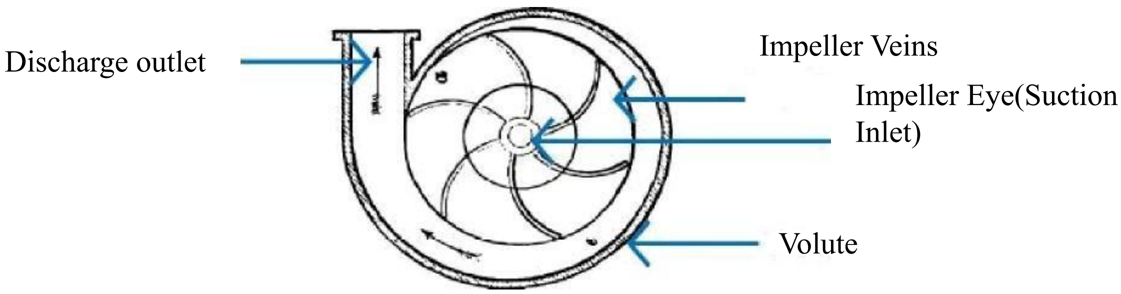


Did you KNOW?

Add Page 4

Delivery

Once the water is sucked into the inlet of the pump, the impeller vane rotating at high speed comes in contact with this water. All the energy of the rotating vane is transferred to the water and the water gets a lot of kinetic energy. This causes the water to be thrown out with high velocity due to centrifugal force. The water thrown out reaches a chamber around the impeller called the Volute.

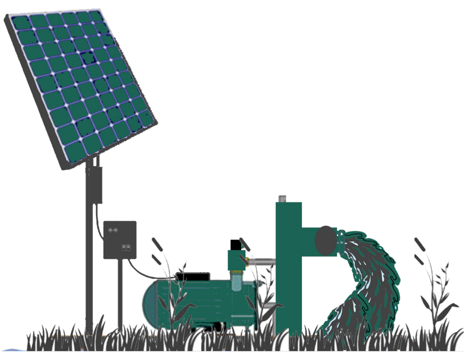


Cross section of centrifugal pump volute chamber

The volute is designed to have a small diameter near the impeller and large diameter near the delivery outlet.

When water moves from small diameter to large diameter, it loses some of its velocity but proportionally it gains some pressure to maintain the total energy in the system constant (This is known as Bernoulli's principle). Since the pressure at the delivery outlet is higher than atmospheric pressure now, the water moves upward. As it moves upward, it loses both its velocity and pressure energies to build up the height energy (potential energy). Please note that the total energy in the system will still be the same.

If the delivery pipe height reaches a height where all velocity and pressure has been transferred to potential energy, the water won't be able to move up further. At this point velocity will be zero, pressure will be equal to atmospheric pressure and the maximum height is called the shut off head of the pump.



Did you KNOW?

Add Page 5

Priming

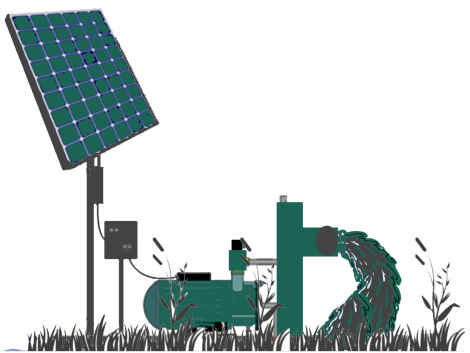
Although the above explanation compares suction of a dynamic pump with sucking water through straw, in reality there is a difference. In a straw, we first suck the air and then the water or juice follows. But in a dynamic pump designed to lift water, it cannot develop enough pressure difference to lift air. If there is air inside the pump chamber, it can damage the pump itself. So before starting the pump, we have to somehow make sure there is no air in the pump chamber. To achieve this, we usually fill the suction pipe and rotating impeller chamber with water manually before starting the pump. We also let out air through an air vent. This is called priming.

We also use a foot valve in the suction pipe to prevent this water from draining out. In some self- primed pumps manual priming may not be required or may be minimal. Please note that even while running, it is important that the pump shuts off when water is not entering the inlet. This is called dry-run protection, it is required in both surface and submersible pumps. In submersible pumps, priming is not usually required as it is anyway submerged in water.

Displacement Pumps

In a Displacement pump, a volume of water is taken from source and it is trapped such that it cannot fall back to the source. Now using various mechanisms, it can be lifted up. When we draw up water in a bucket, we trap water in the bucket and lift it up. So, it is a positive displacement. Here, the volume of the water pumped is independent of the height to which water is pumped to. Trapping water in a rotary vane, by a reciprocating piston or diaphragm, by a rotating screw is all common. It is also common to use one side valves at the inlet and outlet to trap water in such techniques. Hand pumps also use one of these techniques.

Though displacement pumps are more efficient than dynamic pumps, the maintenance costs are high due to stator rubbing against rotors and hence they are used rarely. Even slightest gap to avoid such wear will affect trapping of water through leak. However, in specific cases, if the flowrate required is very less at very high heads, maintenance requirements can be controlled by lowering rotational speeds of displacement pumps to make it more economical than dynamic pumps.



Theoretical Pump Equation

Irrespective of the method used, the energy required to lift water vertically up from a water source, is determined by the formula given below:

Pump Energy = M x H x g

where M is *mass of water to be lifted in kg, H is height to which neater* is *to be lifted in metres and g is the acceleration due to gravity = 9.8m/s^2 to get the energy in Watt-Seconds (Same as Joules)*

The energy mentioned above is called Hydraulic Energy. Since water is generally measured in volume (m^3, Litres, Gallons, etc.) the equation can be changed to:

Pump Hydraulic Energy Eh = V x *p* x H x g Joules

where is V is volume of neater to be lifted in m^3, p is the density of water (1000 kg/m^3), H is height to Which water is *to be lifted in metre and g* is *the acceleration due to gravity = 9.8 m/s^2*

Now if above is pump hydraulic energy, what would be the pump hydraulic power required to lift the water? If Volume (V) of water needs to be lifted up within a second, the power required is:

Hydraulic Power in Watts = (Eh in Joules) / 1 sec

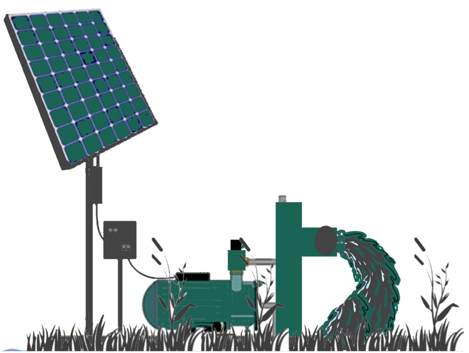
Instead, if the same volume needs to be pumped slowly over an hour, the hydraulic power required is:

Hydraulic Power in Watts = (Eh in Joules) / 3600 sec

If we know rate of water to be pumped in litres per hour and we want to know the Hydraulic Power required for pumping in HP (Horse Power), the equation will be:

Hydraulic Power Ph = Q x p x H x g x 1.34 / (3600 x 1000) HP

where is Q is *flow rate of water to be lifted in ltr/hr, p is the density of water (kg/ltr), H is height to which water is to be lifted in metre and g is the acceleration due to gravity 9.8m/s^2*



Real Pump Equation

Although we have seen the pump equation above, there is a slight difference in practical application of pump. We already saw in the theory of dynamic pump, that a rotating vane first develops high velocity in water, then it develops pressure as it moves through volute to a large diameter discharge outlet etc. So the energy developed in the pump is used for not just building height, but for four purposes according to Bernoulli's principle:

a. To build velocity of water: At first all the rotary vane energy is converted to high velocity of water called kinetic energy (K.E).

K.E = ½ mv^2 where m is mass of water and v its velocity

b. To build pressure: In any pipe, at a given height, if the pipe cross-section area is increased, the pressure increases and velocity decreases. In a centrifugal pump, as the volute diameter increases towards the discharge outlet, pressure energy increases.

Pressure Energy = PV where P is gauge pressure of water and V is volume of water

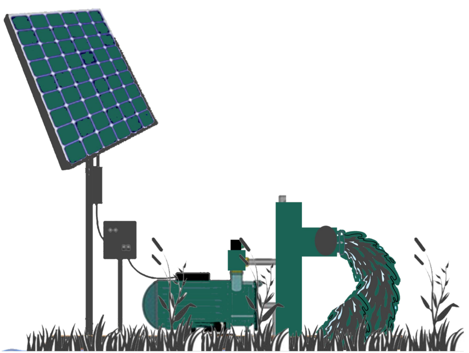
c. Potential Energy: This is what we commonly call the height. The theoretical pump equation we discussed was based on only this factor. As we have seen Potential Energy (P.E) = mgh where m is mass in kg, g the acceleration of gravity, h the height of water column

d. Friction Loss: As water moves in a pipe, there will be friction with the wall of the pipe. Some energy will be lost thus. Friction loss is dependent on volume of moving water and density of the fluid

Friction Loss = VpF where V is volume of water, p density of water, F the friction factor of the pipe

Considering all above, we can write the revised Hydraulic energy equation as

$$Eh = \frac{1}{2} mv^2 + PV + mgh + VpF$$



If we replace volume V with flow rate Q and replace mass m with Qp (Since mass of flowing water = flow rate x density) then we can get the hydraulic power equation;

$$\mathbf{Ph = (1/2\ Qpv^2 + PQ + Qpgh + QpF) \times 1.34/ (1000 \times 3600)\ HP}$$

where Q is *flow rate* in *ltr/hour, p is density in kg/ltr, v is velocity* in *m/s, P is gauge pressure of water in kPa, h the height* in m, *F* is friction/factor

Let us take out Qpg as a common factor, then;

$$\mathbf{Hydraulic\ Power\ Ph = Qpg\ (v^2/2g + P/pg + h + hf) \times 1.34/ (1000 \times 3600)\ HP}$$

where Q is flow rate in ltr/hour, *p* is density in *kg/ltr, u is velocity* in *m/s, P* is *gauge pressure of water* in No, *h the height* in m, *hf=F/g* is friction factor equivalent in *mtr*

Compare above equation to the theoretical Ph derived which was;

$$\mathbf{Hydraulic\ Power\ Ph = Q \times \mathit{p} \times H \times g \times 1.34/(3600 \times 1000)\ HP}$$

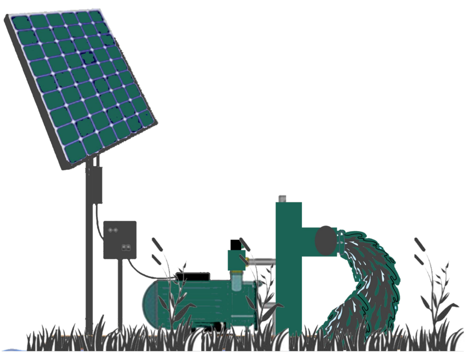
The only difference is, instead of just height H in the theoretical formula, there are four factors ($v^2/2g$ + P/pg + h + hf) in the newly derived formula. This component is known as Total Dynamic Head TDH. It has following four factors in it:

- $v^2/2g$ called velocity head
- P/pg called Pressure head
- h the static head, and
- hf the friction head.

In short the practical formula we will be now using as pump equation is:

$$\mathbf{Hydraulic\ Power\ Ph = Q \times \mathit{p} \times TDH \times g \times 1.34/(3600 \times 1000)\ HP}$$

In any pump system design, we have to determine Q — the required flow rate and TDH — the required head based on customer need.



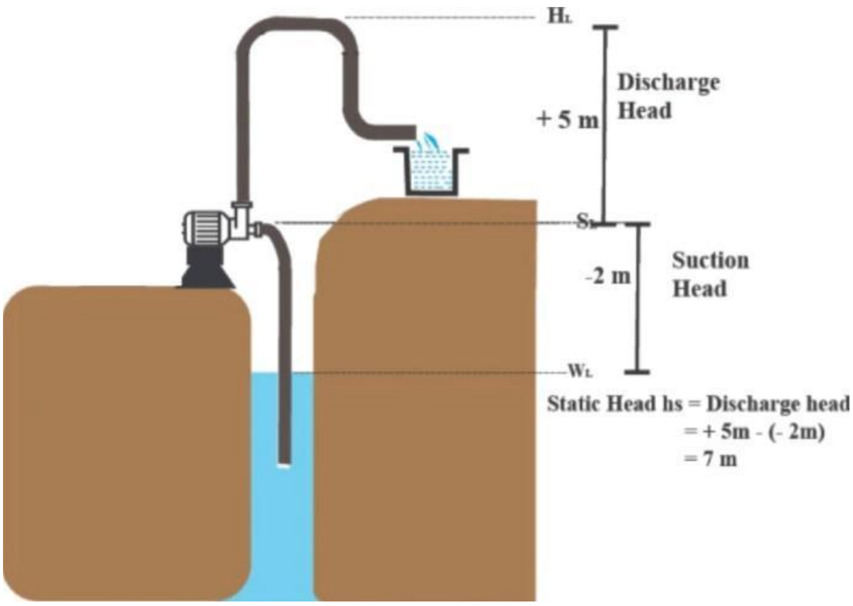
Head determination

Static Head

In the TDH, we have seen height (h) is one of the four factors and the most important one. This height to which water needs to be pumped is the basic requirement we need to understand from the client and it is called a static head. It is called static as it is the only factor in TDH which doesn't change if the flow rate (Q) requirement of the client changes.

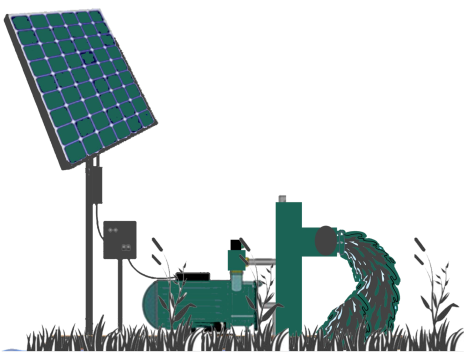
In any pump Static Head (h_s) = Discharge Head(h_d) - Suction Head($h_{suction}$)

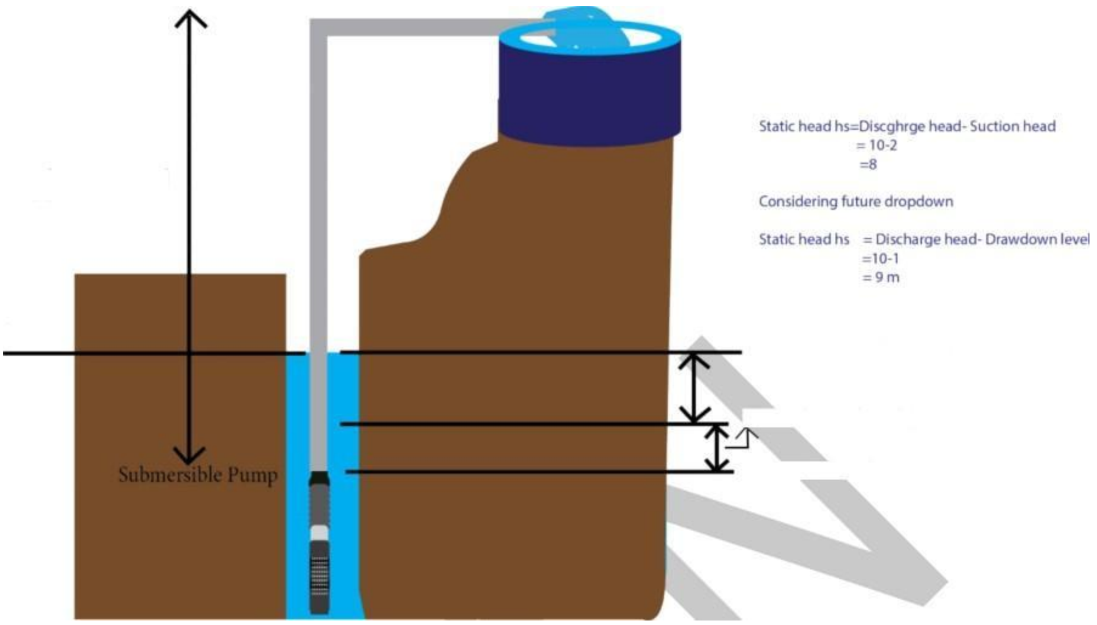
Here the suction level where water enters the pump impeller is considered the reference line. Head above suction level is positive and below suction level is negative.



Determination of static head of Surface Pump

SL is the suction level and from the line of reference
HL- The maximum height in the discharge side including the pipes rind discharged water column
ML- Water Level of the source





Determination of static head of submersible pump

As seen above,

Discharge head is the height difference between suction level and the highest point to which water gets lifted by the pump. (Please remember to respect the sign convention of head)

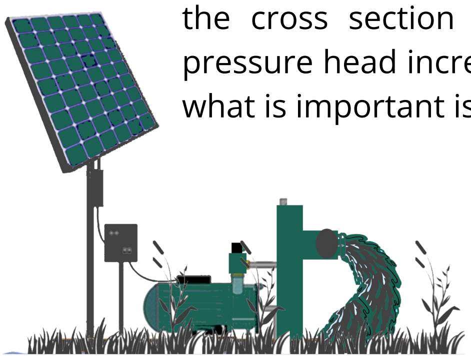
Suction Head

It is the height difference between suction level and the estimated lowest water level in the water source. In a submersible pump, water near the pump inlet bends down a little from the water level while the pump is running. This is called drawdown. So the lowest estimated drawdown level should be considered instead of water level. (Please keep in mind the sign of head)

Dynamic Head (PV Head — Pressure and Velocity Head)

We have seen that TDH has both pressure and velocity head factors.
Velocity head is W/2g and Pressure head is P/pg

There is a reason why they are explained together here. At any given height in the pump, we can change pressure to velocity head and vice versa simply by changing the cross section of the pipe carrying water. If we increase pipe diameter, pressure head increases and velocity head decreases. It is also true vice versa. So, what is important is together as PV head how much energy they



hold. When the pump impeller rotates, its energy is received by water as PV head. Then we strategically select pipe diameter such that pressure is above atmospheric pressure, at the same time velocity doesn't drop to zero. As long as this condition is met, water keeps rising up which means its static head keeps increasing.

As the static head increases, the PV head sacrifices its energy to build the static head. Finally, when the PV head is exhausted, the water cannot go further up as all PV heads have been converted to static heads. This maximum static head is shut off the head of the pump.

We should tap water at a height where most of the PV head has been converted to static head. Conversely, if we select the pump correctly at its peak efficiency operating point, most of the PV head would have been exhausted at our required static head. If not, the extra PV head available at the final discharge point will be a waste of energy and of no use. There is one exception to this. You can purposefully plan to have some extra PV head for sprinklers or cleaning/gardening hose etc which can utilize the extra velocity/pressure. Hence, unless there is such a special requirement by the customer, PV head requirement is usually taken as zero for pump selection.

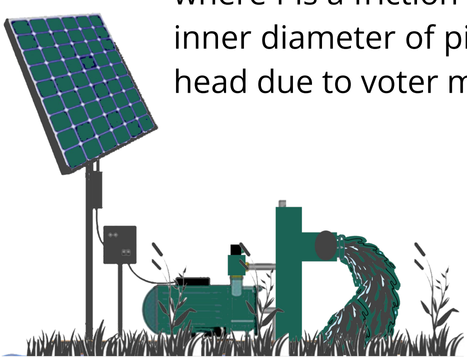
Note that PV head will change if customer changes their flow rate requirement as they are dependent on velocity and volume of water. Hence, they are categorized under Dynamic head.

Friction Head

The Pressure developed in the pump is not fully utilized to just lift the water to a height. Some of it is lost as friction in pipes, bends etc. This is why pumps are not 100% efficient. The friction in pumps, pipes is also measured in units of length (usually metres or feet). The friction thus measured in metres or feet is called Dynamic Head. It is dynamic because every time flow rate changes, the friction also changes. Higher flow rate causes more water to come in contact with the pump impeller and the connected pipes at a given time causing higher friction. Friction head can be calculated by:

$$hf = f \times (39.37 \times L/d) \times V2/2g \quad \text{OR} \quad hf = 1.66 \times 10\text{-}4 \times (L/d4) \times Q$$

where f is a friction constant depending on pipe material, L pipe length in mtr, d is inner diameter of pipe in inches, Q is flow rate in ltr/hour end V2/2g is the velocity head due to voter movement in mtr



Nominal Size	ID (inches)	Velocity(ft/sec)	Head loss (feet)
3.5	3.548	12.98	16.2
4	4.026	10.08	8.5
5	5.047	6.41	2.7
6	6.065	4.44	1.1
8	7.981	2.57	0.3

A typical head loss (hf) data given by a manufacturer for looft straight length steel pipes of various diameters while carrying 1500 litre/minute. Elbows and T bends cause higher frictional loss (An approximate thumb-rule is 12ft additional length equivalent for every bend).

For example, if a pump has both suction and delivery pipe together 4 mtr pipe length. There are 3 elbow bends in the pipe. The flowrate is 25000 lph and the pipe diameter is 3 inch. Let us estimate the friction loss.

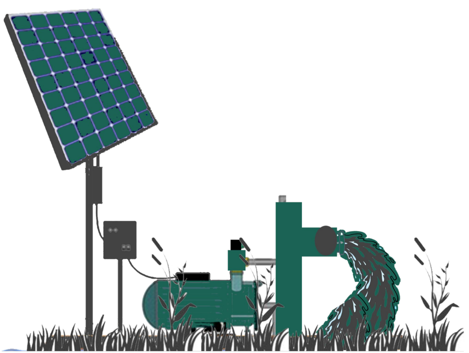
Total length of pipe = 40m

Since each bend is equivalent to 1m and there are 3 bends;

Total length of pipe to be considered L = 40 + 3 = 43m

Diameter d = 3 inch
Q = 25000 lph

Friction head hf = 1.66 × 10.4 × (43/34) × 25000 = 2.2m



Flow rate determination

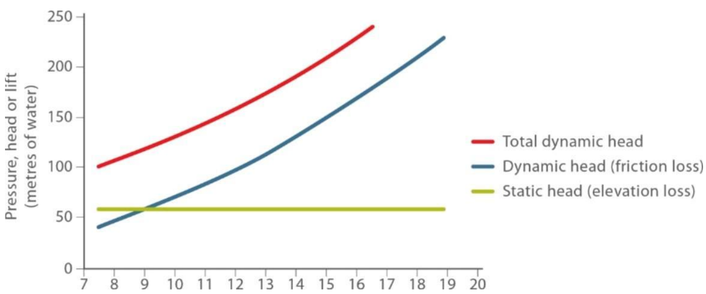
The flow rate is the amount of water pumped in a certain time period. The flow rates able to be met by a pump are usually quoted in L/min or L/hr or m^3/day or Litres per Day (LPD).

The flow rate is a critical figure in the design of a solar pumping system and it must be accurately determined to optimise the pumping system design. Overestimation of flow rate will lead to pump oversizing which in turn increases cost of solar modules installed to run it. It will result in a larger amount of water being pumped than required since solar pumps are generally not manually controlled.

In irrigation, it is always recommended to consult experts in the agri sector to figure out ways to reduce water requirements (Eg; adopting drip irrigation) and determine the lowest possible water requirement, before planning to adopt a solar pumping system. The daily water requirement in each month needs to be determined. If the irrigation demands pumping only in intervals of a few days and not daily, then it may be economical to pump water daily to an overhead tank and release water from the tank as per requirement. Solar modules will be economical if the daily generated power is fully utilized instead of wasting without usage.

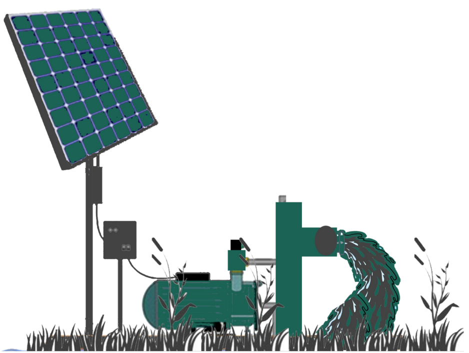
System Curve

When the total dynamic head is plotted against the flow rate, it is called system curve. System curve is extremely important in designing a pump system.



Example of a System Curve (The red fine is the system curve)

If the requirement has just one flow-rate, instead of a line, the system curve will be a point of operation where TDH meets the required flow rate.



NPSHr and NPSHa

For every pump, the pump manufacturer specifies a minimum value of head based on the pump design, beyond which if suction head is increased, it causes air bubbles to enter the pump impeller. This can cause serious damage to the pump. If the pressure in the inlet side of the pump goes below the vapour pressure of water, water starts to evaporate. These water bubbles in large numbers burst inside the pump and damage the pump. This phenomenon is called cavitation. This value given by the manufacturer is NPSHr (Net Positive Suction Head required) of the pump.

Now let us see what is NPSHa (Net Positive Suction Head available)

When we keep a surface pump at a height above the water level, there is a height from the water level to the inlet of the pump. This is Suction head.

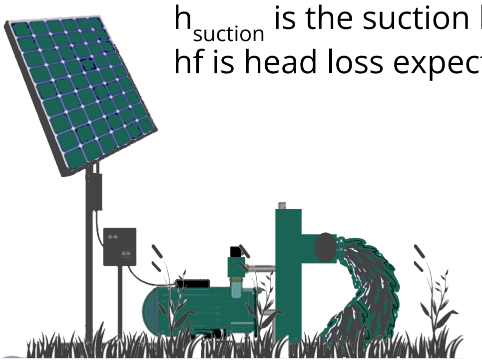
Now we know that it is atmospheric pressure that helps water move up this suction pipe to the pump inlet. So before installing a surface pump, we need to know the atmospheric pressure available on the water surface that will help it move water up the suction pipe.
The atmospheric pressure has to do two more things apart from lifting the water through suction pipe:

1. The atmospheric pressure has to help overcome the friction in the suction pipe
2. The atmospheric pressure has to overcome the vapour pressure of water so that water doesn't turn to bubbles. Vapour pressure depends on the geographical conditions of the region and the temperature of water being pumped

From the above description, we can say that the value:

$P_a - P_v + h_{suction}$ - hf should always be more than the NPSHr

Where,
P_a is Absolute Pressure on the surface of water to be pumped in metres of Water column
P_v is Vapour pressure at ambient temperature in metres of water column below u›hich water becomes water vapour
$h_{suction}$ is the suction head in metres (-ve below impeller and +ve above it)
hf is head loss expected inside suction pipe due to friction in metres



The term $P_a - P_v + h_{suction} - hf$ is called NPSHa (Net Positive Suction Head available)

For a surface pump to function properly without cavitation, following condition should be met:

NPSHa > NPSHr × safety margin

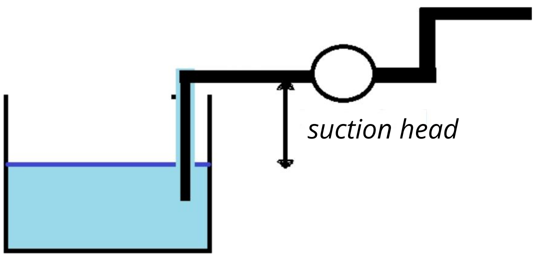
Safety margin is typically a factor of about 1.5

Which also means while placing a surface pump, the positive suction head should be such that:

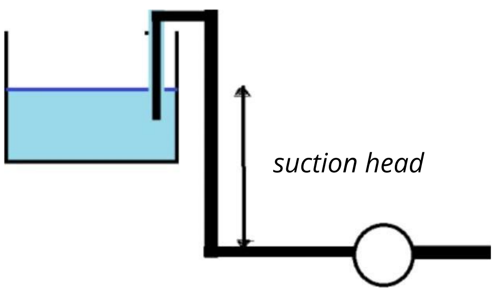
Suction head > NPSHr × safety margin - Pa + Pv + hf

where, Suction head is negative below pump suction level and positive above pump suction level

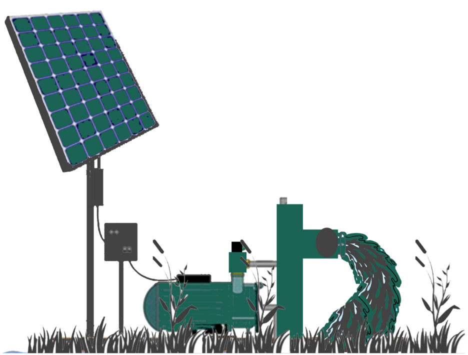
Note: If distance between pump inlet to water level is 5m, suction head is -5. If it is 3m, the suction head is -3. We know -3 > -5 and hence our aim is to reduce distance between water level and pump inlet to increase the positive suction head. This is why in some wells you would have seen surface pumps lowered into the well or we even use floating surface pumps.



Negative suction head



Positive suction head



Tagging of Pump

A pump has two parts. The motor which drives it and the pump itself.

Motor

Most commonly, AC Induction motors are used in running pumps. DC motors are also gaining popularity due to its higher efficiency, in spite of its higher cost. This is because higher efficiency reduces the cost of Solar Power required, significantly. But, due to the simplicity of design, availability and easy serviceability, AC induction motors continue to be the most popular.

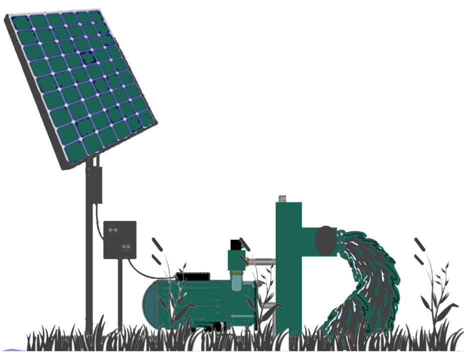
Below are the specifications to look for in a motor:

HP: This is the mechanical power generated in the shaft of the motor in HorsePower (and not electrical power), "when the motor is running at its peak efficiency". Sometimes motor power is given in kW too.

Input Power: Required input electric power to run the motor while running at peak efficiency. Usually given in kW.

Volts: The voltage of input electric power.

- If this voltage is AC, the motor will have an additional parameter called 'Hertz' which is the frequency and 'Phase' which is the number of phase inputs required.



Current: Given in Amperes, it is the current drawn while operating in its peak efficiency. If AC motor, this will be phase current

Power factor: For AC motors, a part of the current keeps circulating in the motor to keep the magnetic flux alive. It doesn't get transferred to shaft power. If Power factor (pf) is 0.8 it means Phase Voltage × Phase Current × number of phase × 0.8 is the available input power to the motor for rotation.

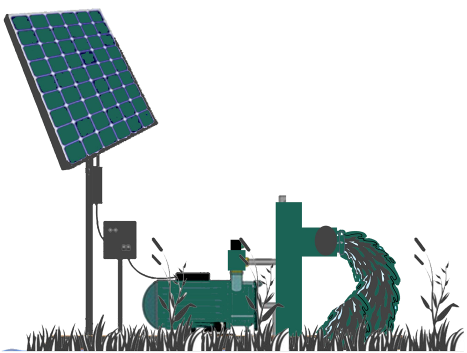
RPM: Speed at which the motor rotates in Rotation per minute during its peak efficiency. Eg: 1800 rpm

Pole: Number of magnetic poles to provide magnetic force needed in a motor. In an induction motor, the number of magnetic poles and frequency decide the speed of the motor.

Capacitance: Single phase induction motor uses a capacitor to start as it is not self- starting. This capacitance is mentioned in Micro-Farad on the motor.

IP: Ingress Protection is mentioned in two digits. Eg: IP35. First letter signifies the degree of protection against solids. 1 is protection from objects above 50mm size like stone. 6 protects from even fine dust. Second digit signifies protection from liquid. i is protection from dripping water vertically and 8 means it can be fully immersed in water still water doesn't enter the pump. Outdoor motors should be at least IP56 rated

Duty:-It mentions if the motor is designed for continuous running or periodic running. S1 duty means it is designed for continuous running.



Pump

The specifications of the pump are as given below. Most common pumps are centrifugal pumps. So let's focus on nameplate of same:

HP/kW : This is the shaft power that the motor develops while running at the motor's maximum efficiency point. The shaft is connected to pump and hence same power is available to pump.

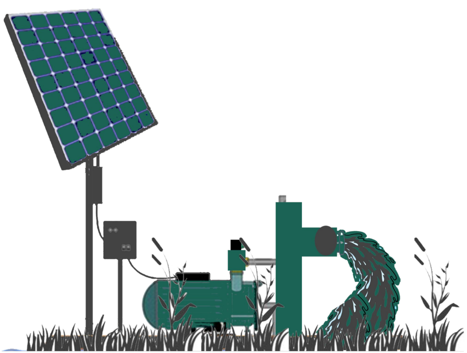
Head: If we keep increasing the discharge head by increasing height on the discharge side of the pump, the flowrate keeps reducing and at a particular pressure (or height) it cannot pump water further. This is the head of the pump in metres of feet. It is not dependent on fluid. It depends on the diameter of the impeller, its speed and the volute design. However, the pressure developed depends on its viscosity of fluid {Since Head = Pressure/(Density x g)}

NPSHr: Required suction head to avoid cavitation. The suction head should not be less than a limit to avoid cavitation.

Bore: This is the diameter of the outlet and inlet of the pipe. Do not use a pipe less than this diameter to connect to the pump. It will unnecessarily increase the pressure. Also, if using a higher diameter pipe, use eccentric couplers only.

Number of stages: A larger impeller diameter can create a larger head for a pump. But in some cases, the pump needs to have an impeller of smaller diameter (Eg; A submersible pump inserted in a borewell hole). In such cases multiple impellers of smaller dia are connected in series into a single enclosure to achieve the desired head. This is called multistage pumps and the number of stages signifies the number of pumps in series. Eg: 2 stage, 3 stage etc.

You would have noticed that the flowrate is typically not an important nameplate parameter. This is because it is not a pump characteristic. Only Bore diameter is a pump characteristic. To know the relation between the head developed in the pump and the flowrate, the pump curve needs to be referred to.



Evaluation

1 **Positive Displacement pump uses the technique of _____ a fixed volume of water and moving it up without letting it fall back to source.**

a. adding
b. mixing
c. trapping
d. Throwing

2 **What is the maximum atmospheric pressure available on earth?**

a. 10 pSi
b. 14.7 pSi
c. 14 pSi
d. 12 pSi

3 **Where does the water thrown out reaches a chamber around the impeller reach?**

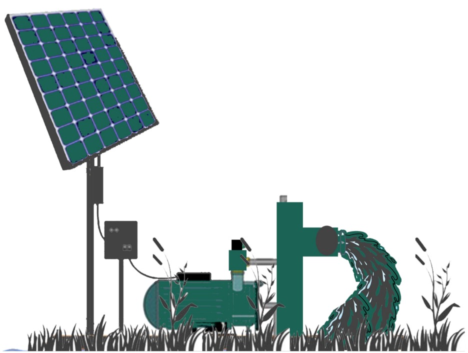
a. Volute
b. Conduit
c. Store
d. None of the above

4 **Why is priming not required in submersible pump?**

a. Submerged in water
b. Borewell is already primed
c. Submersible pumps have oil, so priming is not needed
d. All of the above

5 **Which of the following is not required to calculate the Pump Hydraulic Energy?**

a. Volume
b. Density of water
c. Gravity
d. Diameter of the conduit pipe



Evaluation

6 **RPM is the Speed at which the motor rotates in Rotation per minute during its peak _______**

a. Efficiency
b. Voltage
c. Current
d. Power

7 **Which of the following is correct in case of a surface pump**

a. NPSHa + NPSHr = safety margin
b. NPSHa = NPSHr × safety margin
c. NPSHa < NPSHr × safety margin
d. NPSHa > NPSHr × safety margin

8 **What is the unit of frequency?**

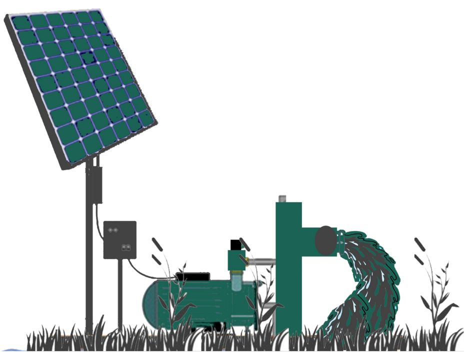
a. Volt
b. Second
c. Hertz
d. Pascal

9 **What does the first number in IP56 signify?**

a. Degree of protection against solids
b. Degree of protection against liquids
c. Degree of protection against fluids
d. Degree of protection against pressure

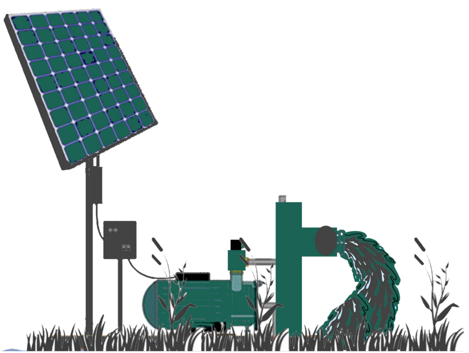
10 **What feature of a borewell are not required for pump design?**

a. Diameter
b. Depth
c. Perimeter
d. Water table



Answers

1	c.
2	b.
3	a.
4	a.
5	d.
6	a.
7	d.
8	c.
9	a.
10	c.



Solar Array and Connections

TOPICS COVERED

PV Module Characteristics

Tagging of Solar Panels

Irradiance and Insolation

Sunshine hours

Design of Solar Power and Energy required

Design of Solar Array

Series Connection of Solar Modules

Parallel Connection of Solar Modules

Series-Parallel Connection of Solar Modules

Example of connections in solar modules

Design of Cables

Did you KNOW?

Add Page 6

PV Module Characteristics

Solar modules contain photovoltaic (PV) cells that convert energy from the sun into electrical energy. These cells produce DC electricity that can be used either by AC-compatible appliances such as many household electrical items, or by an AC water pump.

The electricity produced by a PV module is characterized by the I-V curve: this depicts the relationship between the current (I) and the voltage (V) of the cell. For a given set of operating conditions, the PV module can be manipulated at any point along the I-V curve; for every operating voltage, as shown on the x-axis, there is a corresponding current output, as shown on the y-axis.

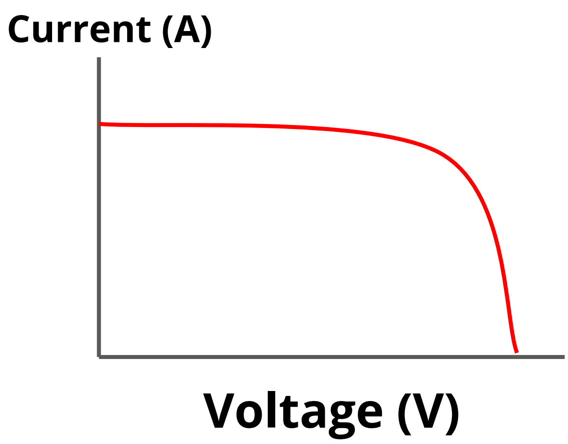
One point along the curve will produce the most power. This point is known as the maximum power point (MPP) and is located at the 'knee' of the curve. Operating a PV module at its maximum power point will result in the greatest possible amount of power. Sometimes, however, it is more beneficial to operate the PV module at a specific voltage or current value that does not correspond to the maximum power point. A maximum power point tracker (MPPT) is the most common way to control the electrical output of a PV module.

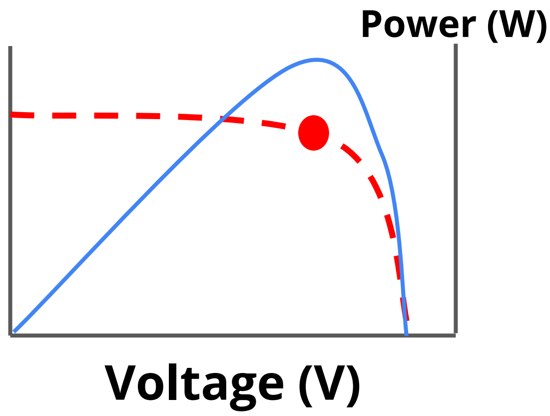
The operating conditions – namely, the solar irradiance levels and temperature of the module, affect the I-V curve of a module. In essence, as solar irradiance levels increase, more current is available; hence, there is more available power.

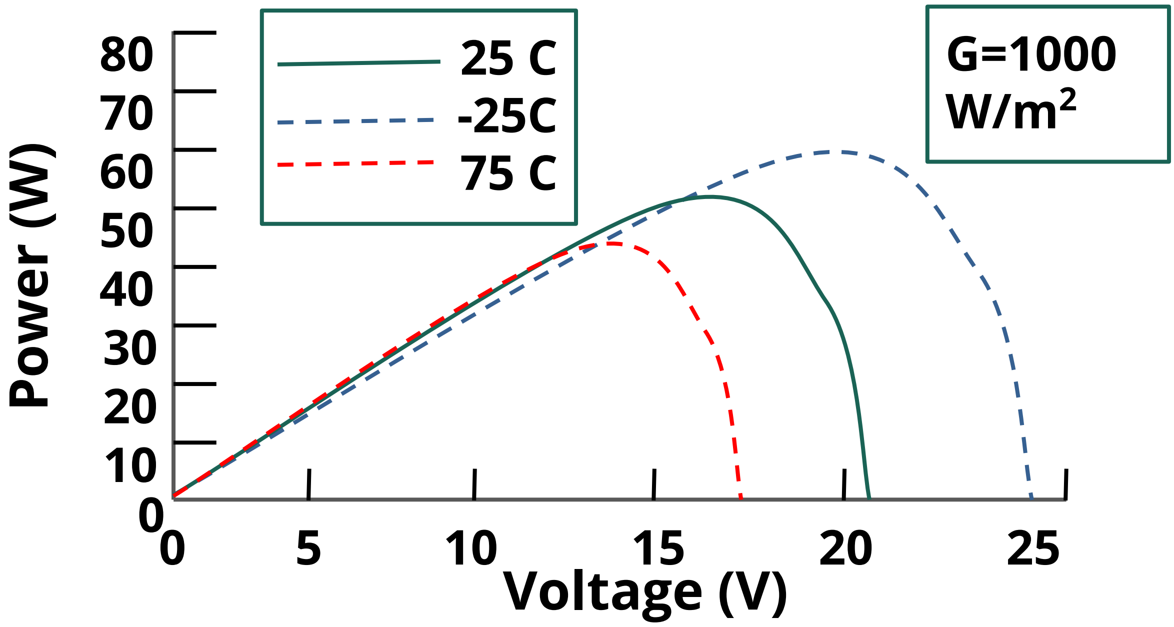
Effect on solar PV pumping of solar radiation levels and temperature

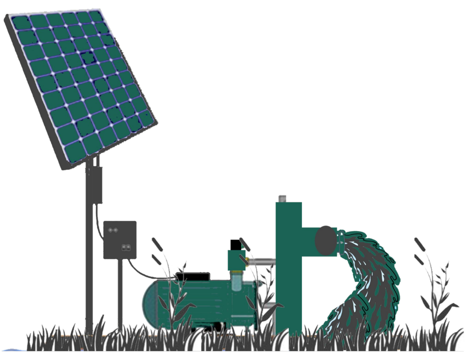
The operating conditions – namely, the solar radiation levels and temperature of the module, affect the I-V curve of a module (Figure a). In essence, as solar radiation levels increase, more current is available; hence, there is more available power. As cell temperature increases, less voltage and hence less power is available (Figure b).

The amount of solar radiation energy received in a period of time is measured in kWh/m^2 or in peak sun hours (PSH).



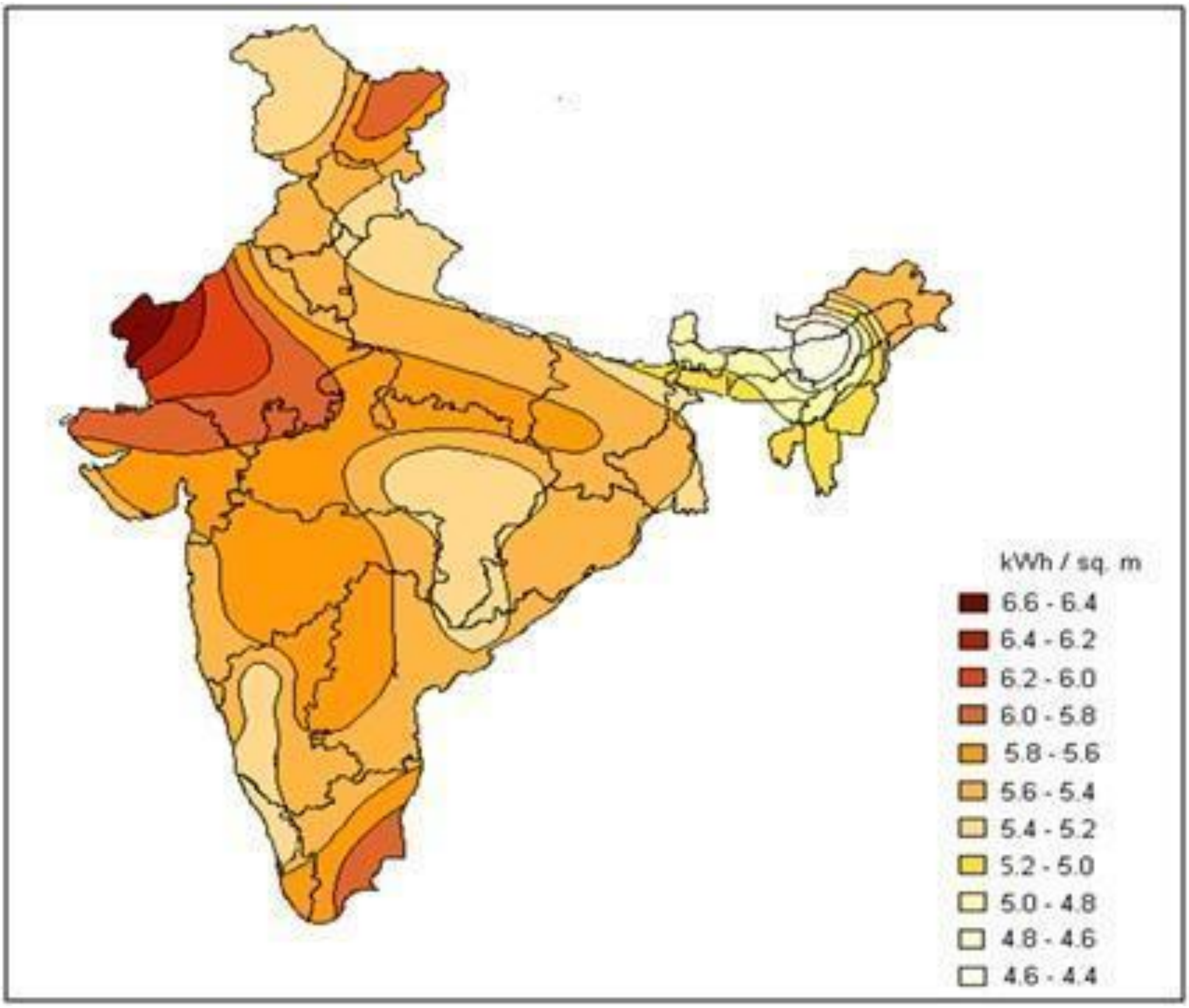




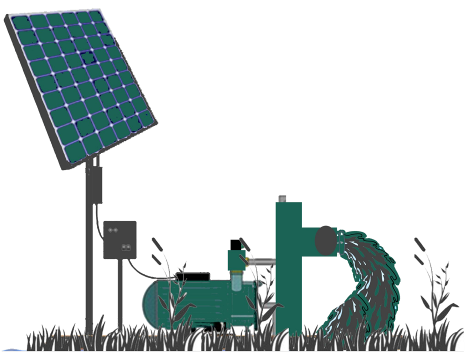


- Increased solar radiation levels = greater power output.
- Increased module temperature = lower power output.
- The amount of solar radiation energy received in a period of time is measured in kWh/m^2 or in peak sun hours (PSH).

A common myth is that solar panels do not work during winter, but on the contrary, the cold temperature will typically improve solar panel output. So, on a sunny winter morning, the panels will actually be more efficient.



Increased Solar radiation levels = Greater power output
Increased module temperature = Lower power output



Tagging of Solar Panels

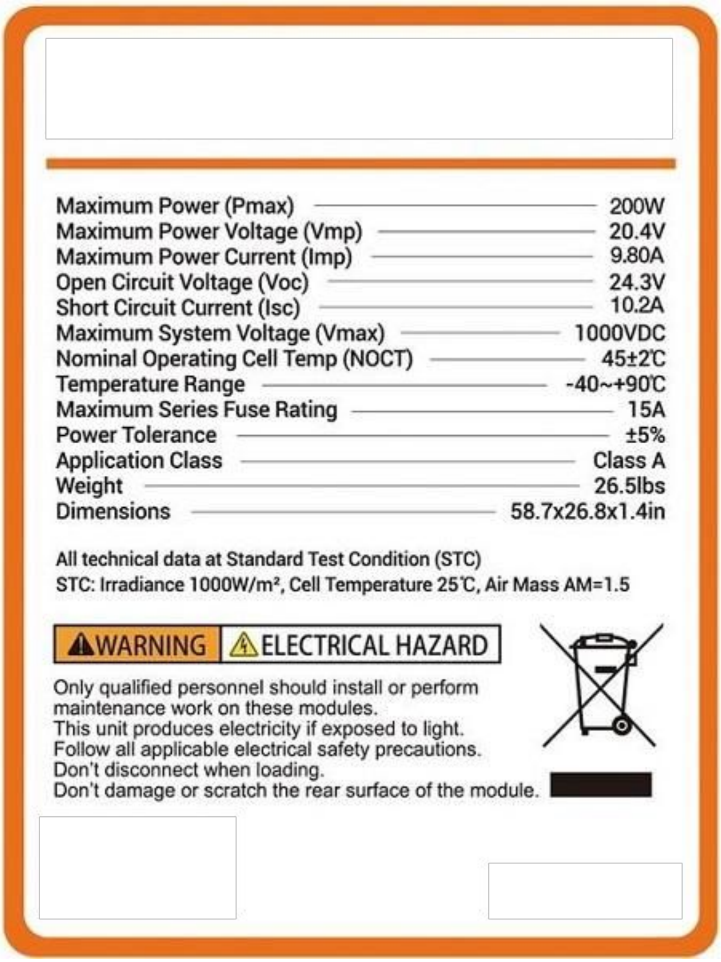
There should be a Name Plate fixed inside the module which will give:

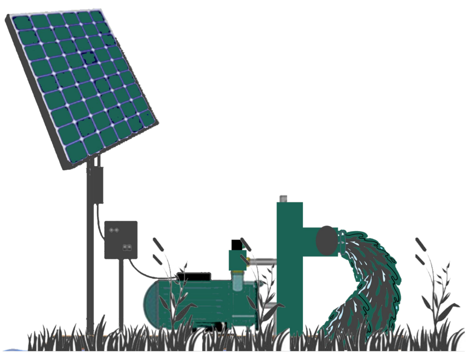
a. Name of the Manufacturer or Distinctive Logo.
b. Model Number
c. Serial Number
d. Year of manufacture

Each PV module must be use RF identification Tag (RFID), which must contain the following information:

- Name of manufacturer of PV module and their logo
- Unique Serial No and Model No of the module
- Month and year of the manufacturing
- Country of origin
- I-V curve for module
- Peak wattage, $I_{mp,}$ V_{mp} and power tolerance of the module
- Date and year of obtaining the IEC PV module qualification certificate
- Name of the test lab issuing IEC certificate.
- Other relevant information on traceability of solar cells and modules as per ISO 9000 series

A distinctive serial number starting with NSM will be engraved on the frame of the module or screen printed on the tedlar sheet of the module.





Irradiance and Insolation

The sunlight has seven colours and many other radiations which are not visible to the human eye. Each of these visible colours and invisible radiations corresponds to a particular energy. All the radiations put together, sun rays falling on a square metre area of earth typically gives about l000 Joules of energy every second. Which technically means the power of sunlight is an irradiance of about 1000 Watt/m^2 on earth's surface. This is not always true everywhere. During cloudy conditions it would be less. During early mornings and late evenings, it would be less. At night it would obviously be zero irradiance. Under shade too, irradiance would be less.

We read above that although sunshine is available for about 12 hours every day, 1000 Watt/m^2 irradiance is not available throughout the day. Hence the total energy available per day would be much less than l2000 Watt-hour/m^2. For example, in Delhi its average is about 5500 Watt-hour/m^2 per day or 5.5 kWh/m^2 per day. In summer months, it may be slightly higher and in the rainy season less than that. This energy over the day is called Insolation and its unit is Watt-hour/m^2.

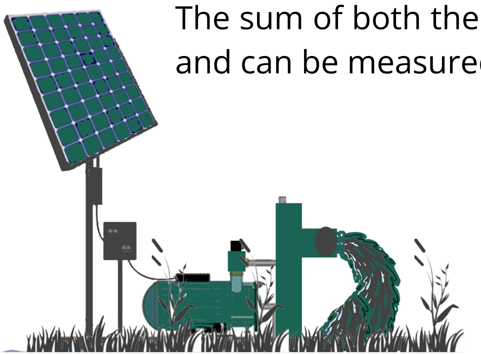
Although predicting irradiance of any given moment is impossible, Insolation per day on any surface can be easily predicted. This is because studies have shown that in most regions, daily energy of sunlight on a particular date of a month is almost the same every year. Given below is the monthly average of Insolation per day of different years in a place in Delhi.

All over the world, meteorological departments of many countries collaborate to collect data of solar insolation in different parts of the earth through satellite and on-ground measurements. This data is available with a history of more than 3 years for most regions on earth. Below is a link to one such website from NASA which can get you insolation data for a given coordinate (Latitude and Longitude).

There are two types of Irradiances:

- Direct Irradiance: The power of sunshine per sq.m due to direct sun rays falling on the surface
- Diffuse Irradiance: The power of sunshine per sq.m due to sun rays falling on the horizontal surface after reflecting off clouds, buildings, lakes and other hindrances on the way.

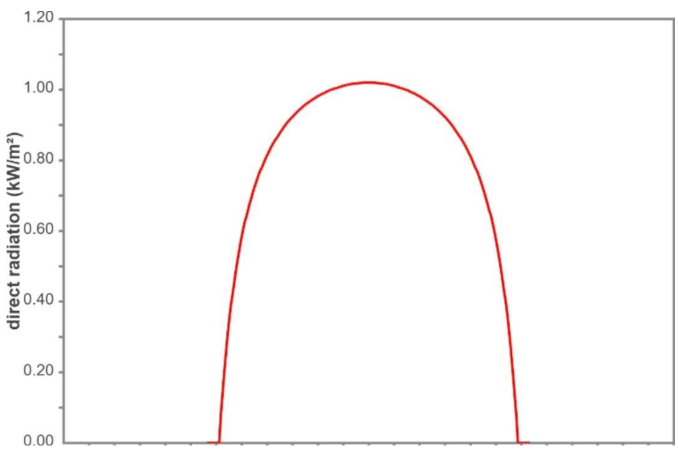
The sum of both the above irradiances is called Global Horizontal Irradiance (GHI) and can be measured with a pyranometer in any surface at any given time



Months	1985	2001	2005
Jan	4.2	4.4	4.4
Feb	5.2	5.4	5.5
Mar	6.5	6.6	6.5
Apr	6.8	6.8	6.7
May	6.3	6.4	6.6
Jun	6.1	6.0	6.2
Jul	5.8	6.1	6.1
Aug	5.7	5.9	5.5
Sep	5.3	5.2	5.2
Oct	5.2	5.2	5.1
Nov	4.4	4.5	4.4
Dec	3.5	3.8	3.7
Yearly Average	5.4	5.5	5.5

Comparison of monthly average of per day Insolation in kWh/m^2 over 3 different years at a place in Delhi.

Sunshine hours



The graph given aside is an indication of how the Irradiance varies from 6 AM to 6 PM on a day. Depending on the month and which place we are in, this changes completely. Let us assume overall during that day, the Sun gave us 5 kWh/m^2 energy in the place where this graph is plotted.

Modules are rated in 1 kW/m^2 irradiance.

This means a 100 Watt-peak rated module will give 100 Watt when 1 kW/m^2 falls on it. So on a day when 5 kWh/m^2 Insolation falls on it how much energy will it give?

100 Watt X 5 kWh/m^2 = 5 Watt-hour.

So here the value 5 kWh/m^2 is behaving like hours. The only reason why this happened is because modules are rated in 1 kW/m^2 irradiance. Hence, we call this value Sun-Shine hours or Equivalent Sunshine Hours (ESH). In this example, we can say the day received 5 hour ESH. It is same as the overall Insolation per day in kWh/m^2.

Design of Solar Power and Energy required

The electric power to run a pump
Pe = (Hydraulic Power/$\text{Efficiency}_{\text{Pump}}$) / $\text{Efficiency}_{\text{motor}}$

In a Solar Pump system, it is the responsibility of Solar PV Modules to provide this electric power. But for designing a solar pump, we prefer to design based on energy required in a day and not power, because solar power keeps varying and hence we cannot predict instantaneous power.

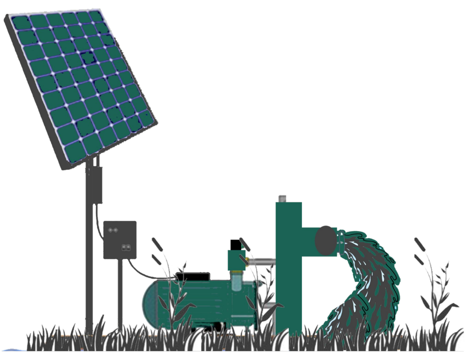
So let's modify above equation to calculate energy:
The electric energy per day needed
E = (Hydraulic Energy per day/$\text{Efficiency}_{\text{Pump}}$) / $\text{Efficiency}_{\text{motor}}$

We have learnt that
Hydraulic energy per day Eh = V (Ltr/day volume) x p (1 kg/Ltr) x H(m) x g (9.8m/s^2)
The unit is in Joules

Hence the Solar energy needed E = (Eh / 3600 x $\text{Efficiency}_{\text{Pump}}$ x $\text{Efficiency}_{\text{motor}}$) in Watt-hour

Now the responsibility of solar is to give this energy over a day. Let's design that step by step

- Step 1: Calculate E for each month based on water requirement
- Step 2: Get the coordinate (Latitude and Longitude) of the area where pumping is required
- Step 3: Check the average insolation per day of every month in the coordinate from NASA website httns://power.larc.nasa.gov/data-access-viewer/
- Step 4: Select the month with highest value of E
- Step 5: For the month see what the average insolation per day is (Assume 5.5 kWh/m^2)
- Step 6: Get solar power required = E/Insolation = E/5.5



- Step 7: Assume inefficiency of 5% losses due to dust, temperature etc, 3% loss in cables and 25% losses in equipment like MPPT, Inverter, VFD etc. So, 7% of efficiency is assumed for the solar power system components on the supply side ($Efficiency_{supply}$). If actual values of efficiency are available for all components, multiply all the efficiencies to get supply efficiency.

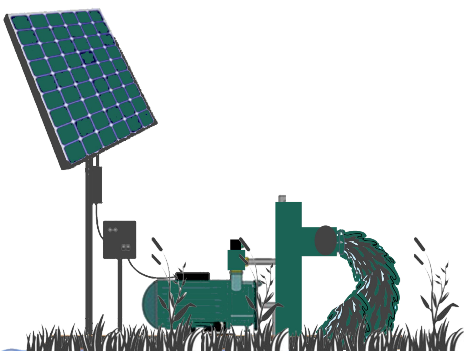
- Step 8: Solar power required
  Ps = E / (Sunshine hours x $Efficiency_{supply}$) in Wp

- Step 9: Calculate the water pumped per day in each month from above Solar power using
  Qmonth = Ps x SShr x $Efficiency_{supply}$ x $Efficiency_{motor}$ x $Efficiency_{pump}$ x 3600/(p x H x g) where SShr is average daily sunshine hour of the month being checked.

- Step 10: Cross check if in any month water pumped is more than the requirement and plan to employ manual or auto switching off of the pump in those months after enough water is pumped.

Water conservation methods and replacement of pumps for higher efficiency etc need to be done before designing solar. Only then we can design solar for the least cost.

After solar is installed if water conservation and better efficient pumps are implemented, already oversized modules will be a waste investment. Also it may cause higher than required water to be pumped out of the source due to higher efficiency.



Design of Solar Array

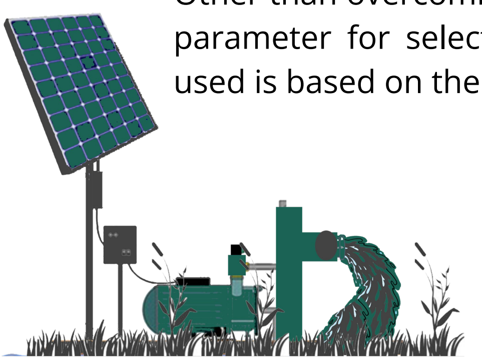
We learnt to calculate solar power theoretically. Now practically there is a certain capacity of solar modules available in the market. Eg: 45 Wp, 100 Wp, 250 Wp, etc. Hence an array of such available modules needs to be designed to add up to the rounded-up value of Ps.

Example if Ps is 2.3 kWp, either 10 numbers of 250 Wp modules can be used or 23 numbers of 100 Wp modules can be used or 8 numbers of 330 Wp modules can be used. Altogether they form an array.

So, what are the factors we should consider to decide which modules are to be used in the array?

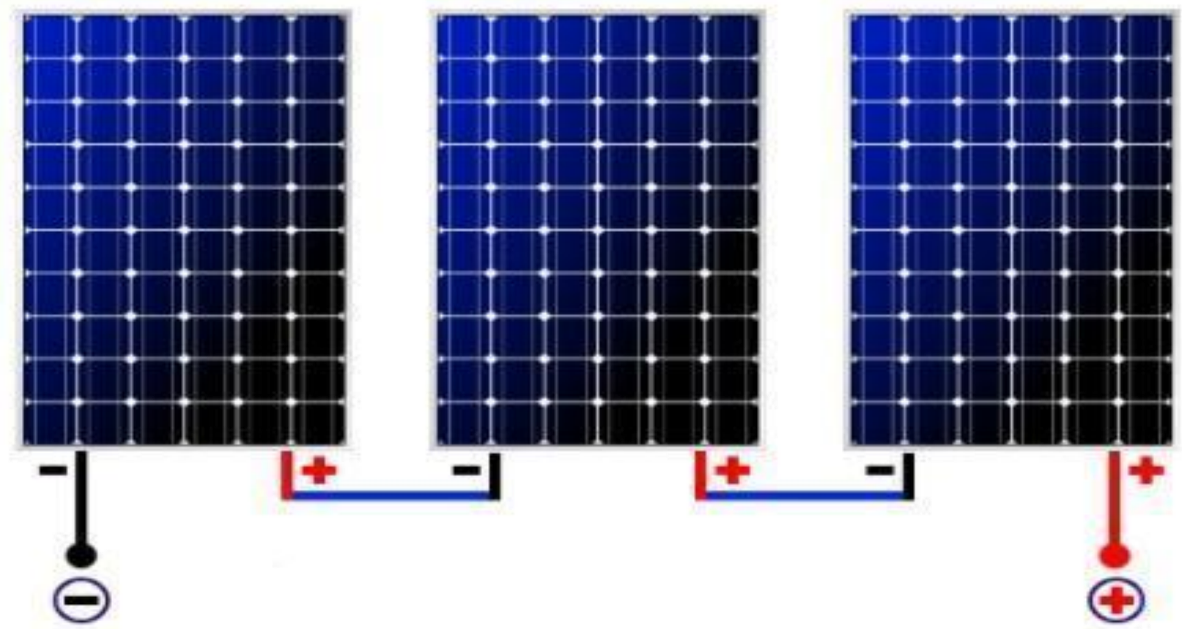
- Rule 1: Different types of modules cannot be mixed and matched. It reduces output due to mismatch losses
- Rule 2: Rounding up should not cause too much oversizing and value should not be rounded down.
- Rule 3: The voltage generated by the array should be a value market available devices are compatible with. Especially, the voltage range of the device the solar gets directly connected to (the motor or the MPPT or inverter etc), needs to be able to accept this voltage generated by the array.
- Rule 4: The current generated by the Array should be compatible with the device it gets connected to directly.
- Rule 5: Try to maximise voltage and minimize current within the restraints mentioned above
- Rule 6: The cost should be optimized (Certain modules have lower Cost per Wp for being fast selling like 330 Wp)
- Rule 7: Where space is restricted consider higher efficient panels like monocrystalline or multi-junction cells. Usually, solar pump installations are in open fields where space restrictions are not common and hence this rule may not be applicable.

Other than overcoming space restriction, efficiency of modules is not an important parameter for selection of modules. Ultimately selection of module type to be used is based on the impact on IRR (Internal rate of return).

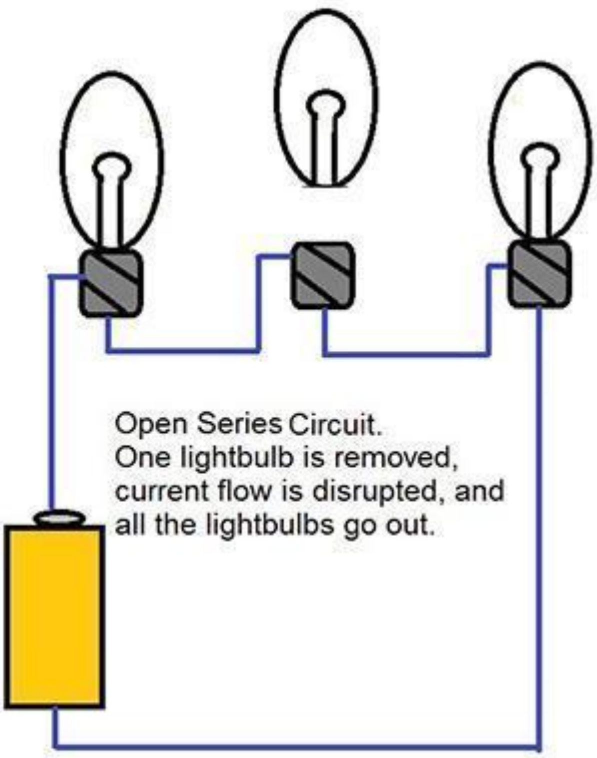


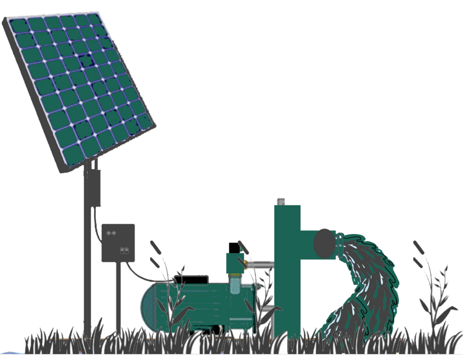
Series Connection of Solar Modules

When the system voltage required is much more than a single PV module can produce, a number of solar modules are connected in series to deliver the required voltage level. Connecting the panels in series will increase the voltage while keeping the current same. In series connection, the positive of one solar panel is connected to the negative of another solar module. This is similar to installing batteries in the torchlight.



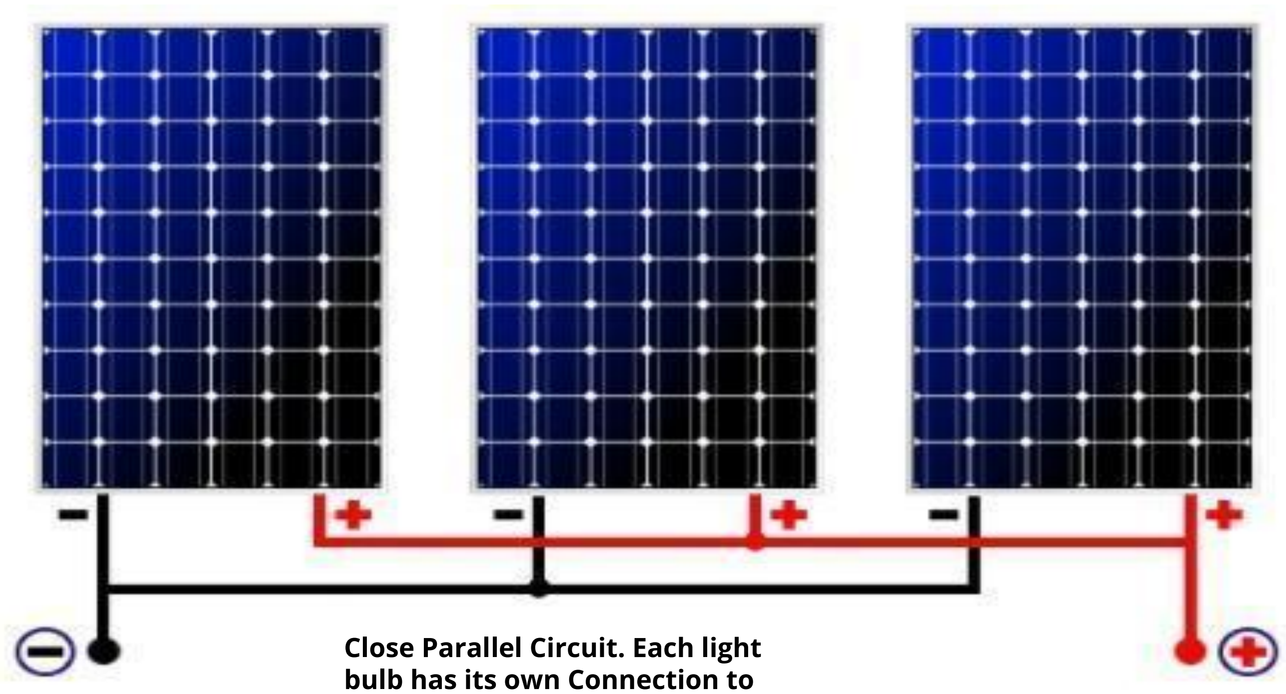
Series connection has only one path and can be extended upto longer lengths as per required voltages. It is continuous and a closed loop, and breaking this connection at any point stops the entire series from operating. Shading of the solar panels can also affect the entire series as they depend on each other.



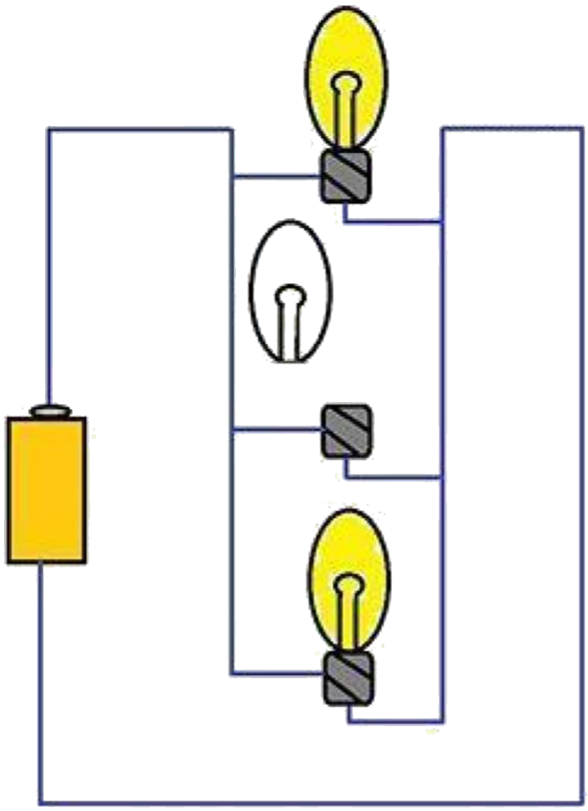


Parallel Connection of Solar Modules

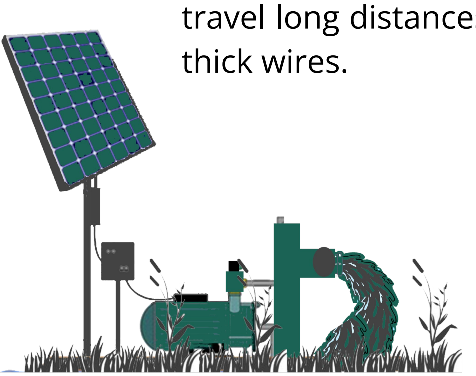
When the system current requirement is more than a single PV module can produce, the solar panels are connected in parallel to increase the current. Connecting the panels in parallel will increase the current in amps while the voltage remains the same. In parallel connection, the positives of multiple modules are connected together and all the negatives of the same modules are connected together.



Close Parallel Circuit. Each light bulb has its own Connection to the power source. So it still works even with one Bulb removed.



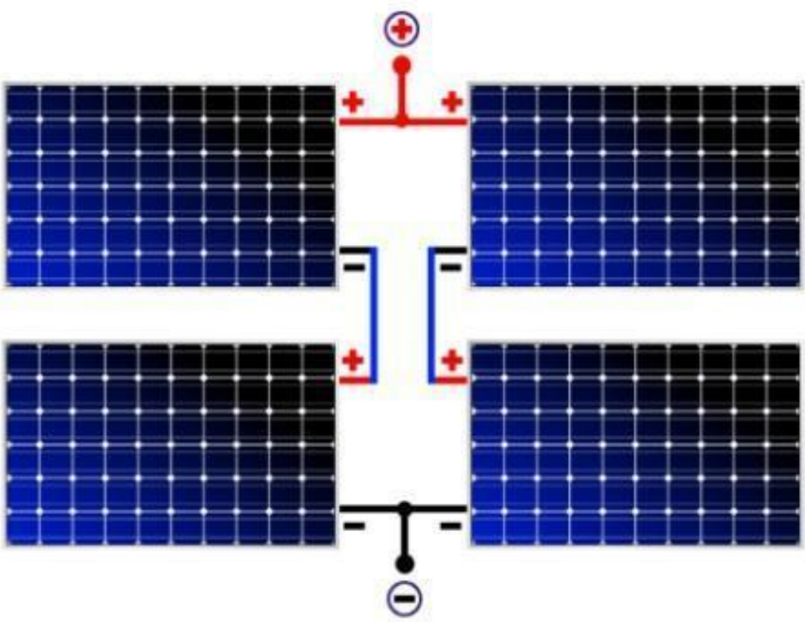
When connected in parallel, if the connection between any two modules is broken, it will not affect the other modules and power transmission will continue. It is similar to the connection in our household electrical wiring. When you turn off the TV, it doesn't turn off your lights. These are mostly used in smaller, basic systems as the high amperage is difficult to travel long distances without using very thick wires.

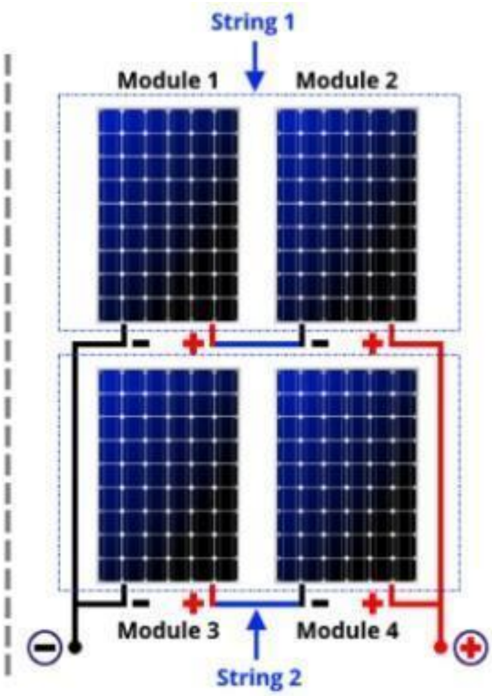


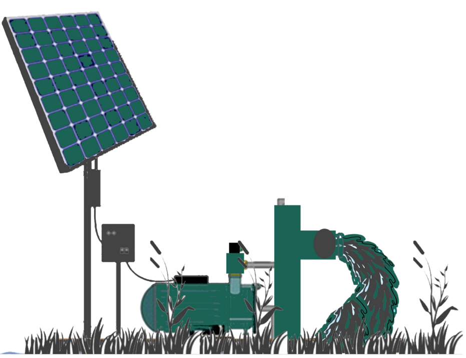
Series-Parallel Connection of Solar Modules

When we need to generate large power from the PV system, we need to connect the modules in a combination of both series and parallel. Usually in this type of connection, the modules are connected in series known as PV module string to get high voltage levels and these strings are connected in parallel to obtain the required current level for the system.

Note:
For Series Connection: Current remains constant
For Parallel connection : Voltage remains constant

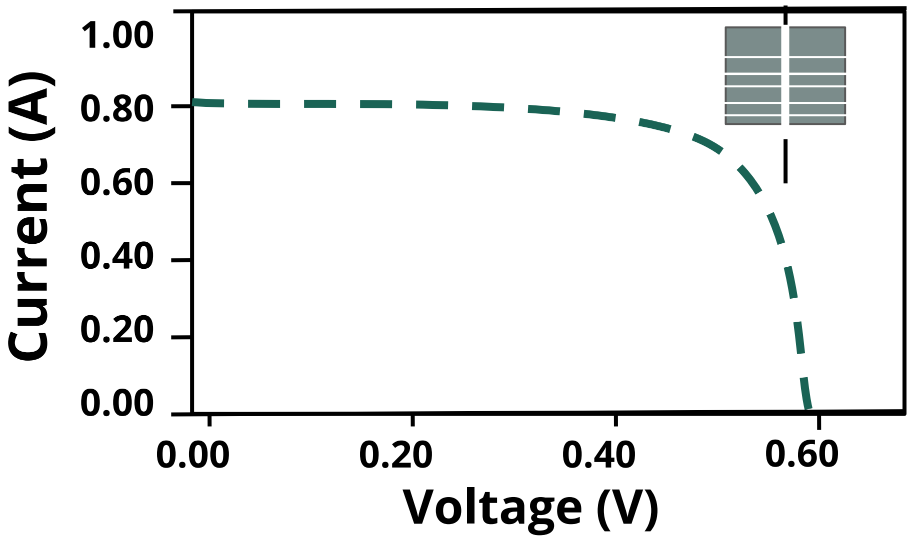






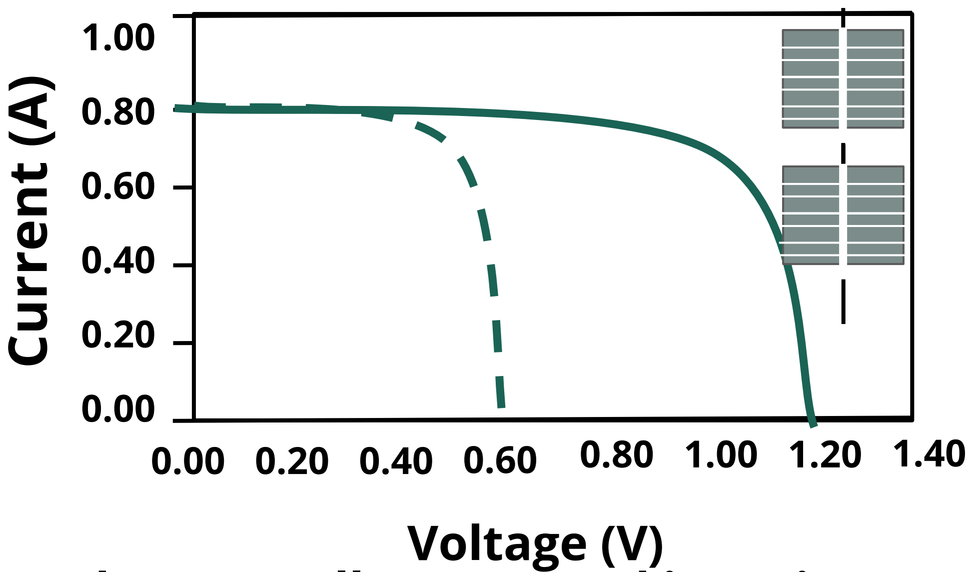
Example of connections in solar modules

Let us consider a solar cell having voltage of 0.6 V and current 0.8 A.



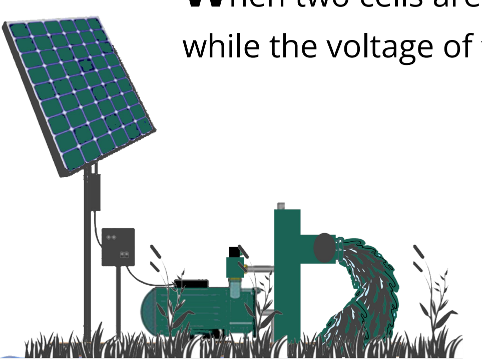
(a) Single cell

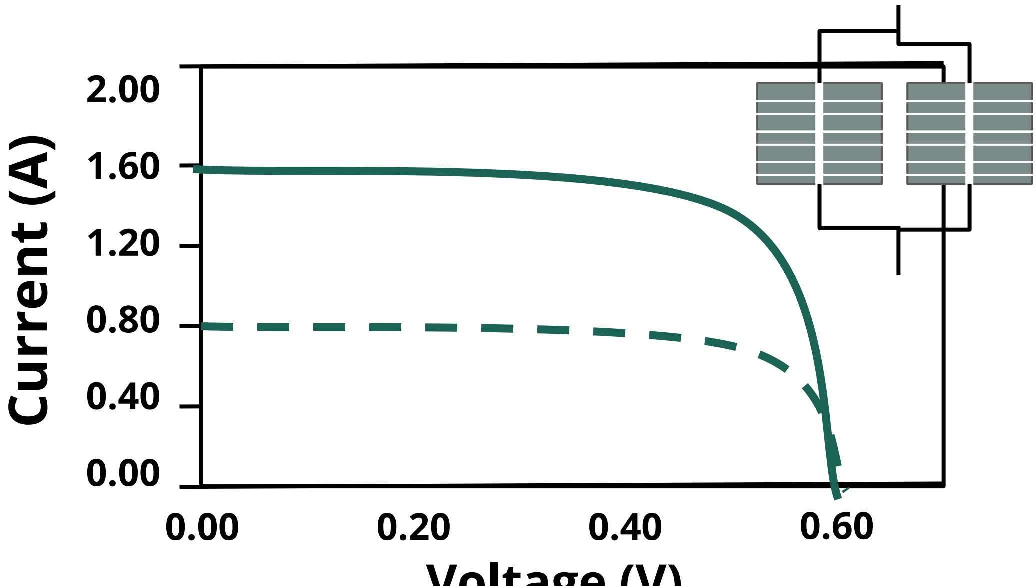
When two identical cells are connected in the series, the voltage between the two cells will be added while the current through the combination will be the same (see figure). In order to connect the cells in series, the positive terminal of one cell should be connected to the negative terminal of the next cell.



(b) Two cells connected in series

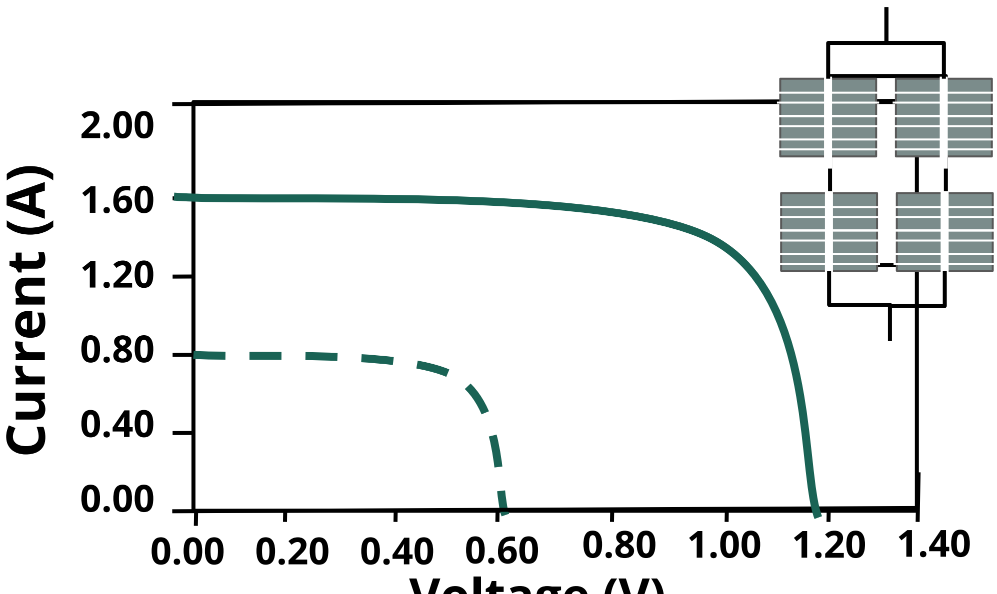
When two cells are connected in parallel the current from two cells will be added while the voltage of the combination will remain the same as that of a single cell.





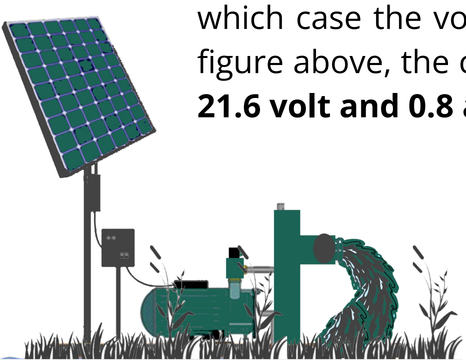
(c) Two cells connected in parallel

When more than one set of cells that are connected in series are connected in parallel to each other, both current and voltage single cell can be obtained as a combination of cells in series and connection of two such series and parallel is shown in the figure. The combined voltage is 1.2 volt and current is 1.6 ampere. In this way, both voltage and current can be increased to the level of our desire.



(d) Series and parallel combination of cells

In typical solar PV modules 36 solar cells are connected together in series in which case the voltage of 36 cells are added. Considering the details provided in figure above, the cells in series combination of 36 cells will provide us **0.6 V × 36 = 21.6 volt and 0.8 ampere.**



Various combination of series parallel connection to get desired power output

150W	**265W**	**340W**
Max power: 150W Short Circuit Current: 9A Open Circuit Voltage: 22V Max Power Current: 8.4A Max Power Voltage: 18V	Max power: 265W Short Circuit Current: 8.7A Open Circuit Voltage: 36.6V Max Power Current: 7.68A Max Power Voltage: 30.6V	Max power: 340W Short Circuit Current: 9.5A Open Circuit Voltage: 46.2V Max Power Current: 8.9A Max Power Voltage: 38.2V

Design of Cables

Electric cable carries current from the solar module to the load connecting all power conditioning equipment in between. In solar pumps, the current from solar panels is DC current and the motor could be AC or DC. Whether DC or AC current, as current passes through the cable, it loses voltage and power due to the cable's electric resistance. The voltage and power lost are given below:

$$V = I \times R$$

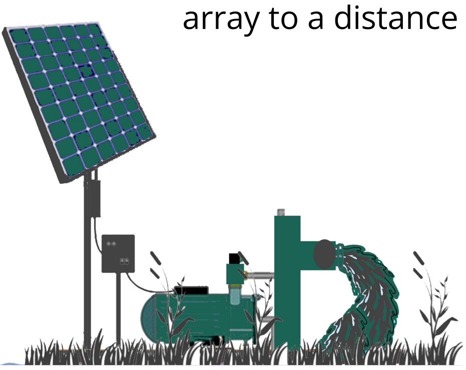
where V is voltage loss, I is current in ampere and R is resistance of cable

$P = I^2 \times R$ where P is the Power loss

Now R is pL/A where p is resistivity constant of the cable material, L is length of the cable and A signifies thickness of the cable mentioned in sq.mm of cross-section area

As you can see above with more length of cable, resistance increases and with more thickness of cable, resistance decreases. So, we try to reduce cable lengths of connections and increase thickness of cable. But since the cost of cable increases with its thickness, we need to optimize the thickness.

Usually accepted practice is to design cable to limit voltage drop to 4% of the system voltage. So, if a copper cable is carrying 2 Amp current from a 24V solar array to a distance of 10 m, the thickness of cable to be used is:



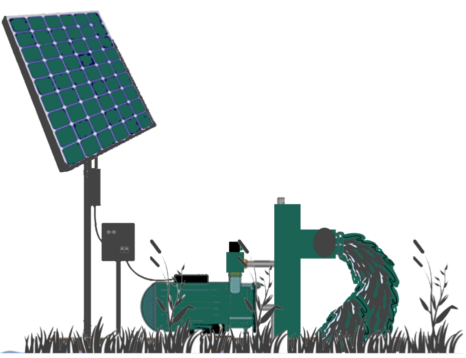
A = I x pL/V where I = 8 Amp, p = 0.017 Ohm-mm^2/m for copper, L = 10 x 2 = 20 m (multiplied by 2 because two cables carry current in case of DC and 1 Ph AC currents. If 3 Ph AC current, then 3 cables each carry the phase current in one direction and neutral carries zero current. So multiplied by 2 is not required to calculate thickness of each phase cable), V = 4 % of 2.4 V = 0.96 V

Hence, A = 8 x 0.017 x 20/0.96 = 2.8 mm^2

So safely a 4 sq.mm cable can be used in above example 3sq.mm is not a standard available thickness in market

Note: Please note that when system voltage is high, current becomes less and thus voltage & power loss also becomes less. So if given a choice, we always prefer higher voltage to reduce cable loss. But higher the voltage, higher the cost of protective devices. Also a particular module available in the market would be for certain voltage ratings only. Hence the trade-off should be properly analysed.

Ingress Protection of cable: Since the cable is used in outdoor installation, it should be weatherproof and UV protected with proper protective sheathing around the cable. Specially designed cables are available for solar applications. Usually 4sq.mm and 6sq.mm cables are common for most systems.



Evaluation

1 **The Solar PV is used to generate electricity anytime and anywhere provided _________ is available.**

a. Wind
b. Water
c. Sunshine
d. Silicon

2 **The conversion of Solar Energy into Electrical Energy is based on the principle of**

a. Photosynthesis
b. Photovoltaic effect
c. Radiation
d. Heat

3 **Traditional solar panels produce _________ electricity as output.**

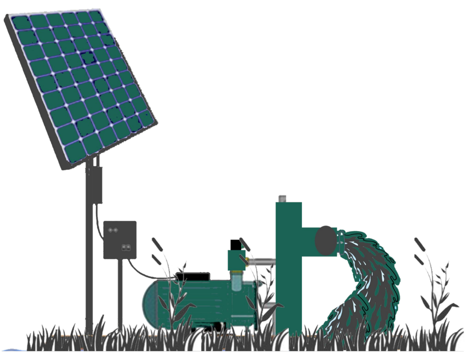
a. Alternating current
b. Direct current
c. Both a and b
d. None

4 **When two cells are connected in series, ________ of the two cells is added.**

a. Power
b. Current
c. Voltage
d. Energy

5 **The current of the two cells is added when they are connected in**

a. Series
b. Parallel
c. Combination of series and parallel
d. None



Evaluation

6 **Higher power can be obtained using low power solar cells by making _______ Connection of cells.**

a. Parallel
b. Series
c. Combination of series and parallel both
d. None

7 **What are the two types of insolation?**

a. Direct and diffuse insolation
b. Straight and bent insolation
c. North and south insolation
d. East and West Insolation

8 **What is the formula to calculate the electric power to run a pump?**

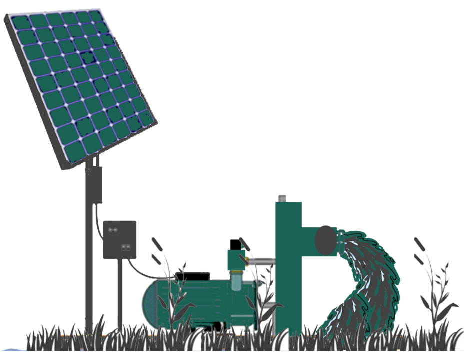
a. Hydraulic Power/$\text{Efficiency}_{\text{Pump}}$
b. (Hydraulic Power/$\text{Efficiency}_{\text{Pump}}$) / $\text{Efficiency}_{\text{motor}}$
c. (Hydraulic Power/$\text{Efficiency}_{\text{motor}}$) / $\text{Efficiency}_{\text{pump}}$
d. $\text{Efficiency}_{\text{Pump}}$ / $\text{Efficiency}_{\text{motor}}$

9 **When do we observe maximum solar irradiance?**

a. Morning
b. Afternoon
c. Noon
d. Evening

10 **Power cables are designed to handle how much voltage drop?**

a. 2%
b. 4%
c. 10%
d. 5%



Answers

1 c.

2 b.

3 b.

4 c.

5 b.

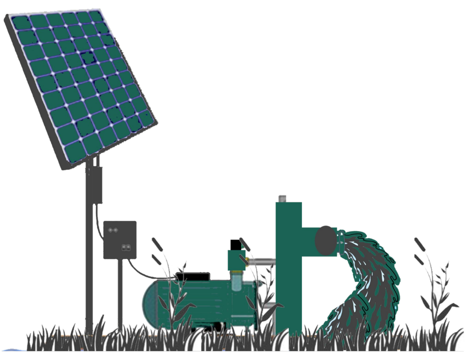
6 c.

7 a.

8 b.

6 c.

10 b.



Solar Pumping System Design

TOPICS COVERED

Basic Considerations

Site Survey

Site Selection

Pump Parameters

Factors affecting solar pump selection

Types of Pumps

Pump Selection Process

Flow chart for Pump selection for Solar PV System

PV Modules required per HP of Pump Power

Evaluation

Basic Considerations

In order to design and successfully implement solar water pumping systems, you need an understanding of several concepts as well as information specific to how you will use your system. These include:

- Daily water requirements and usage — drinking, irrigation, etc. Requirements for high volumes or flow rates may limit applications.
- Available sunlight, which depends on location. Low levels of sun may limit PV energy production.
- Well characteristics, such as depth of water table, drawdown levels and recharge rates, seasonal variations, discharge elevation from earth's surface to water discharge point, total length of pipe, nominal diameter of the borewell and discharge pipe, valves, and elbows, etc.
- Storage systems like catch tanks, concrete or plastic storage tanks, etc., to ensure the daily water requirement is available during low-light conditions.
- Costs — capital, operation and maintenance, labor, life-cycle, etc.

Site Survey

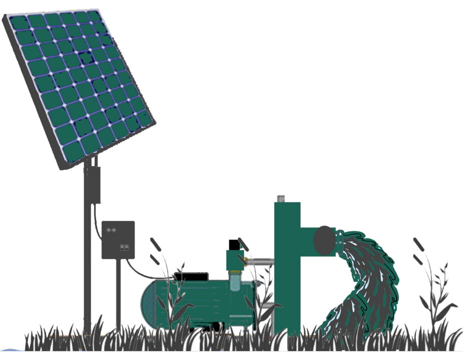
While planning for installation of a solar pumping system it is important to identify key parameters and anticipate major risk involved. Especially in large scale installations it is critical to decide in advance what to do, how to do it, when to do it, and who should do it. Well planned activities can significantly reduce the time of installation and proper process should be followed while deploying the system.

The following steps should be kept in mind while conducting the site survey.

- For conducting this survey the tools required are
  - Survey sheets
  - Camera, or a good quality mobile phone camera
  - Measuring tape and rope or water level indicator
  - Compass
- In this survey the farmer or group of farmers are asked regarding their
  - Land area to be irrigated
  - Size of existing borewell if any
  - Crops grown
  - Water requirement
  - Water level in their area especially during summer season
  - Distance from the borewell to the farthest point of water requirement
  - Site where the solar pump will be installed
  - Any other details that the farmers would want to share
- Photographs and 360 degree video of the installation site is captured using the mobile phone camera for site identification and designing purposes.

Sample Site Survey Questionnaire

Survey Questionnaire	
Client name, address, phone and other details:	
Single point of contact:	
Name of the surveyor:	Date of survey:
Purpose of enquiry:	
Water requirement:	
Can water requirements be reduœd?	
When is the water need year round?	
Any existing solution?	
Plan to replace the existing power source or pump?	
Water source details:	
If well, its diameter, water recovery rate etc:	
If river/stream the coordinate of water drawing point:	
Depth of water availability throughout the year and history of water table:	
Area where pump is expected to be installed with coordinate:	
Geographical description of the area (attach photographs):	
Vertical and horizontal pumping distance with contour of the area:	
Suction side details:	
Delivery side details:	
Coordinate of nearest shadow free region for module installation with photographs:	
Existing pipeline and storage tank details:	
Pressure requirement if any (Eg; for sprinklers):	
Current energy expenses for the requirement:	
Nearby buildings, lightning arrester etc:	



How to Determine the Groundwater Level of the area

Groundwater level in the area is checked by either conducting a drop test through an open borewell at the site, and inquiring neighbouring farmers, local pump technicians or from the agriculture office. The most reliable way to check groundwater at the site of pump installation, is to do a drop test. To conduct a drop test, a heavy object like a rock is tied to one end of a rope and lowered through the open borewell till the water level is reached. The dry length of the rope from the surface of water to the opening of the borewell is then measured which gives the depth of water level in the borewell. Keep in mind the water level reduces during peak summer time, since it is the lowest during that season and that needs to be estimated and enquired from a local reliable source.

How to Determine the Water Output of Borewell

To determine the amount of water required per day on an average, based on crops grown and agricultural land area to be serviced by the pump, the water output of an existing pump if used by the farmer is measured. This can be done by a bucket test.

In the bucket test, a 20 Litre bucket is taken and water pumped out is filled in it. The seconds taken to fill the bucket is recorded with a stopwatch. The time taken to fill the bucket is then multiplied by the total time the pump will operate in a day - this will give us the average water in litres required by the farmer for irrigation. This will then need to be verified by the land area for irrigation and crops to be grown.

For example if the bucket is filled in 10 seconds,

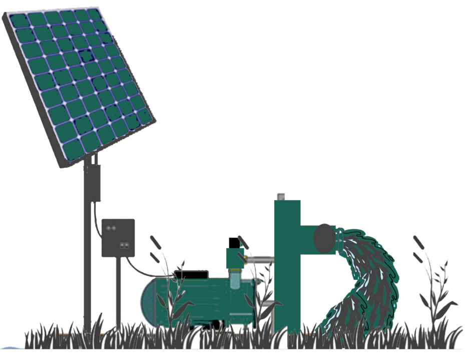
then the water output is about

(60 ÷ 10) x 20 litres = 120 litres of water per minute.

Now, if the pump is operated for 2 hours everyday to irrigate the agricultural land,

then the pump runs for **2 x 60 = 120 minutes every day**

Thus, the water requirement is **120 x 120 = 14,400 litres per day.**



Site Selection

As a rule of thumb, the solar modules and solar pump installation requires a south-facing square or rectangular area of 100 square feet per HP of the solar pump. For example, if the farmers install a 5 HP solar pump, then the farmer needs an area of approximately 500 square feet. The area should be shadow free at all times of the day and year, otherwise solar power generation will not be adequate to run the solar pump. The areas for installation of solar module mounting structure, earthing pits and pump boring are measured and marked.

The pump needs to be facing south since the installation is being done in the northern hemisphere. In case of the southern hemisphere, the solar modules should be installed facing the north direction.

Preferably the pump should be installed near the solar module to reduce the repair and transmission costs. During site selection, the distance between the solar modules and pump is measured. This is important to calculate the length of pipes and wires required.

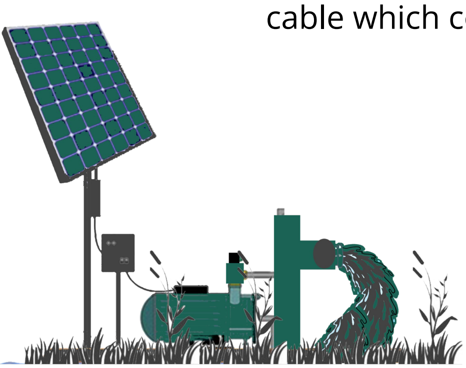
Solar PV Location

The location for installing solar panels should fulfill the criteria given below:

- Even surface for mounting the solar panel structure;
- Shade-free area (no shade from nearby houses, structures, overhead tanks, electricity poles, etc.)
- Low dust and dirt, low incidence of bird droppings;
- Easily accessible for cleaning of panels;
- As close as possible to the pump and water source; and
- Provision of space for unrestricted tracking movement.

For a proper site selection, there are a few things to be kept in mind.

- Trees or other structures that may cause shading near the borewell need to be noticed and marked and asked to be removed or cut partially before installation.
- Any other physical feature like mound, ditch/pit, any overhead electrical cable which could cause a hindrance in installation need to be avoided.



Did you KNOW?

Add Page 7

- An access road or path needs to be maintained to the installation site to carry out any maintenance operations if required.

Hence, a shadow free south facing site has to be selected for module installation to ensure uninterrupted solar irradiation on the solar modules. The farmer technical and site survey are extremely critical and can lead to the success and failure of a solar pump selection and installation.

Pump Location

The location of the pump should fulfill the criteria given below:

- Minimal suction head should be preferred: If the water level is within 10 meters, a surface pump can be installed; when water level is below 10 meters, submersible pumps are installed.
- Low suction lift (vertical distance between the water surface and the surface pump);
- As close as possible to solar panels;
- Suitable (higher/central) location within the area to be irrigated; and
- In case where multiple water sources are available, the location with the highest water table should be chosen

Pump Parameters

a) **Pressure:**

The force per unit area of resistance in the system. The pressure rating of a pump defines how much resistance it can handle or overcome. The amount of pressure exerted by the fluid at a particular point. The strength of flow of water depends on the water pressure.

Unit: Pascal (Pa), N/m^2

b) **Flow rate:**

Flow rate is defined to be the volume of fluid passing by some location through an area during a period. It is referred to as capacity, is the volume of liquid that travels through the pump in each time.

Units: Cubic Meter per Second (m^3/s)

c) **Head:**

Head is the maximum height that a pump can move fluid against gravity. The purest example of this is if you have a vertical pipe extending straight up from the discharge outlet. A pump with 5m of head will pump fluid up the pipe 5m from the discharge outlet.

Units: meters

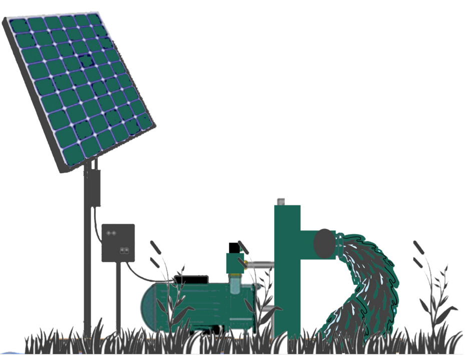
d) **Pump Efficiency:**

Pump efficiency is defined as the ratio of water horsepower output from the pump to the shaft horsepower input for the pump.

$$\eta_{pump} = P_{out}/P_{in}$$

Water horsepower is the minimum power that is required to move the water. Shaft horsepower is the power delivered to the shaft of the pump.

Keep in mind that any efficiency rating of the pump given by the manufacturer assumes certain system conditions such as the type of fluid transported: water is a typical standard. The efficiency may not be accurate if these assumptions differ from the consumer's intended application.



Factors affecting solar pump selection

There are many factors that should be considered before deciding on the size of solar water pumps, like

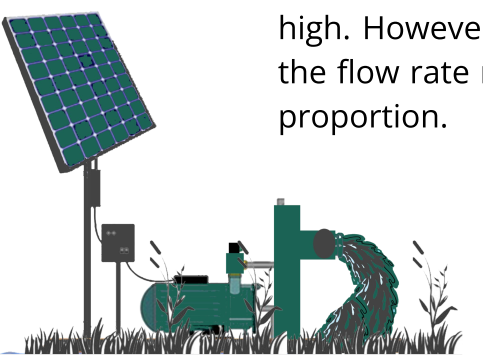
- **Daily water requirement, based on the area to be irrigated and crops grown throughout the year**
  The daily water requirement depends upon the landholding size and cropping pattern of the particular farmer. A typical 2 HP solar pump can irrigate about 1 acre of land per day when the depth of water for irrigation is 2 inches in a day. Thus, the irrigation requirement is high, especially required for growing crops like Rice. In case low water intensity crops like mustard, sesame, and pulses are grown, a 2 HP pump can irrigate about 2 acres of land while a 7.5 HP pump can irrigate upto 10 acres of land.

- **Amount of water required to be drawn or flow rate**
  The actual flow rate varies depending upon the season and the water level of the region. So, it is difficult to estimate the actual maximum flow rate in the water pipe. However, the solar pump manufacturer provides the maximum flow rate for the pump supplied with the system.

- **Total Dynamic head or the Depth of water source**

Daily Flow in m3 for surface mono solar water pumping system						
6.5 kW/hr average performance ranking						
	System size (Watts)					
Head (m)	200	400	600	800	1200	1600
5	33	53	102	104	110	112
10	24	46	81	93	105	108
15	17	39	47	79	98	104
20	14	31	42	62	90	99
25	11	25	36	49	80	93
30	9	20	31	34		
35	7	16	26	30		
40	6	12	15			
45		10	13			
50		8	11			

As you can see from the table for a 1 HP or 750 Watt solar water pump if the water level is upto 5 metres or 16.4 feet, the flow rate is significantly high. However, when water level goes down below 10 meters or 32.8 feet, the flow rate reduces by two thirds, reducing the water output in the same proportion.



- **The size of the boring well if already present**

  The size of the existing bore well is important, for example if the bore size is 6 inches, then before selection of pump we need to check the diameter of the pump and the pump diameter should be less than the bore size. This is only applicable for submersible pumps.

  Boring depth is required by the engineering team to determine the length of the column pipe.

  For submersible pumps the pump inlet should be matched with the bore diameter or plumbing fittings need to be incorporated as per pump and bore.

- **In case of surface pump, distance of the water source from the pump and running length of discharge pipe is important**

  A surface pump's suction lift is maximum upto 20-25 feet, and the horizontal pumping distance is 100 feet for every 10 feet vertical head. If a customer uses a 100 feet pipe for water discharge, as a rule of thumb 10 feet of vertical head or depth is added in the original head of the pump. Thus, the distance from source to supply location for the solar pump is important. If the distance to be pumped over ground is more, a submersible pump is advisable.

- **Water level of the region in peak summer season**

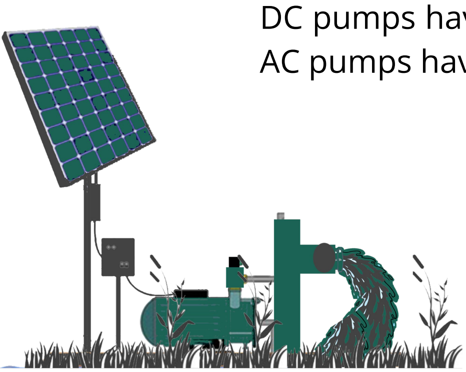
  From the summer groundwater level data, the engineering team can understand the head range of the pump to be installed. The depth of peak summer water level and the delivery of discharge water distance information is required for pump selection.

- **Grid power availability at the site and if it is single or three phase**

  If Grid power is available at the site and the customer wants to run the pump through the grid, then we need to incorporate an AC change over switch between Solar and Grid in the pump controller. Depending upon which grid connection phase available at the site, the pump selection will vary accordingly/. 1 and 2 HP pumps can only run through a single phase line, while above 3 HP, a three phase power supply is required to run the pump via grid.

- **Budget**

  The cost of a solar pump is a determinant factor in pump selection as well. DC pumps have higher efficiency and lifetime, but come at higher cost, while AC pumps have lower efficiency but are cheaper and can be serviced locally.



Characteristic	Why is this characteristic important?
Static water level	The static water level is the level the water source reaches without pumping applied to it. This figure forms the basis for calculating the total dynamic head.
Water source depth	The depth of the water source must be known in order to determine its volume.
Recovery rate	The recovery rate is the rate at which water enters the source from natural processes. The recovery rate must exceed the proposed pumping rate or the water source will run dry.
Topography	The topography of the site must be known in order to determine distances and gradients of water movement. This information is used to determine pump sizing and the location of components.
Water quality	The quality of the available water can affect pump selection as well as whether the water is suitable for its intended usage.
Seasonal variations	Seasonal variations in the available water source must be known in order to evaluate a pump's performance over the whole year.
Other water losses	Other potential water losses, such as evaporation, must be considered when planning a pumping system.

Types of Pumps

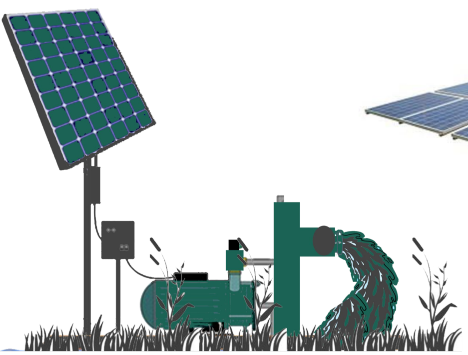
As discussed in the previous chapter, we have seen there are various kinds and quality of solar water pumps available in the market. To summarize we will get total four combinations of motor-pump sets:

1. AC Surface Pump

2. DC Surface Pump

3. AC Submersible Pump

4. DC Submersible Pump



Pump Selection Process

Step 1: Determination of the amount of water required per day

The amount of water required each day or week will depend on the actual application. If the water is being used within a village, household or a resort then data should be available on the amount of water required per person in the village, household or resort. This information could be obtained from the relevant government departments or could already be known by the client. The designer might need to have an ongoing consultation with the client to determine the actual daily volume of water required.

As an example, the World Health Organization (WHO) states that a person requires, as a minimum, 20 liters per day. If the site includes showers, washing machines etc. then the water usage would increase accordingly.

If the water is required for agricultural use, then the requirement is determined using the survey done pre-installation The water requirement depends upon:

1. The total agricultural area to be irrigated
2. The type of crop grown
3. Growing season

Let's learn this with an example.

A field of 10 hectares needs to be irrigated where a cereal is growing which needs 4 mm of water per day. Determine the water requirement for the field per day, assuming there is a 30% wastage or loss of water due to various environmental factors.

Now we know 1 hectare = 10000 m^2 = 10^{10} mm^2

So, water required per day = 4 × 10^{10} mm^3

1 litre = 10^6 mm^3

Water requirement per day in litres = 4 × 10^{10} mm^3 / 10^6 mm^3 = 4 × 10^4 litres = 40,000 litres

Considering 30% wastage, water requirement per day = 40,000 + (30% of 40,000) = 52,000 litres

Based on the rain, a plan of pumping system and tank storage needs to be done. This is site specific and is done by the engineering team of the solar installation company.

Step 2: Check the available type of water source (Open Well, Borewell, etc)

The type of solar pump (Surface/Submersible) will depend on the water source. If the source is a borewell, then a submersible pump that fits the borehole or well should be selected. If the water source is a river, shallow well, pond or lake, then either a surface or floating pump may be selected. During the site visit the designer selects the pumping system that is most suitable for the site.

If groundwater is to be extracted for irrigation, then a submersible pump is used. If the system is connected to a borehole then the designer must obtain information on the diameter and depth of the borehole during site survey. Diameters of boreholes are typically 100 mm (4 inch) diameter or 150 mm (6 inch) diameter but they can be greater.

Step 3: Determination of total dynamic head

The Total Dynamic Head or TDH signifies the effective pressure at which the pump must operate. It primarily consists of four parameters - pressure head, velocity head, friction head and static head. Out of these the variable values are of vertical head or total vertical lift and friction head or total frictional losses.

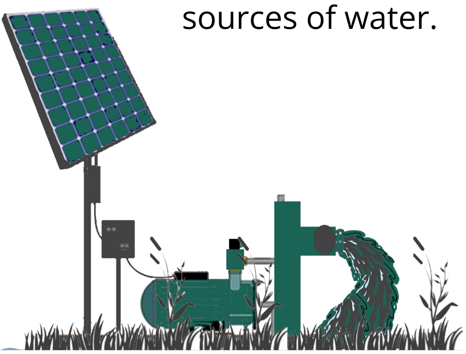
Total vertical lift = Elevation the pumping + Standing Water Level + drawdown of pump + height at which water is discharged.

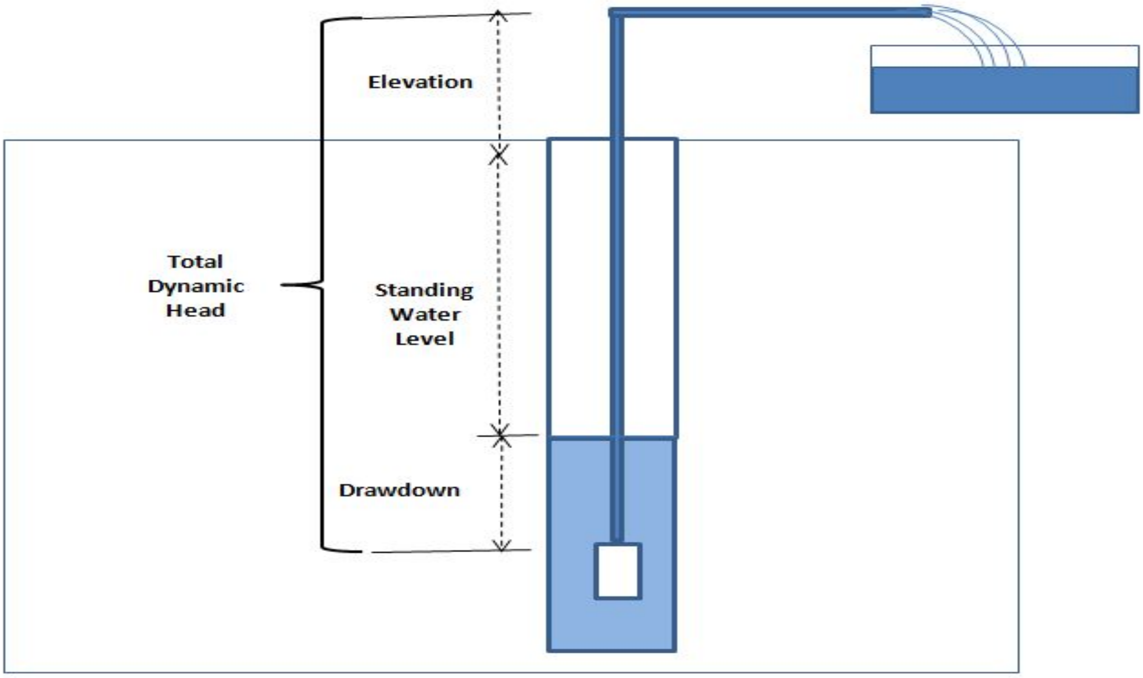
Standing water level is the difference between the ground surface and the water level in the well, when the well is fully charged.

Drawdown is the height by which the standing water level drops due to pumping.

Frictional Loss is the pressure required to overcome friction in the pipes from the water pump outlet to the point of water discharge. It is given in meters. Due to the frictional losses, the total dynamic head increases. Use of borewell with higher diameter and reduction in the number of turns the water delivery pipe reduces the frictional loss.

In case of surface pumps, the suction head or total dynamic head is based on the vertical elevation and the friction head. The drawdown effect is absent for open sources of water.



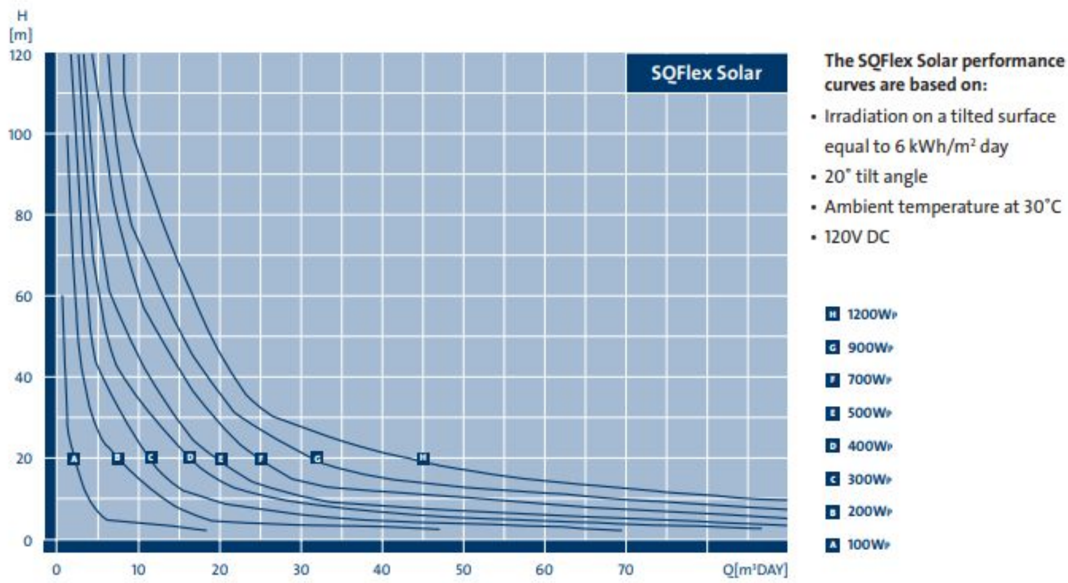


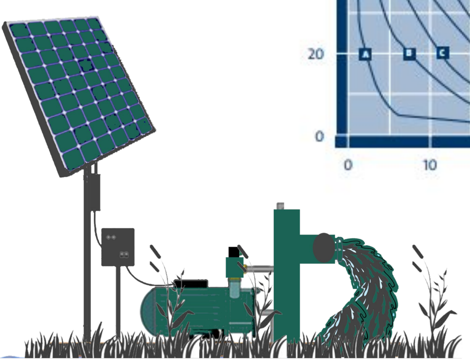
The head loss due to friction in the diameter of borewell is given in the following table:

Diameter of Borewell (in inches)	Head Loss due to friction (in feet)
3.5	16.2
4	8.5
5	2.7
6	1.1
8	0.3

SQFlex Solar Curve:

The SQFlex solar performance defines the range of solar pumping for particular capacity of wattage or Wp. At particular head it will show expected water output.





In the graph, the x-axis represents the total dynamic head or effective depth of water. On the y-axis, the water output is represented in m^3/day. 8 separate lines are shown, each representing a corresponding power obtained from the solar panels, ranging from 100 to 1200 Wp. At a constant head of 20 meters, we see there is a significant difference in the water output as shown in the following table:

Point	Wattage of panels	Head	Water Output (m^3/day)
A	100	20m	3
B	200	20m	8
C	300	20m	12
D	400	20m	16
E	500	20m	20
F	700	20m	25
G	900	20m	32
H	1200	20m	45

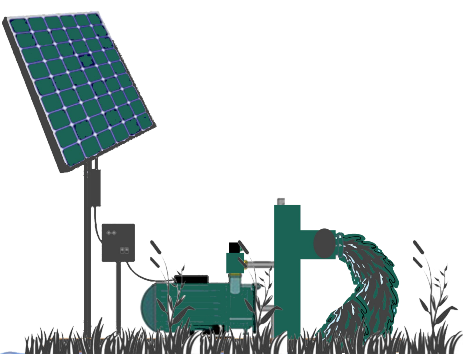
The SQFlex Solar performance curves are based on:

- Solar panels placed at 20° tilted angle
- Solar insolation at the rate of 6 kWh/m^2 per day
- Ambient temperature is 30°C
- The supplied voltage is 120 Volts with direct current supply

Step 4: Determination of the solar radiation available at given location

The insolation at a location is the total solar energy falling on a surface on a day, and measured in watt-hour/m^2. This is the summation of the direct irradiance and diffuse irradiance.

The average value of solar insolation is approximately 5500 watt-hour/m^2, with an equivalent sunshine for 5.5 hours every day. Therefore, the average insolation per hour is 1000 watt-hour/m^2 which is also the standard test condition (STC) for solar energy calculations.



Step 5: Determination of hydraulic energy required per day (in Watt-hour/day) to pump the required amount of water

Total hydraulic energy required by the submersible pump = Mass x g x Total Dynamic Head where g = acceleration due to gravity = 9.8 m/s^2

Also, hydraulic energy required = Density x Volume x g x TDH

or, hydraulic energy required (in Wp) = (Density x Volume x g x TDH) ÷ $3.6x10^3$ where $3.6x10^3$ is the conversion factor.

Taking cue from the previous example, let us see how much energy is required to pump the field per day.

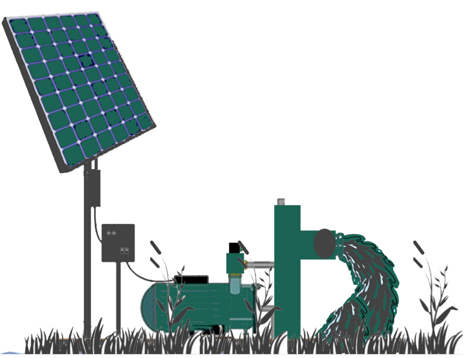
Daily water requirement = 52,000 litres
Effective sunshine hours = 5.5 hours
Hourly effective water supply = 52,000 ÷ 5.5 = 9455 litres

Therefore, volume of water required per hour = 9455 litres
Density of water = 1 kg/litre

Assuming the total dynamic head of the region to be 20 metres,

Hydraulic energy required per hour (in Wp) = (1 x 9455 x 9.8 x 20) ÷ $3.6x10^3$ = 514.7 Wp

Thus, this is the total hydraulic or potential energy of the water raised due to pumping, which must be supplied to the pump. For a surface sump, the total dynamic head is replaced by the length of vertical lift of water from the source to the pump.



Step 6: Determine the Pump capacity and size and number of PV modules required

Nowadays, various types of PV modules are available, with capacity ranging from 5 Wp to 400 Wp. Panels with suitable specification are used for solar PV systems. Most commonly used panels are 300 Wp panels, widely available in India.

Solar PV modules have an efficiency of approximately 15-20% depending upon the type and condition of the panels. The average efficiency of solar PV modules is 18%. This is considered while providing the power rating of the solar panels.

Pumps-motor set has an average efficiency of 80% and the controller including VFD and MPPT has an efficiency of 90-95%.

Operating factor is the estimate of the actual output from a PV module. The operating factor is between 0.6 and 0.9 implying the output power is 60 to 90% of the rated output power in normal operating conditions, depending on temperature, dust on module, etc.

System efficiency = Pump-motor efficiency x Controller efficiency x Operating Factor

Total power requirement from the solar modules (in Wp) = Hydraulic power required ÷ System losses

Number of Solar PV Panels required = Total power requirement ÷ Power rating of each module

Power rating of motor (in HP) = Total power requirement ÷ 746

Let us determine this with the solar panels and size of pump required for the example we were discussing before.

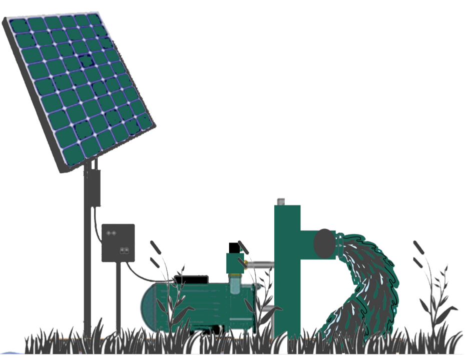
Considering,

Pump-motor efficiency = 80%

Controller efficiency = 95%

Operating factor = 0.85

System efficiency = 0.8 x 0.95 x 0.85 = 0.646 or 64.6%



Total power requirement from the solar modules (in Wp) = 514.7 ÷ 0.646 = 796.75 Wp

Solar panels of rating 300 Wp are commonly used.

Number of Solar PV Panels required = 796.75 ÷ 300 = 2.65 ~ 3 panels

Power rating of motor (in HP) = 796.75 ÷ 746 = 1.06 ~ 1 HP

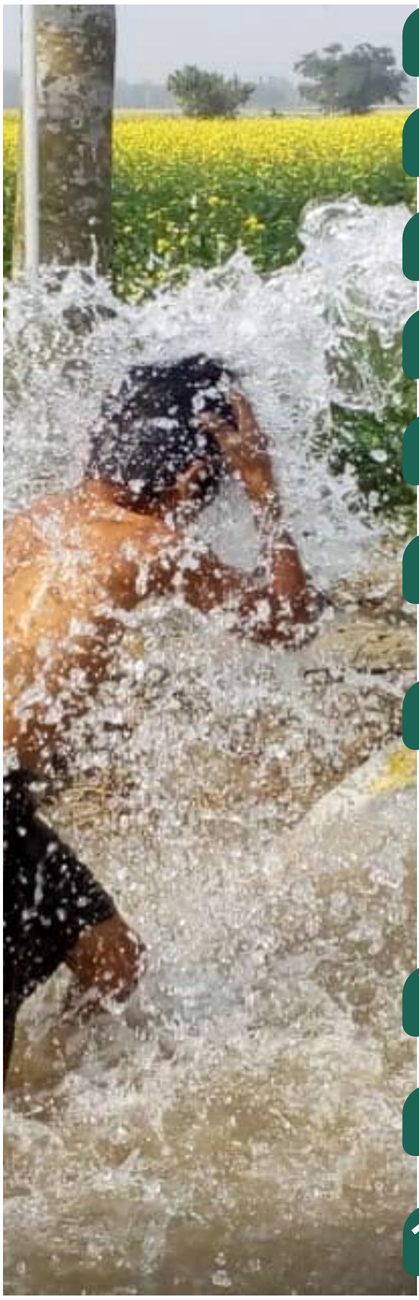
Step 7: Choice of motor based on efficiency and other factors

The above calculations are done considering the DC motor driven pump. A system can also be designed for an AC motor but one must consider the inverter and its efficiency in the calculations.

Voltage of the solar pump motors can be AC (alternating current) or DC (direct current). Direct current motors are used for small to medium applications. The cost of DC motors are higher than AC motors and for the same capacity they provide better water output as compared to AC pumps. But recently, prices of DC motor driven solar pumps have reduced considerably.

Flow Chart for Pump selection for Solar PV System

Off Grid Surface and Submersible Pumps (AC / DC)



1. Find Head and LPD
2. Get Insolation
3. Find Litre per hour
4. Plot the system curve
5. Find the Pump shaft power
6. Compare pump curve of few pumps with required shaft power
7. Select the one which matches system curve at its maximum efficiency point

Ensure NPSHa and decide pump positioning

8. Calculate motor input energy
9. Design solar array
10. If intended to use tracking check its feasibility and design solar array accordingly

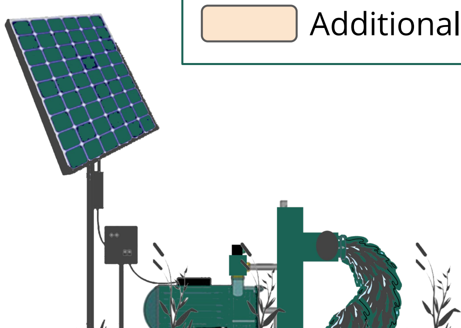
Select the MPPT, Inverter and VFD panels as per requirement

Select the MPPT, DC-DC Converter and Voltage regulator as per requirement

Common Steps

Additional Steps for AC

Additional Steps for DC

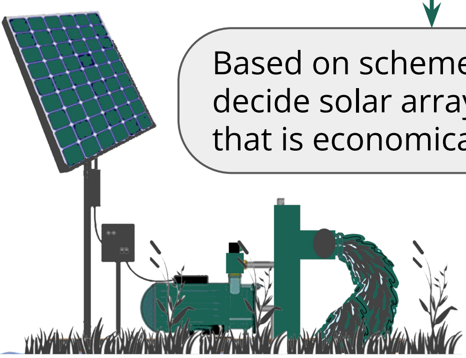


Off Grid Solar Pumps with battery backup

1. Find Head and LPH
2. Plot the system curve
3. Compare pump curve of few pumps with required shaft power
4. Select the one which matches system curve at its maximum efficiency point
5. Select pump position
6. Calculate motor input energy
7. Design battery bank
8. Design solar array
9. If intended to use tracking check its feasibility and design solar array accordingly
10. Select the MPPT or Charge controller, Inverter or DC-DC Converter

On Grid System - Surface or Submersible

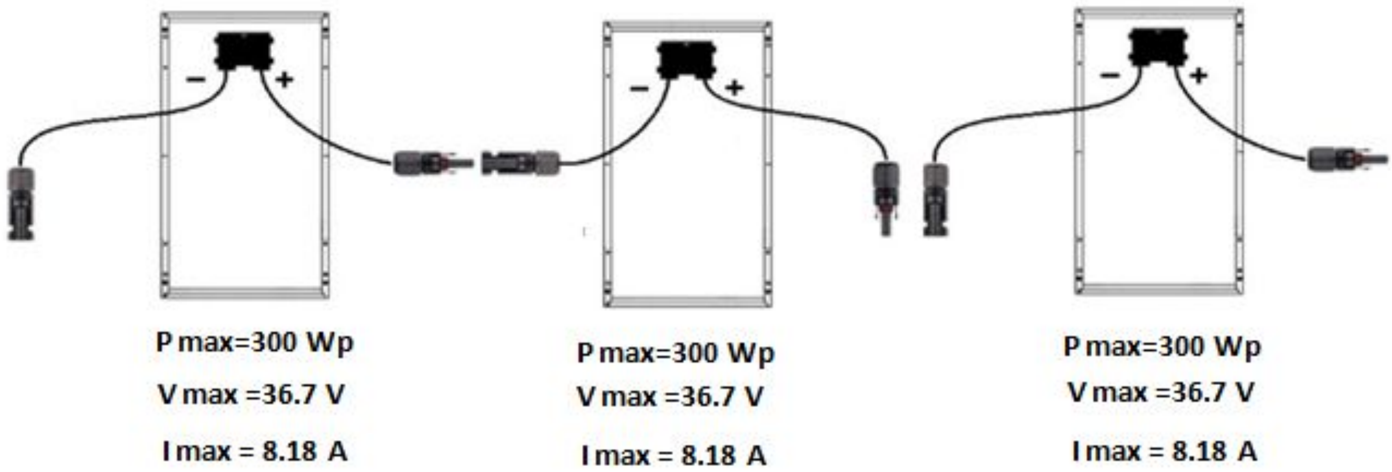
Find Head and LPH → Plot the system curve → Find the Pump shaft power → Compare pump curve of few pumps with required shaft power → Select the one which matches system curve at its maximum efficiency point → Select pump position → Calculate motor input energy → Based on scheme running decide solar array capacity that is economically feasible → Select the MPPT and Grid tie Inverter



PV Modules required per HP of Pump Power

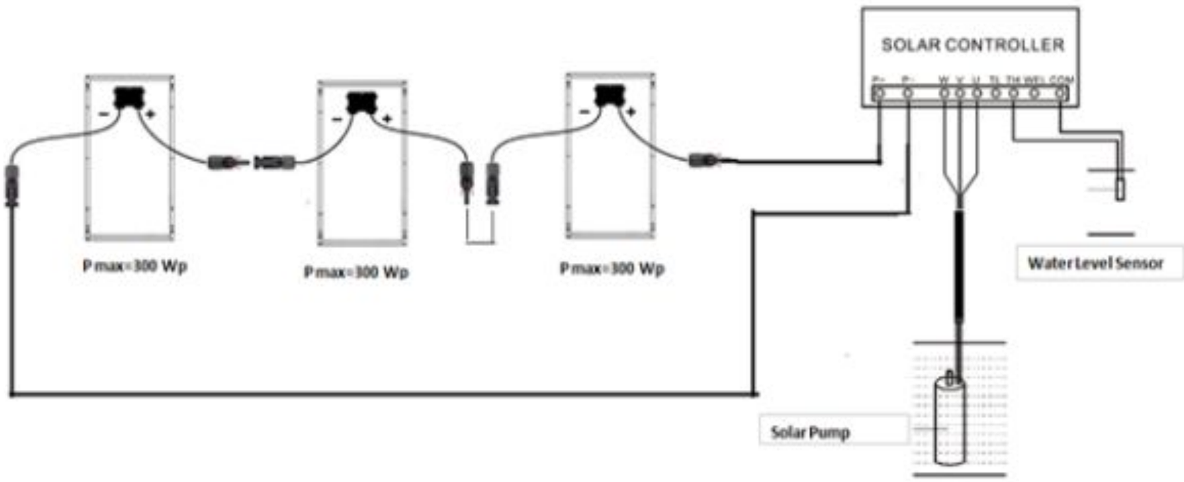
We know, 1 HorsePower (HP) is 745.7 or 746 Watts.

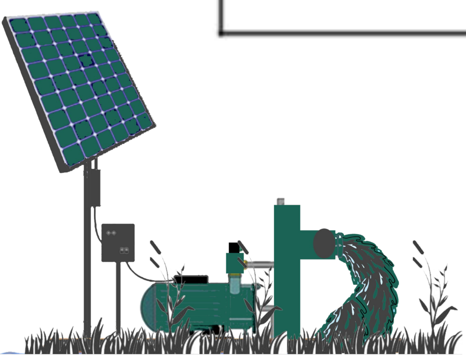
Considering the PV modules are connected in series, the voltages are added while the current remains constant.
If the PV Modules are connected in parallel, then the currents are added, while the voltage remains constant.



Total Voltage = 36.7 V + 36.7 V + 36.7 V = 110.1 V
Total current = 8.18 A
Total Power output of PV array = 110.1 x 8.18 = 900.62 Wp

To run a motor-pump set of 1 HP capacity, considering the system losses, we need 3 Solar modules of 300 Wp connected in series to get 900 Wp.





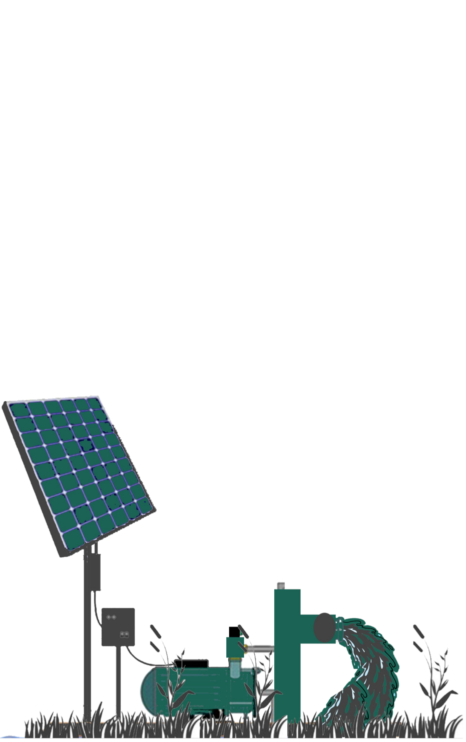
Similarly for higher pump capacity more number of panels can be added to get desired power output, as shown in the following table:

Motor Pump set capacity (HP)	Motor Pump set capacity (Watts)	Solar PV Power (Wp)	No. of Modules of 300 Wp
1	745.7	900	3
2	1491	1800	6
3	2236.5	2700	9
5	3727.5	4500	15
7.5	5591.25	6750	23
10	7455	9000	30

The number of panels need to be aligned with the structural compatibility with the mounting structure and connections. For example, if 200 Wp modules are used, then the number of panels will vary according to the following table:

Motor Pump set capacity (HP)	Motor Pump set capacity (Watts)	Solar PV Power (Wp)	No. of Modules of 200 Wp
1	745.7	800	4
2	1491	1600	8
3	2236.5	2600	13
5	3727.5	4400	22
7.5	5591.25	6400	32
10	7455	8000	40

Note: When an odd number of panels are used, especially when more than 3 HP pumps are being installed, then there can be issues with alignment and connections. Therefore, even numbers of panels are preferred.



Evaluation:

1 **If depth of the water source is 110 feet then it is advisable to use surface pump**

a) True
b) False

2 **Overall efficiency of AC pumps is better than DC**

a) True
b) False

3 **Submersible pumps are used as they are more efficient than surface pumps**

a) True
b) False

4 **Which type of pump should be required to draw 25,000 liters of water every day from depth of 30m**

a) DC Surface pump
b) AC Surface pump
c) DC Submersible pump
d) AC Submersible pump

5 **Calculate the water output from the SQFlex Solar graph, if 900 Wp of panel is connected to 1 HP pump at a total dynamic head of 30m.**

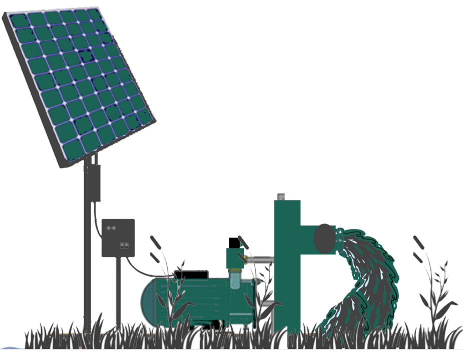
a) 8 (m^3/day)
b) 12 (m^3/day)
c) 23 (m^3/day)
d) 32 (m^3/day)

6 **In above question water output flow rate will increase when**

a) Increase in radiation
b) Decrease in radiation
c) Increase in Total dynamic head
d) Decrease in Total dynamic head

7 **Efficiency of pump will increase with increase in ambient temperature**

a) True
b) False



Answers

1 c.

2 b.

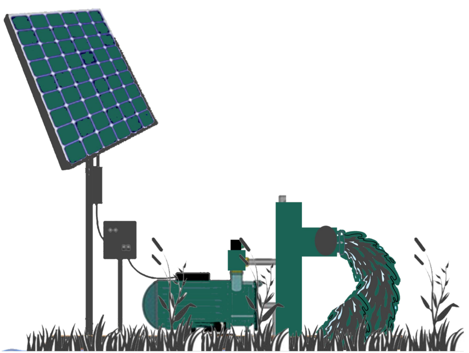
3 b.

4 c. or d.

5 c.

6 a & d

7 b.



Chapter 6

Solar Pump Installation

TOPICS COVERED

Material management checklist for Installation of Solar Pumping System

1. **Solar PV Array**

- ✔ Note brand & references of solar panels on the identification sheet
- ✔ Count number of solar panels
- ✔ Measure tilt of solar panels
- ✔ Verify state of solar panels, note number of damages panels if any
- ✔ Cover the solar panel with a blanket/cardboard cover while transportation

2. **Motor-pump set**

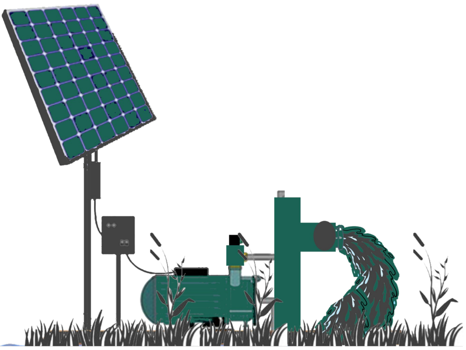
- ✔ Note brand and model on identification sheet
- ✔ Verify depth of immersion
- ✔ Carry a wire rope to support the suspension of pump
- ✔ Cable is not tense (reserve for pipe elongation)
- ✔ Note length of borehole pipe
- ✔ Note length of cable

3. **Controller box**

- ✔ Note brand and model on the identification sheet
- ✔ Verify connection within the box
- ✔ Verify height from the ground
- ✔ Disposed under shadow

4. **Structures & Support**

- ✔ Verify support alignment
- ✔ Verify verticality of poles
- ✔ Verify the good sizing and robustness of foundations



Material management checklist for Installation of Solar Pumping System

5. Cables

- ✔ Verify type and section of cable
- ✔ Verify cable tightening in cabinet and at terminal connections
- ✔ Presence of cable glands at cabinet entrance
- ✔ Cable correctly fixed and attached
- ✔ Underground cables are installed inside ducts
- ✔ Cables between structures (panels groups) are undergrounded if any
- ✔ The solar panel support is connected to the ground with a cable
- ✔ Solar panels are connected to their support with suitable cables
- ✔ Pump and its controller are connected to the ground by a cable of same size than power cables

6. Lightning arrestor & Earthing

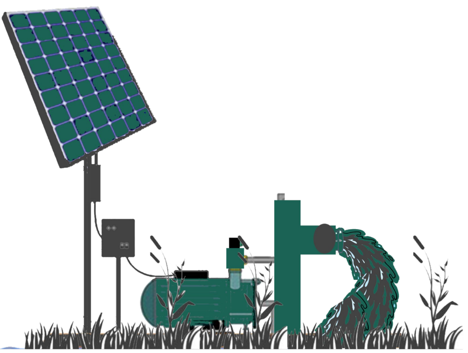
- ✔ Lightning arrester connected to ground by a cable of 16 mm^2 at least
- ✔ This should be attached to structure as per drawing
- ✔ Earthing rod (grounding) should be connected with lightning arrestor

7. Water-level sensor (Optional)

- ✔ Generally float switch is used as a water level sensor
- ✔ Suspend the water level sensor in the tank at appropriate height
- ✔ Check the connections with controller box

8. Pipes

- ✔ Select the pipe of suitable length as per requirement
- ✔ Diameter of pipe depends upon the type of discharge
- ✔ Length of pipe is sum of depth at which submersible pump is suspended and distance at which water is discharged



Precautions for Solar Pump Installation

Most of the pump manufacturers provide the pump, water pipes, controller, nozzles, foot valve and connectors with detailed installation manual. Hence, pump installation has lately become a plug and play system. The PV module, mounting structures and associated components however are usually tailor designed for the terrain and application. In any case there are certain safety precautions and preparations to be taken care of before installing the system. Few are given below:

- The entire process of installation, safety precautions, naming, labelling, quality standards to be adhered to, customer training and documentation need to be planned beforehand. All the activities, their sequences and the responsibilities need to be clearly communicated to the team members
- Safety boards, equipment, emergency instruction etc. need to be accessible to all, easily
- Solar PV modules need to be treated as electrically live during daytime
- Risks at the site should be anticipated based on survey. Mitigation plan against risks like snake bite, marshland etc. need to be made as necessary
- Transport documents, invoice etc. to be secured before supply of material
- Cable continuity and resistance, module batch and serial number details, equipment identifiers etc. need to be captured before transport or at site before opening the package
- Tools should be handy as per plan. Electrical measuring tools, tools for fastening, grinding and cutting, adhesives, Teflon tapes, level tube, pneumatic measurements, flow meter, spares of few consumable items etc. are some examples

Civil Work for Solar Pump

Civil work is a very important part for the solar pumping system, as it bears the load of steel structure and solar panels. Any mistake in civil work can cause irreversible damage to the structure and solar panels. The foundation should be strong enough to support the structure and moreover it is very important that concrete work should facilitate the alignment of structure as per design. Mis-alignment in structure can lead to misalignment of panels. Exact shape of the civil work foundation may slightly vary depending upon the design of the structure which is used, but more less a basic pattern is followed.

Before installation and commissioning of the solar pump, some important documents need to be shared with the Installation team. The documents that needs to be shared with the team before going to site are:

- Site address with customer contact details
- Site survey report with open site map
- Balance of materials list (BoM) including electrical equipments, mechanical tools and safety gears
- Structure drawing and design of the installation site
- Single line diagram (SLD) of the solar pump system being installed

The first task undertaken is clearing the undergrowth of herbs, shrubs and trees from the installation site. The plants are uprooted and any debris in the area is removed to facilitate formation of civil structure on clear ground.

Types of Civil Foundations

Typically there are 3 types of civil foundations for solar pumping systems.

Foundation bolt grouting type with RCC *(Reinforced cement concrete)*

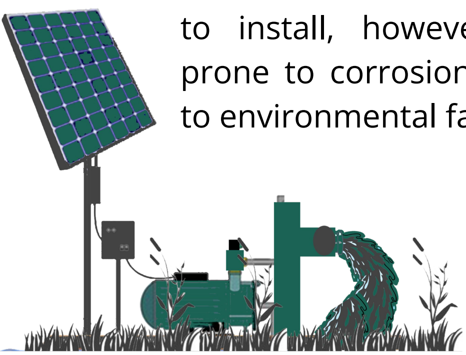
This structure is made using GI rods and Reinforced concrete base and fixed with anchor bolts to fix the module mounting structure. These structures are used for single pole module mounting structures which are used for smaller sized solar pumps (1 to 3 HP). These are structurally strong and can resist flood damages. However, the structure base is strengthened with iron, which is susceptible to corrosion after a few years of use.

Foundation pipe type

The pipe type structure is the most preferred civil structure due to ease of installation as well as durability of the structure. The structure includes a pole pipe and pipe holding structure embedded in the ground in a concrete pillar. This civil structure is easier to construct as well as has lesser chances of loss due to corrosion. However, the pipes can bend in case of severe winds, so they are not suitable for single pole mounting structure, and used mostly for four or more legged mounting structures.

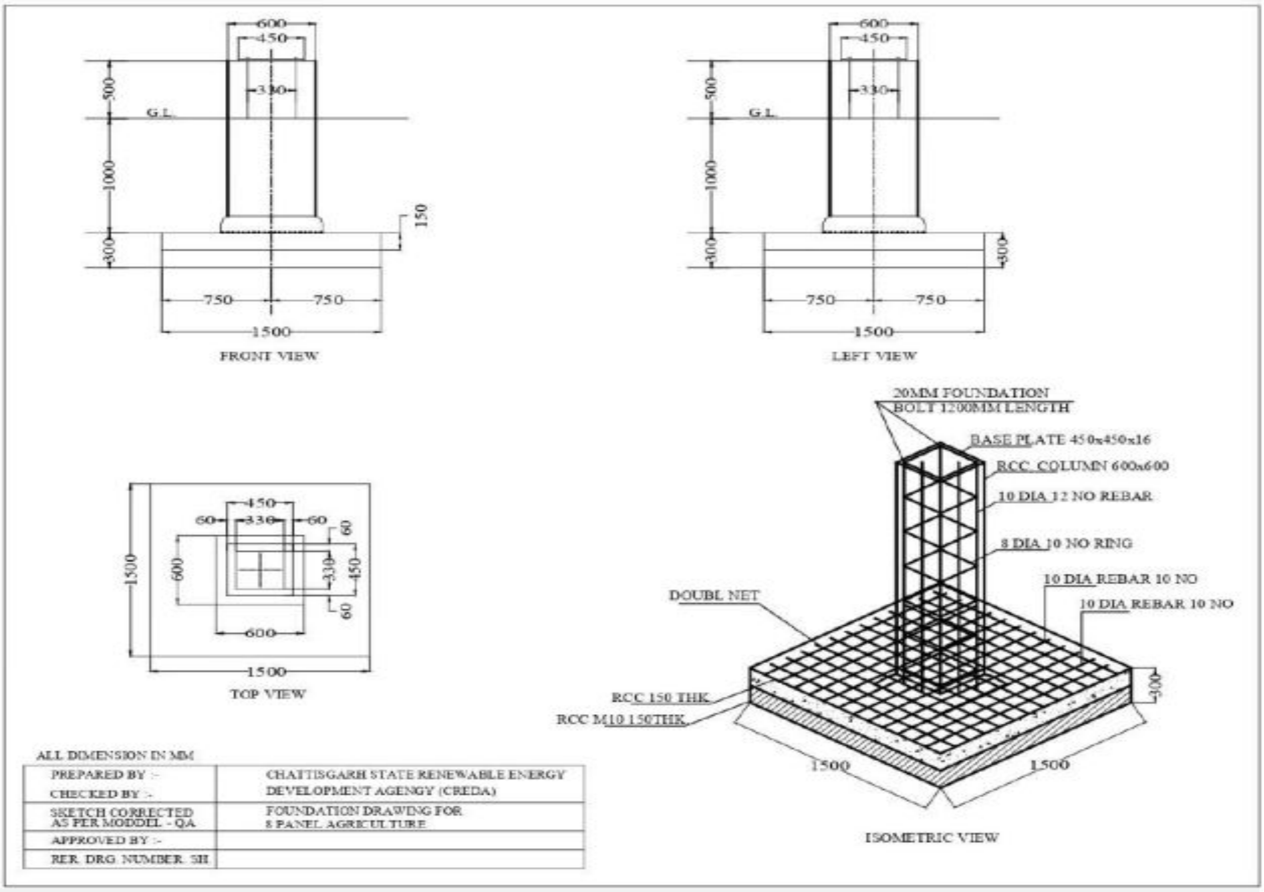
Foundation with fixed structure

These structures are similar to the pipe type, however, instead of pipes, GI rods are used to make the base and they project out on the ground, and on them the module mounting structure is fixed. These are cheaper and easier to install, however they are more prone to corrosion and damages due to environmental factors.



Construction of the Civil Foundation

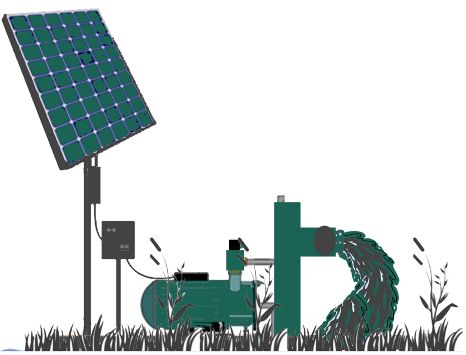
Foundation bolt grouting type with RCC (Reinforced cement concrete)



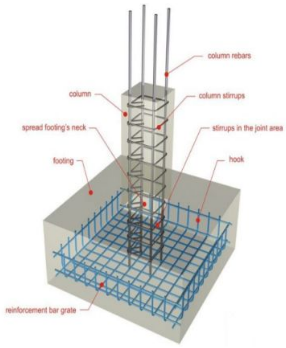
Structure Sketch of Bolt Grouting Type Foundation for Solar Modules

Step 1: Dig up the pit with dimensions of 1.5 X1.5 metre as shown in photograph

Step 2: Prepare the concrete with M20 ratio (refer annexure for composition). Pour appropriate amounts of water in the concrete mixture. Pour the cement upto 15 cm height before placing the RCC cage.



Step 3: The RCC Cage is inserted in the hole. Anchor bolts (nut with two legs) inserted in each corner that go up. L structure fixes in mesh.



Step 4: Place the column at the centre of the RCC cage. The space between the RCC cage and base is filled with cement mixture.

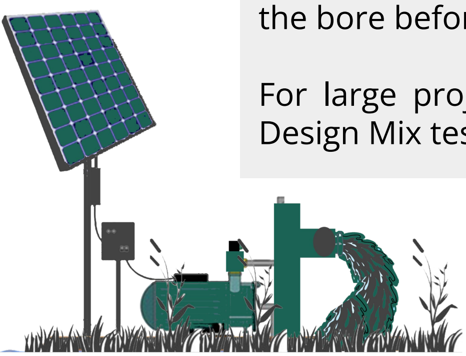
Step 5: Set up the column shuttering using wooden planks

Step 6 : Pour the concrete mixture into the pit.

After concreting, the foundation needs to be cured by pouring water frequently and keeping it wet for a minimum of 3 days. Before curing, if we start loading the column with weights, it may fail to hold the load.

The bore size, the column post size etc. is decided based on the weight of the mounting structure and on the strength of the soil. In cases where soil is of very low strength (Like black cotton soil), first soil strengthening measures like compacting may have to be carried out before laying the foundation. In certain cases, instead of plain PCC, RCC (reinforced cement concrete) will be required by placing steel bars in the bore before concreting.

For large projects cement and aggregates used need to be sent for Design Mix test in authorized labs to ascertain strength of concrete.



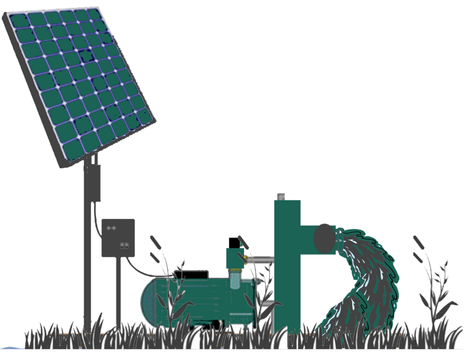
Step 7: Fix the bolt into the column using pro-farma plate

Step 8: Check the alignment with a spirit level indicator

Step 9: Put cement concrete into the column for fixing the nuts

Step 10: The structure is ready for installation of the single pole module mounting structure.

If motor-pumpset, motor controllers etc. are planned to be mounted on a concrete plinth or stand, foundations for the same can be built similarly.



Foundation for Fix Structure (for Multiple legged Structure)

Installer Tip: This is a common mounting structure used for 5 HP and higher sized solar pump installations.

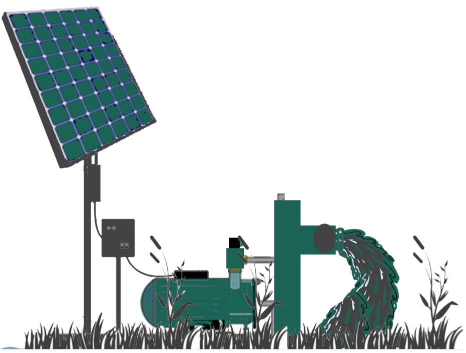
Step 1: Line up posts 2 m apart. Dig holes about 1.2 m depth there. *(As per design provided by manufacturer)*

Step 2: The fixed mounting posts or structure legs are fixed by placing them in the holes and pouring the concrete in the foundation and setting the piers

Step 3: Make sure the ground is level and use string line or chalk to mark the exterior measurements and the location of the posts.

Step 4: Posts are fixed in these holes with the help of cement mixture for strong foundation. Some shuttering support is given for elevated ground structure, providing higher support. The foundation is cured with wet gunny bags overnight for a strong foundation.

Step 5: Make sure all the posts are of the same height.



Please note that if there are multiple column posts, their height level needs to be adjusted before concreting is complete. After the concrete is set, no change in the height or position of the column post will be possible.

Did you KNOW?

Add Page 8

Assembly of Module Mounting Structure

Solar arrays can be installed on structures (roof-mounted), tank mounted, on the ground, on poles or on trackers. Suitable mounting structure can be selected based on the requirement and site conditions. The structural supports used to attach the PV panels to their mounting posts are typically provided by the solar panel manufacturer. The supports must be installed per the manufacturer's specifications to avoid any unintended stresses.

Solar module mounting structures contribute to only around 10% of the entire Solar Pumping system cost. However if chosen the wrong structure, it may have an adverse impact on the overall installation. Today, there are wind speed and galvanizing norms such as 150 km /hr and minimum 85 microns for design of structure.

Various module mounting structure solutions are available as per requirement of site / project / customer. They are designed in order to maximize yield within a minimum area. Tailor made structures are also available to suit project requirements, which maximize the generation from solar modules. Before mounting the solar module on the mounting structure, the module serial numbers are noted for warranty and maintenance purposes.

The MMS drawing, component details etc. need to be handy before starting MMS installation. The sequence of installation should be clearly understood

Assembly of Single Pole Structure on Bolted Civil Structure

Step 1: Place the main pole on the structure and fix it on foundation bolts

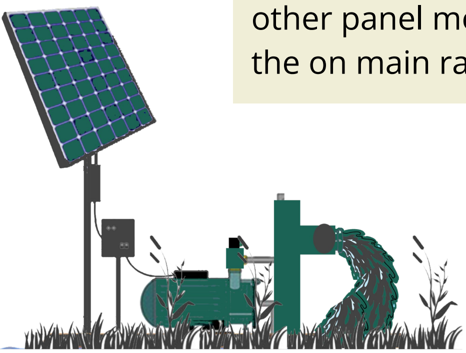
Step 2: Fix the top plate and vertical bracket plate

Step 3: Place the main rafter on top plates

Step 4: Place the panel mounting purlin on main raft

Step 5: Similarly place the other panel mounting purlins the on main raft

Step 6: Fix the side support bars and purlins to main rafter

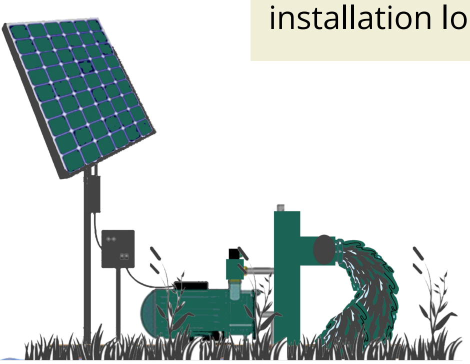


Step 7: Fix the clamps on the panel mounting purlin

Step 8: Place the panels on the structure

Step 9: Place the panels such that connectors output should be near the centre pole for easier connection with the pump controller

Step 10: Similarly put the other panels on the rafter. Check the south direction facing structure of the module. Angle of tilt from the ground parallel level should be the latitude of the installation location



Assembly of Pipe or Fixed Module Mounting Structure

Step 1: In case of fixed mounting structure, rafters are attached to join two structure legs. Two rafters are attached on each side of the mounting structure. Galvanised iron nuts and bolts are used to join the structures.

In case of pipe mounting structure, place the main pole on the ground pipes and fix them with screws provided.

Step 2: The module mounting member is installed on the foundation of C-channels.

Step 3: The structure alignment is checked using a spirit level indicator. If the bubble in the spirit level comes to 90 degrees, then the installation is properly aligned.

Step 4: The back legs of the structure and rafters are joined by rods at a defined angle as per the mounting structure plan, and they are called cross members. These cross members are attached using GI nuts and bolts.

Step 5: Each end of the C-channel is bolted to the structure legs. Stainless Steel nuts and bolts are to be used to prevent corrosion and rust.

Step 6: The Tilt bracket is installed on the mounting structure to hold the solar modules in place. This is fixed with stainless steel nuts and bolts.

Step 7: Once the alignment of the mounting structure is checked, the modules are placed on the mounting structure one by one and fixed using anti-theft stainless steel nuts and bolts.

Step 8: The orientation and tilt angle of the solar array is checked using an angle finder instrument. The angle of tilt from the ground parallel level should be the latitude of the installation location.

All the fasteners (like nuts and bolts) will have a torque value for the required tightness. The basic principle is that it should not be too tight to cause stress in the MMS nor should it be loose causing the MMS to fail from holding the module weight. Also, it is a good practice to keep the fastened slightly loosened until the modules are all fixed, since for levelling the modules, the rafter and purlins will need to be adjusted a little bit. After the adjustments, when the module is completely installed, all the fasteners can be tightened properly.

In case of tracking mechanism, the actuator unit, motor and the tracker MMS need to be installed in the presence of the manufacturer of the tracker or by a trained expert.

PV Array installations

Solar PV array is one of the main components of any solar PV water pumping system. Thus, the performance of the solar PV water pumping system highly depends on the proper installation of solar PV arrays.

Determine the position where the array needs to be installed

The solar PV array is to be installed carefully at a proper location to avoid shadowing of any part of the array or other obstructions throughout the day any time of the year. The output from the solar array is maximum when solar radiation falls perpendicular to the surface of the module.

For optimum power output, the array should be south facing and tilted at an angle equal to the latitude of the site. A manual tracking system is a cost-effective option for maximizing power output. The array can be tilted monthly or every couple of months, according to the required scheduling.

Following factors shall be considered while installation of solar PV array:

a. **Shadow:** When a solar panel is shaded in whole or part, for example, by tree branches and or a building, it captures less energy from the sun, thus its performance is reduced. Even minor shading can result in significant loss of energy. It is recommended that the solar PV system be installed in a shadow free area.

Possible sources of shading include:

- Vegetation – trees, bushes, long grass, leaves
- Structures – buildings, shelters, fences, telegraph poles,
- Landforms – hills, rocks, and
- The array itself – not leaving enough room between rows of tilted modules can cause one row to shade the row behind it.

b. **Orientation:** In the northern hemisphere, south facing panels are in the best possible orientation. If the solar PV is to be mounted at a tilt, a wider range of orientations will still give a reasonable energy yield.

c. **Tilt:** A tilted array will receive more light than a vertical array. For self-cleansing, a minimum tilt of 20° to the horizontal is recommended to allow the rain to wash dust off the solar panels. The solar module has to be installed at a tilt angle approximately equal to the latitude of the area.

Installation of Solar Modules

Step 1: Modules are placed over the purlins and secured to the purlin with the fasteners provided. Please ensure two persons handle each module installation to avoid any risk of breaking.

No matter how small or big the system, the modules should be neatly arranged over the purlin and secured properly. If required, spacers can be used to keep the same space between each module. A small gap needs to be given between modules for air movement

Step 2: For module interconnections it is always recommended to use MC4 connectors instead of joining them in the module junction box with lugs. All cables need to be properly dressed without hanging using cable tie.

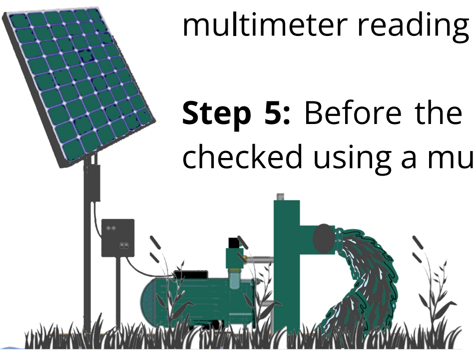
For parallel joining all the string +ves and —ves and taking out just two cables out, a string junction box can be used. Also, a DC SPD is provided for protection.

Step 3: Please follow the Single line diagram or SLD provided by the engineering team.

- For pumps upto 5 HP, modules are mostly connected via a series connection, wherein adjacent modules are connected to each other and the positive wire from first model and negative wire from last module is connected to the pump controller.
- For pumps over 5 HP, we may need to connect modules in series and parallel connection as per SLD. It must be noted that the positive and negative terminals of the connectors need to be connected correctly.

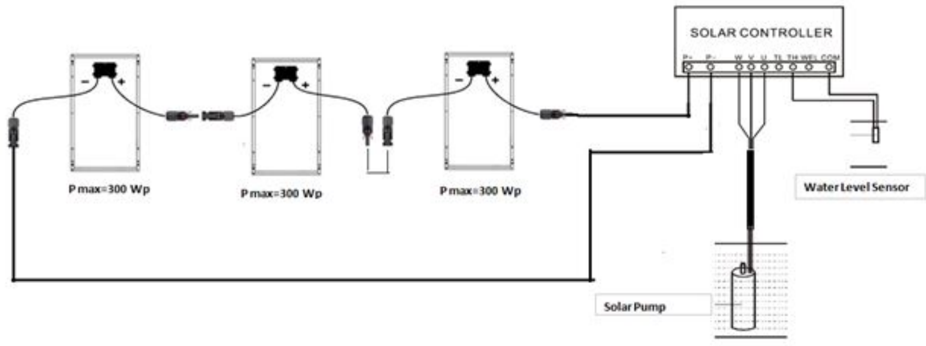
Step 4: The voltage and current of each solar module must be checked using a multimeter. For this, the positive and negative terminals of the solar module are connected to the positive and negative heads of the multimeter and the multimeter reading is recorded.

Step 5: Before the solar array is connected to the pump controller, it should be checked using a multimeter and reading recorded.

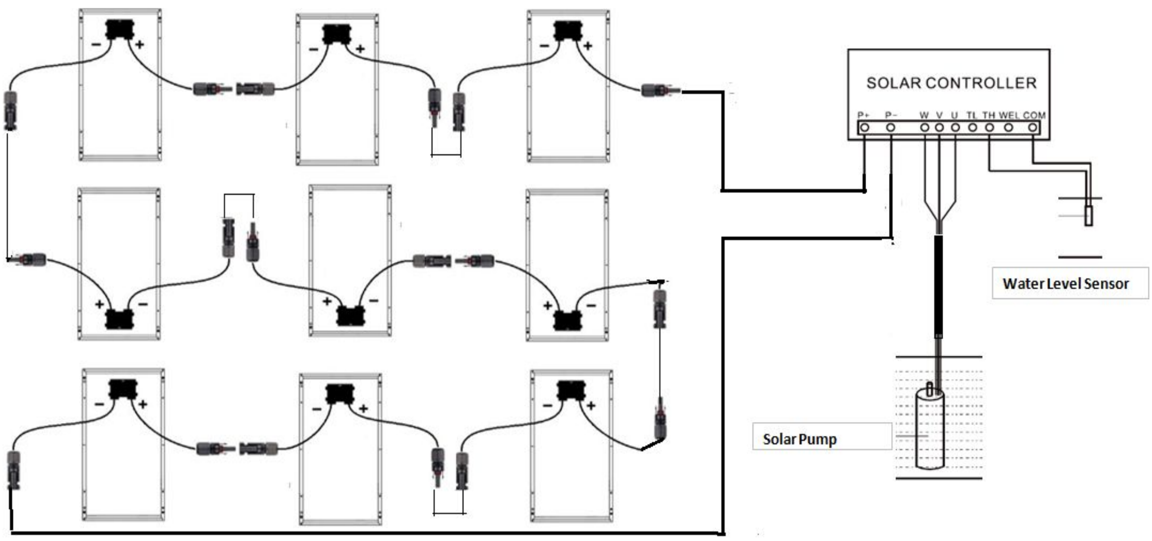


Connections in the PV Modules

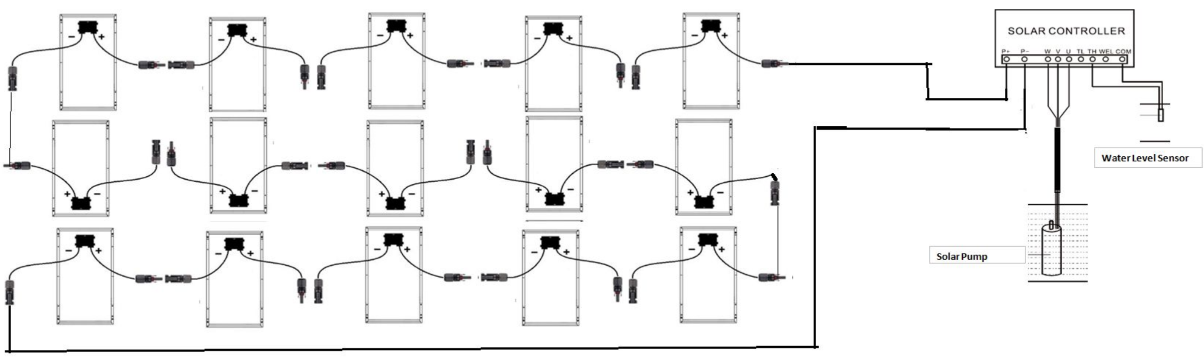
Typical connections for 1 HP Pump set with PV array of 300 Wp panels:

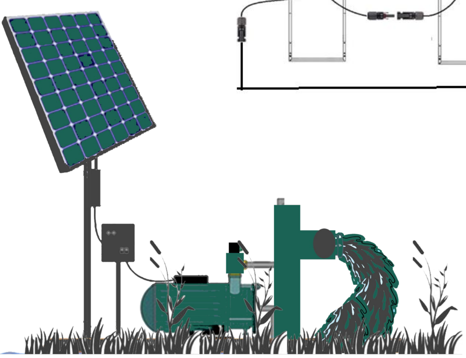


Typical connections for 3 HP Pump set with PV array of 300 Wp panels:



Typical connections for 5 HP Pump set with PV array of 300 Wp panels:





Installation of Submersible Pump

Installation of the motor-pump set includes placing the set in the designated region and installing the suction and delivery pipes.

The pump should be located at least 1 metre (3.3 feet) above the bottom of the borehole/well and sufficiently below the “drawdown level” so as not to allow the pump to operate dry.

It is recommended that a water level sensing system be incorporated into the system to prevent the pump from going dry during operation.

Step 1: Inspect the well/ Borewell

- Check the depth and standing water level.
- Check the well total depth – the distance from the ground level to the bottom of the well.

Step 2: Check components

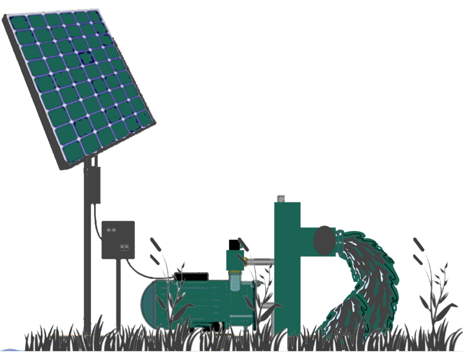
- Carefully check all the components required for the installation.
- Check the details of the motor such as power supply ratings, whether its 3-wire single phase or 2-wire single phase and if it needs a pump starter box or 3 phase configurations. Look for signs of external damage to casing,

Step 3: Check the power rating

Check the details on the surface/submersible motor looking for power supply rating.

Step 4: Check the cable rating

Check the cable rating that suits the motor cable and motor and is correctly rated for submersion in water.



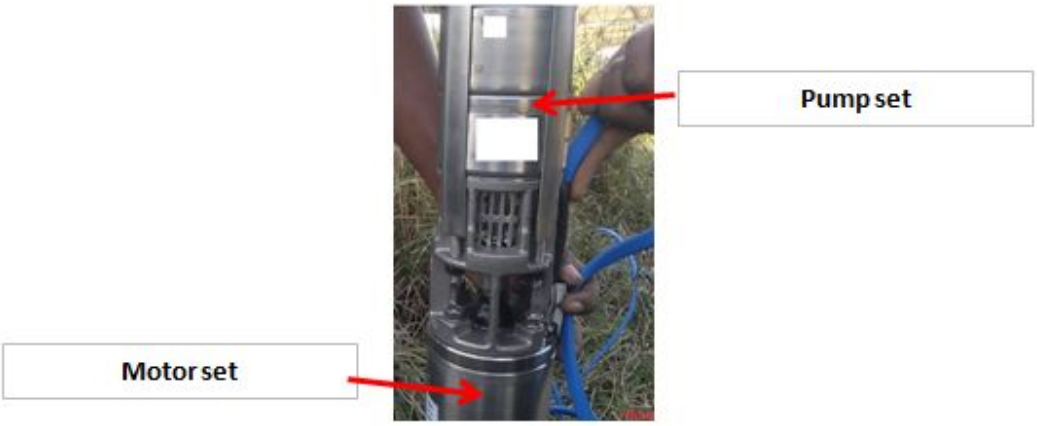
Step 5: Pipe & Fitting

Check that the fittings match the outlet on the pump, the rising main and the bore cap.


Step 6: Fit motor to pump

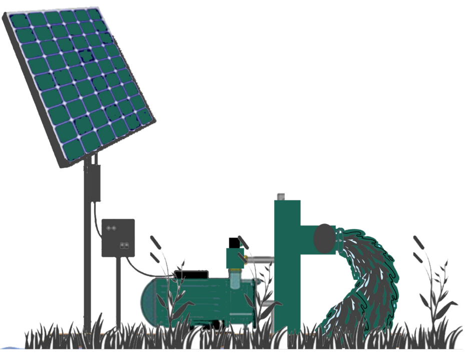
In case of submersible pumps, pumps and motors come in different boxes. Motor needs to be fitted with pumps.

- Check the shaft of the motor to match with the pump set.
- Use the grease provided and lubricate and seal the splined shaft on assembly.
- Use a poly pipe or lay flat fitting with thread tape and screw into the pump and fix the motor to pump.

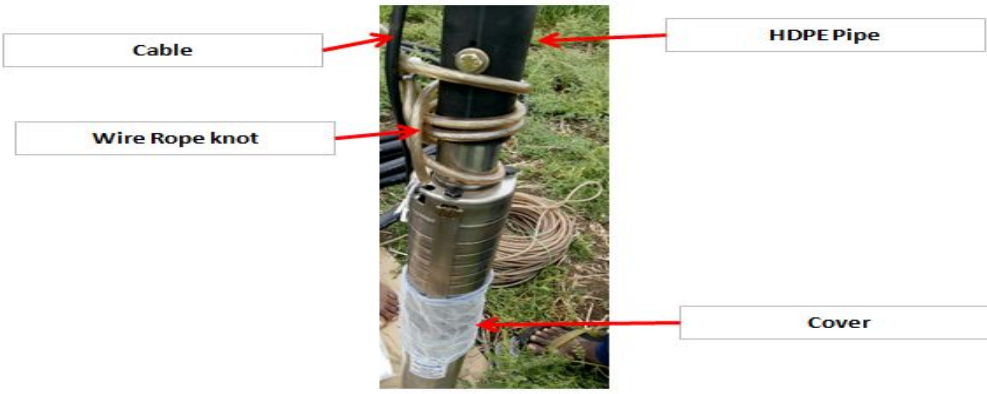


- Splice drop cable to motor cable with supplied cable splice kit When drop cable is connected to motor, it is necessary that the splice be water tight.





- Carefully follow the instructions on the kit you start the splicing process.



Step 7: Cover the motor pump joint to prevent stone particles from entering into the pump set.

Step 8: Tie the rope : In case of submersible motor tie the rope or wire rope with knot as shown in diagram or as shown in the figure

Step 9 : Fix the pump

- Fit the rising main to pump carefully and roll out.
- Fit bore cap to the other end of the rising main. Rising main is the pipeline that conveys water from pump discharge to distribution chamber.

Step 10: Roll out drop cable

- Connect the safety cable to pump, the rising main and drop cable
- Attach safety cable end to bore cap allowing for rising main to stretch

Step 11: Check the connections are tightly held

Step 12: Cable tie

- Tie the cable along the length of pipe at regular intervals to prevent the cable damage
- If it is loosely suspended attach stainless steel safety cable to pump and roll out with rising main and drop cable.
- Attach safety cable end to bore cap allowing for the rising main to stretch

Before lowering the pump to the water source, complete the electrical connection as well.

Step 13: Lower motor pump set into the well

- If the weight of the assembly is light enough to handle, gently lower the pump end into the well with an assistant to hold the bore cap end.
- Feed the assembly down the hole, pay particular attention to preventing damage to the electric drop cable.
- The assembly should be suspended by the bore cap on top of the casing.
- Recheck all the fittings to ensure every component is perfectly attached and working.
- Lower the pump end into the water well to hold the bore cap end.

In case of an open well submersible pump, the installation shall be on the floor of the water source or at any planned height inside the water source. Either it can be hung from a support or placed in a housing made inside the water source for installing the pump.

- Connect pump starter, pump controller and pump protection device to power supply and test pump.
- Allow a few moments for the water to reach the surface.
- On completion of the initial test proceed to connect the required pipe work to the bore cap.
- Finally test pump operation and operation of pump protection devices and controls.
- Position roller over in the well/borewell. Slowly allow the pump to be lowered into the well.
- Lower the last meter by hand if possible or allow the well cap to bump over the roller and into position on the casing.

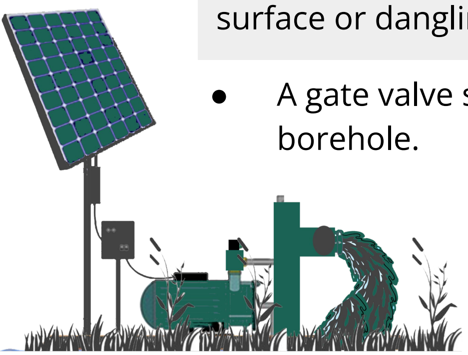
If recommended by the pump manufacturer, a non-return (check) valve should be installed in the discharge pipe just above the pump.

Step 14: Installation of Delivery Pipe

- The discharge pipe should be screwed into the outlet of the pump to help support the weight. All connections should be watertight.

If any portion of the delivery pipe needs to be run horizontally on ground and to the storage tank, necessary precautions must be taken for either burying the cable in ground at lm or supporting the cable with a metal raceway, properly clamped. In any case, avoid leaving pipes freely on the ground surface or dangling vertically without support.

- A gate valve should be installed in the discharge pipe after it exits the borehole.



Cavitations can have such force that it tears apart metals or ages pump materials prematurely. Air bubbles in pumping applications are when subjected to low pressures. This occurs because at low pressures, water boils at a lower temperature than normal, and boiling water releases air bubbles. As water moves from a low-pressure area to a high-pressure area, these air bubbles can implode, damaging the pump.

- To prevent cavitations, it is important to ensure that the flow rate of the pump will remain on its prescribed curve, as given in the specification sheet. This will prevent excessive pressure drops in the water that is being pumped, minimizing the risk of cavitations.
- Avoid sharp bends and also use the right kind of diameter both for suction and delivery pipes. The friction losses are less in PVC pipes compared to GI pipes.
- Avoid usage of reducers or bends as they normally create impediments and reduce the head. In case of bends, always use smooth bends rather than sharp 90° bends.

Installation of Surface Pumps

Step 1: Placement of pump
Mount the surface pump on a secure and strong base such as a base made of concrete. This will ensure pumps do not vibrate or move when in operation. Also make sure the pump is close to the water source.

It is also recommended that all pumps be protected from direct sunlight. This can be done using a sheet metal cover.

Step 2: Check all components
Select the diameter and length of the suction and pressure pipes as well as those of any additional components. The diameters of the pipes must be equal to or greater than the connection sizes on the pump. The power rating of the installed drive system must be sufficient.

In case of wells, if the depth is much higher than the suction head allowed to achieve NPSHa > NPSHr, then the pump will have to be lowered into the well and installed inside the well at a height where the suction pipe is within allowed suction head.

Step 3: Intake piping

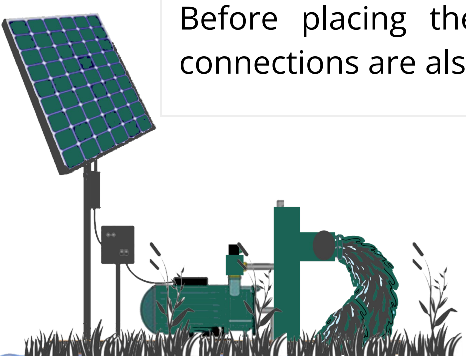
- To minimize the vertical lift, the height of the surface where the pump is placed should be reduced.
- The length of the pipe should be minimal at the suction end.
- Before placing the suction pipe into the water source, make sure to install the foot valve with strainer (unless manufacturer specifies not to) in the end of suction pipe to avoid draining of primed water while the pump is non-operational.
- A short flexible hose is provided to make connection to the pump easy.
- The suction pipe should always be as large as the inlet on the pump. If it happens to be larger, then an eccentric reducer should be used; a concentric reducer should not be used
- Suction pump should be full of water while installing.

- Suction pipe should be connected to the suction inlet to the nozzle provided by the manufacturer.
- First drape the nozzle thread with a Teflon tape and slowly insert the HDPE or PVC or metal pipe over the nozzle. Then secure the pipe with a metal clamp around the pipe with a fastener.

Make sure that at least for a distance of 5 times the diameter, no bend is given in the pipe. Also, if any pressure gauge is to be connected in the suction side, plan it early to get required accessories for the connection.

If more than 3m of the pipe needs to run horizontally, please bury the pipe underground in a lm deep trench. If less than 3m, provide a UV protected PVC conduit or metal raceway support to place the pipe neatly and secure it with a clamp. In any case the pipe should not be left freely over the ground. It may cause damage to the pipe and expose it to risks like rodent attack.

Before placing the suction pipe in the water source, make sure electrical connections are also complete.



When installing the suction pipe:

- Maintain NPSH a > NPSHr
- The length of the pipe shall be kept at a minimum and if using rigid pipe keep the number of bends to a minimum using sweeping bends instead of right-angle bends where practical.
- The suction pipe shall be installed such that the end of the suction pipe is clear from obstruction (e.g.the bottom of the water source) and at a suitable depth below the water surface, so as not to suck in any air or floating debris.
- If possible, ensure that at no point in the suction pipe that the pipe is higher than the inlet of the pump nor should there be a point where the pipe (on the water source side) is higher than another section of the pipe between that point and the pump. This may result in air being trapped.

Step 4: Outlet piping

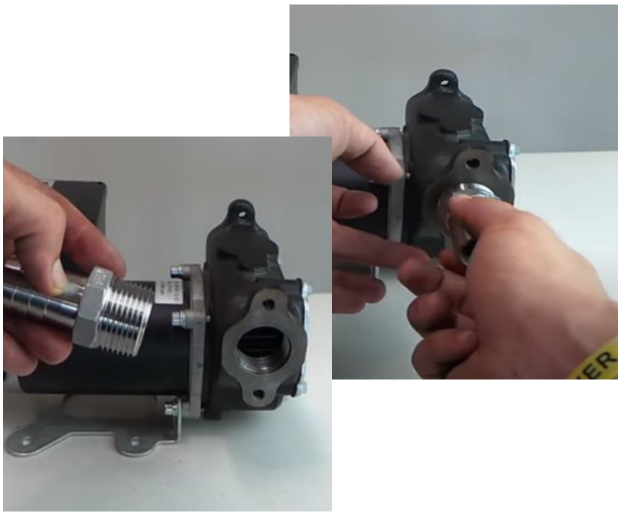
- Similar to suction pipe, delivery pipe also should be connected to the outlet nozzle given by manufacture by draping Teflon tape on the nozzle thread and inserting the pipe over the nozzle.
- The pipe needs to be secured with a metal clamp around it with a fastener.
- A gate valve shall be installed at the outlet of the pump as per manufacturer's instruction.
- Delivery pipes also need to be buried 1m below ground if more than 3m horizontal run is expected. The unburied portion needs to be inside a UV protected PVC conduit or a metal raceway support with clamp, to avoid the pipe being freely left in open ground or to avoid the pipe dangling without support vertically.
- If water is delivered to a tank, at the tank end too, the delivery pipe should be properly secured with clamp and take all measures to avoid leakage in the pipe in any connections.
- If flowmeter or pressure gauge is to be connected to the pipe, plan the same prior to installation to avoid rework and cutting of pipes at site.

Always read the manufacturer manual to understand if the pump is self-priming or not. All priming requirements and associated accessories need to be understood properly before installing the pipes.

Plumbing connections

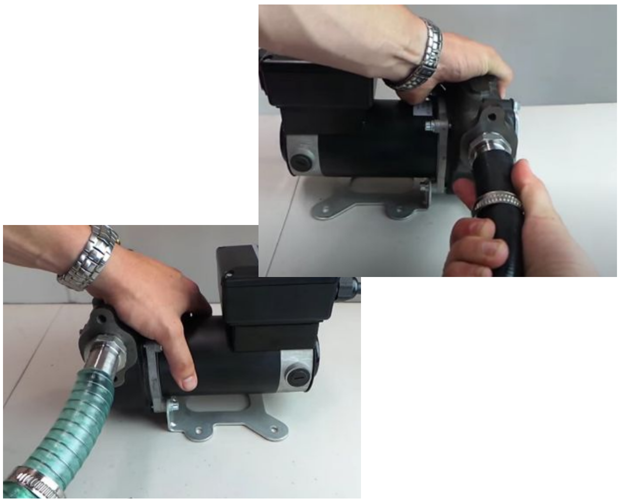
Hose:

Hose is basically a flexible tube provided to convey water. Most of the pumps have hose already fixed at the inlet and outlet. But if not provided, you can pick the suitable hose that fits the inlet or outlet hole and fix it.



Suction pipe & discharge pipe:

Suction and discharge pipes are the pipes attached to inlet and outlet of the pump respectively for the water flow. The suction pipe should always be either equal or larger than the inlet size of the valve and minimum length of the pipe is recommended to avoid bends. Discharge pipe is also recommended to be in large size.

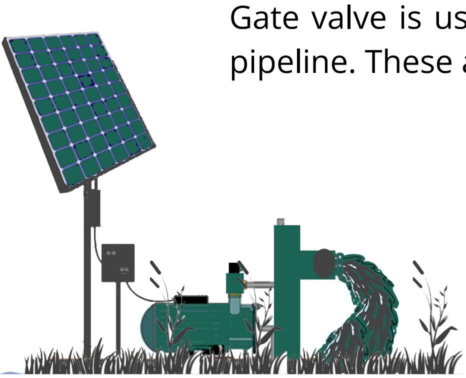


Foot valve:

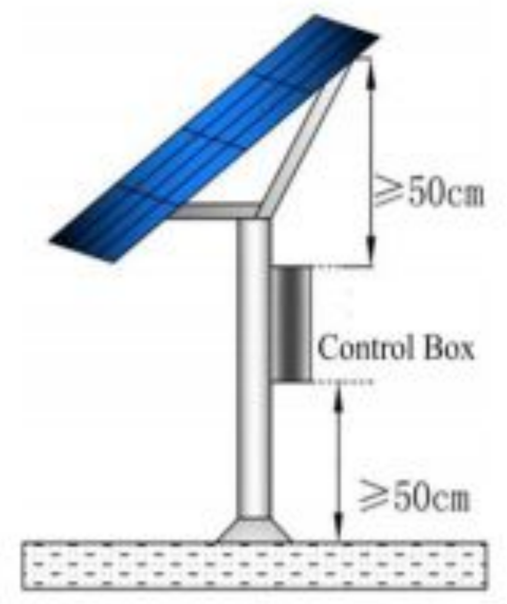
Foot valve is used at the end of the pipeline at the suction end. It acts as a check valve but they also have a strainer fixed at the open end. When pressure inside the pump column changes, the valve opens and stops water from going back.

Gate valve:

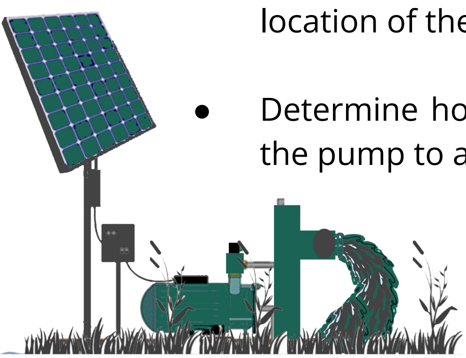
Gate valve is used to shut off or open the fluid flow in a pipeline. These are fixed at the discharge end of the pipe.



Installation of Controller Box



- Normally a solar pump controller is intended for operation in ambient temperatures up to 60℃, but in order to avoid overheating caused by the failure, it is recommended to install the controller in the shadow position.
- The solar pump controller must be installed into a control box which has a tight enclosure to avoid direct sunshine, rain, dust, moisture, animals, plants, etc. The control box should have a bottom gland plate for installing wire cord or conduit.
- These are typically installed on a bracket on the array frame or on the array mounting pole. They should be mounted as per the manufacturer's instructions and should be suitably mechanically supported.
- The solar pump controller shall meet the appropriate ingress protection (IP) rating for outdoor usage at the site. A minimum of IP56 is required and IP66 or higher is preferred.
- The distance between the array and the pump controller is often known by the manufacturer/supplier; however this distance should be clarified while at the site.
- The critical distance is that between the pump controller and the pump. This must be determined during the site visit so the correct size cables are selected to avoid voltage drop issues and that the correct length of cable is either supplied with the complete system or obtained prior to system installation.
- For surface pumps, the length of cable shall be dependent on the location of the solar array/pump controller and solar water pump.
- For borehole/well pumps the length of cable will be dependent on the location of the solar array/pump
- Determine how the cable will be installed between the pump controller and the pump to avoid the risk of mechanical or local fauna (e.g. rat) damage.



- The input connection to the motor is usually taken from the motor controller provided by the manufacturer. The solar connections or MPPT output, VFD connections, Inverter or Grid connection etc. are all usually given to the motor controller and connection to the motor is facilitated from the controller.

- In case the grid connection is to be provided in the system, provide an IO box with an isolator to connect using incoming grid line as and when required.

- Lugs are used to connect 3 phase connections. It is important to match the colour codes in the lug connections. It is a good practice to name the cables.

- Before making any connection to the controller, make sure the solar PV power connection is OFF at the string junction box or at the controller end. For this purpose, a breaker needs to be provided at the controller end to disconnect the DC power from the Solar PV array. Ensure the Grid or VFD or Inverter output are also OFF before making connections.

- All connection terminals need to be checked with the manufacturer for a circuit diagram. Separate conduits should be provided for DC power cables, AC power cables and sensor cables.

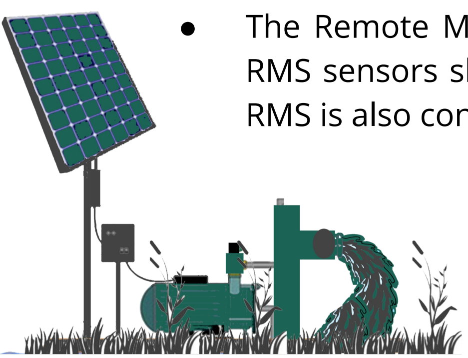
- The electric connections can be surface or submersible:
    - In case of surface electric connections, heat sealing of connections need to be done
    - For submersible electric connections, heat sleeves and cables are used for waterproofing

- Route markers are used to demarcate the path of PVC conduits and wires. This prevents the accidental damage of the same during land preparation. Also, in case of uneven or elevated areas, raceways can be made for the pipes to pass through to the fields.

- As already explained in the earlier chapters, the controller takes DC inputs from solar PV arrays and supplies pulsating DC or variable frequency AC to the motor. Proper care should be taken that the MPPT range of the controller and the array output voltage match properly.

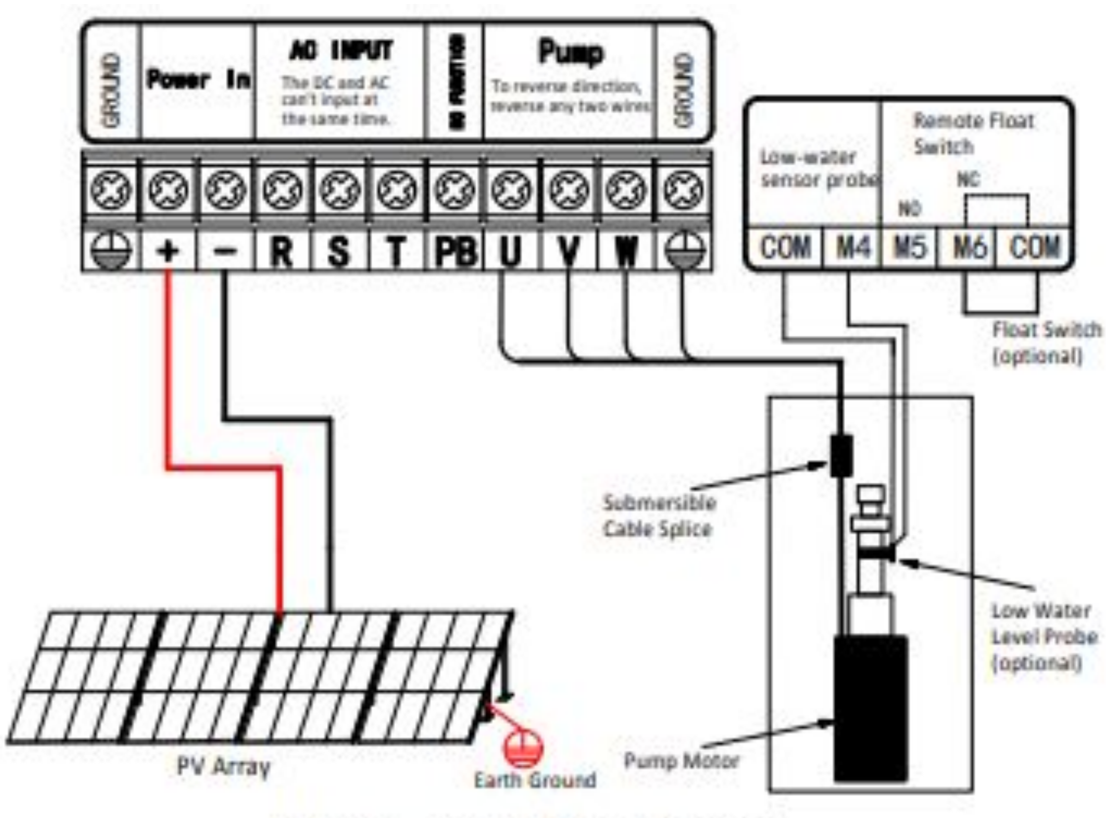
- It is also advised that the farmers should not open the controller box for the purpose of repair to avoid high voltage DC shocks.

- The Remote Monitoring system should be installed in the controller, and all RMS sensors should be connected to the data loggers for data transfer. The RMS is also connected to the VFD.



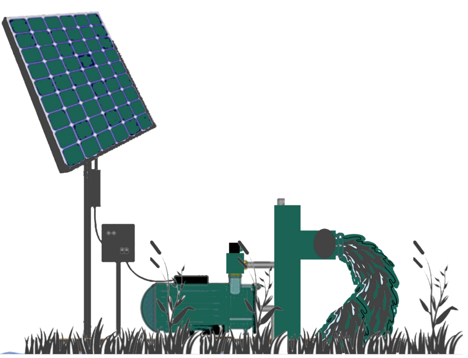
Typical Connection of Controller Box:

Many solar pumping system packages will include solar modules with interconnecting cables/connectors set up for 'plug and play' by using plug and socket connectors. These modules should be installed and connected according to the manufacturer's instructions. The output of the array shall be connected to the pump controller with the plug that has been supplied by the Manufacturer/supplier.



1. Before making any connection to the controller, make sure the solar PV power connection is OFF at the string junction box or at the controller end. For this purpose, a breaker needs to be provided at the controller end to disconnect the DC power from the Solar PV array. Ensure the Grid or VFD or Inverter output are also OFF before making connections.

2. The solar array is connected to the pump controller with Red and Black wires to the positive and negative connectors of the pump controller respectively using MC4 connectors.



3. No compromise should be made on the cross-section thickness of wire as per design. No cable joints with insulation tape shall be acceptable. Always use insulated joining couplers if required, or plan such that a requirement for joining cables midway never occurs.

4. MCB is installed before the solar array is connected to the pump controller to protect the device from excess current. Also, another MCB is installed between the pump controller and the pump to overcurrent. A third MCB is placed if the solar pump is connected to the grid.

5. All connections to the terminals, whether at the motor end or at the controller ends, should be made with proper lugs or connectors. Direct insertion of cable threads to terminals should be avoided. It is a good practice to always use labels on all the cables at both the ends for future service

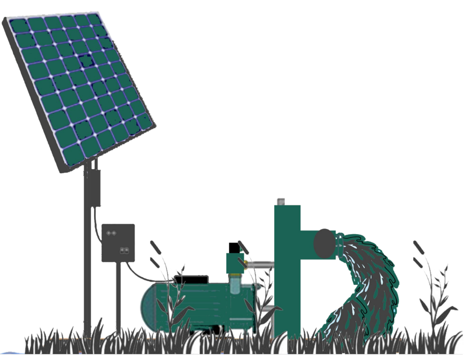
6. The pump is connected to the pump controller using a lug connection. The colour coding is followed, and crimped and connected. The colour coding followed in 3-phase conductor is red, yellow and blue wiring, along with black wire for neutral and green wire for earthing.

7. Splice kit is used to waterproof the connection, for otherwise short circuits can happen during heavy rains.

8. Remote Monitoring System (RMS) is placed in the controller box and connected to the pump controller through the wires. A recharged SIM card is installed in the RMS.

9. For monitoring purpose following components may be provided: CT/PT, energy meter, data logger for remote monitoring with sensor input terminals for various sensors (like temperature, pressure, flow rate, water level etc), CAT6 cable connection ports and internet provision.

10. All cables should have a spare length to avoid undue pressure and to utilize for future service.



Installation of Earthing Rod

The installation of earthing can be split to two parts — the earth electrode installation and the earth grid construction

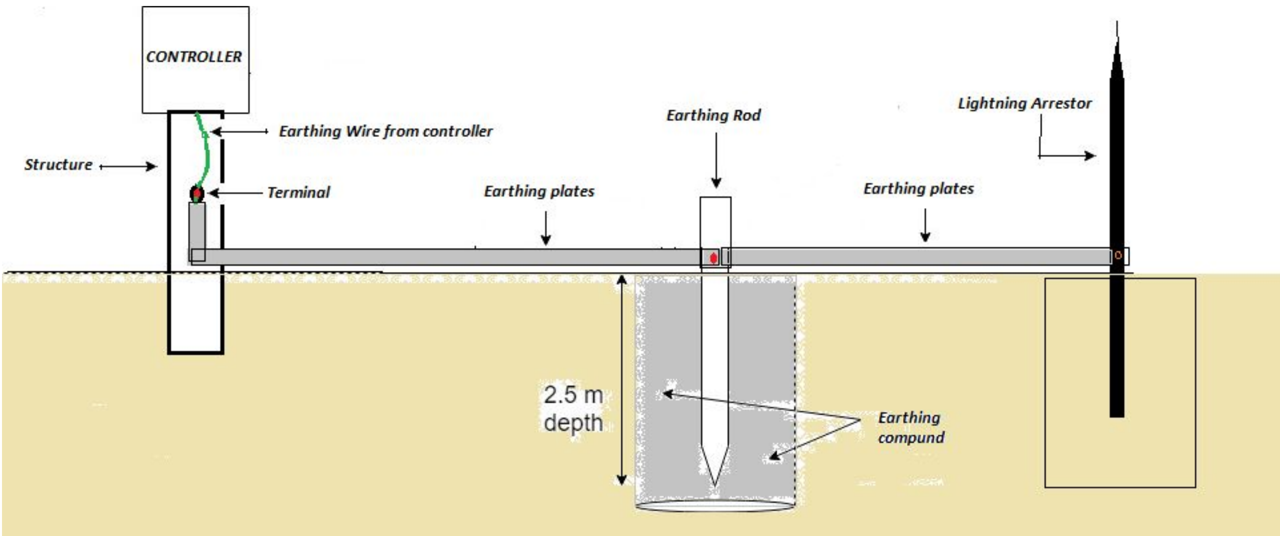
Earth Electrode: The basic purpose of earthing is to pass any fault current safely to earth via a high conducting low resistance path. or an off-grid pump system, it is generally recommended to have a separate earth pit for the DC side, one earth pit for AC side and if lightning arrester is used, a separate earth pit for it.

Earth pit can be maintenance free chemical earth pit or maintenance demanding regular pipe/plate earthing.

Step 1: Ground excavation - a typical hole of 2 metres depth and 10 cm diameter is made near the solar module installation.

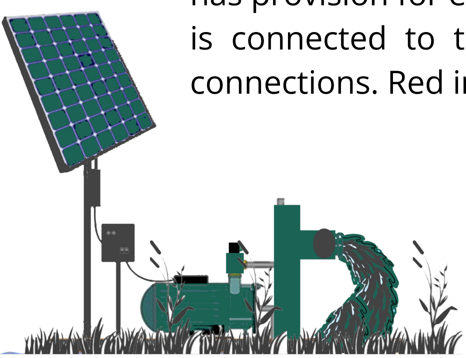
Step 2: Installation of the Earthing rod

- Insert the ground rods or other electrodes deep inside earth.
- Normally charcoal and salt are added in earth pits to make good conductivity. Water improves the conductivity of earth soil. Nowadays Earthing compound mixtures are available ready made. About 5 kg of earthing mix or mixture is required.



Earth grid installation: Once the earth pits are installed, we now need to connect various metal surfaces and system earthing if involved into these pits.

Step 3: Typical earthing connections are shown in figure. Typically the controller has provision for earthing. Earthing wire from the coming out of the controller box is connected to the terminal. 10 or 16mm^2 wires are used for the earthing connections. Red insulators are used to sheath the connections.



Note: : Separate earthing connections are needed for DC surge protection from solar panels, AC surge protection from Pump controller and Lightning arrester.

Installation of Lightning Arrester

To protect the system from lightning, a lightning arrester might be installed on the Earth pit cover provided for installation. In case a lightning arrester is to be installed at site, a separate earth pit needs to be provided for the lightning arrester.

Most probably, for systems less than 10 HP, a copper 4 spike lightning arrester would be provided. The pole on which the lightning arrester is to be mounted needs to be first secured into the ground or to the wall on which the arrester is to be installed.

Step 1: Mount the arrester on the pole and secure it with fasteners.

Step 1: Create an earth pit, preferably chemical earth pit with Cu bonded electrode, separately for the lightning arrester.

Step 2: Using a 25X3 copper earth flat or 16 sq.mm Cu earth cable, connect the arrester to the earth rod.

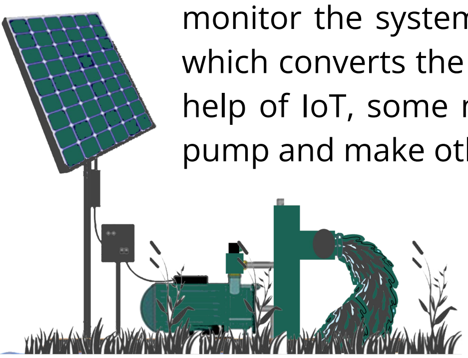
Step 3: Then interconnect this earth electrode with other earth pits in the site using a GI 25X3 earth flat.

Installation of Remote Monitoring System

Remote monitoring system works by installing various sensors in different parts of the pumping system in order to measure data. Few common sensors are pyranometer, module temperature sensor, pressure gauge, flowmeter, water level sensor, dry-run alarm, voltage and current sensors on both DC and AC side, energy meter etc.

The measured data gets converted to digital signal and is transferred via signal cable to a datalogger in the controller. The signal cable, if run underground, with the same trench in which the electrical power cable is laid, maintains a layer of sand in between and a distance of at least 10 Cm from the power cable. Do not run both power cable and signal cable in the same PVC conduit or in the same raceway. The data logger logs these signals in its memory.

The site should have an internet facility. A microcontroller takes data from the datalogger and sends it through the internet to any location the client wants to monitor the system from. The client will be given software by the manufacturer, which converts the signals to readable values and presents it to the user. With the help of IoT, some manufacturers also allow you to remotely switch off or on the pump and make other controls when necessary.



Quality Standards

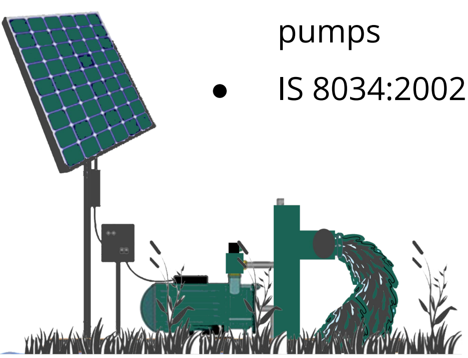
Quality in any system is usually referred to as how close the system is to the requirement provided by the user. Without specifying a requirement, quality is meaningless. Also, quality should never be compared for two products made for different requirements.

Nevertheless, for electrical, electronics and related technologies, the International Electrotechnical Commission (IEC) has prepared certain codes that detail certain requirements of the technology and their codes. It is called IEC codes. For example, the process of pump installation, the process of manufacturing PV modules, and the design of earthing systems all have certain codes. If we adhere to the codes, it becomes easy to be accepted internationally as a company adhering to set standards. Whether small or large firm, adhering to the IE standards has its benefits.

Although IEC is only for electrical and electronics related technology, ISO (International Standardization Organization) provides codes for various quality requirements of all available technologies and processes related to various technologies. ISO QOO1 is the code for generic quality management practices of any small or big organization. India also has its own standards named Indian Standards (IS Codes) prepared by Bureau of Indian Standards. For electrical and electronics related technologies, IS Codes mostly comply with ISO and IEC standards with certain additions or adaptations for Indian sub-context.

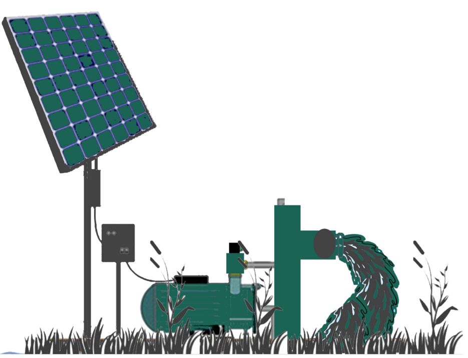
Few relevant codes for solar pumping system are given below:

- IS 14286:2010 — Crystalline Si PV Module design qualification and type approval
- IEC 61215-1:2016 — Crystalline Si PV Module design qualification and type approval
- IS 5120:1977 — Technical requirement of rotodynamic pumps
- IS 3043:1987 — Code of Practice for earthing
- IS 11346:2003 — Agricultural and water supply pump tests — Code of Acceptance
- IS 6603:2001 — Stainless steel bars and flats
- IS 7538:1996 — 3 phase squirrel cage induction motor for agricultural water pumps
- IS 8034:2002 — Submersible pump specifications



- IS 9079:2002 — Electric moonset pumps for agri and water supply purpose
- IS 9283:2013 — Motors of submersible pump sets
- IS 14220:9 94 — Specification of open well submersible pumpset
- IS 14582:1998 — Single phase AC motor for centrifugal pumps
- ISO 9905:1994 — Technical specifications for Class I centrifugal pumps
- IEC 60068-2-6:2007 — Environmental testing - Test Fc vibration (Sinusoidal)
- IEC 60068-2-30:2005 — Environmental testing - Test Db Damp heat cycle
- IEC 60146-1-1:2009 — Semiconductor converters (Basic requirement)
- IEC 60364-4-41:2005 — Protection in low voltage electrical installations
- IEC 60364-7-712:2017 — Requirement for installation of low voltage solar PV systems
- IEC 6052 :1989 — Degree of protection by enclosures (IP Codes)
- IEC 60947-1:2007 — Low voltage switchgear — General rules
- IEC 61000-6:2016 — Electromagnetic compatibility — Generic standards
- IS/IEC 616 3:1999 — PV system-Efficiency measurement of power conditioners
- IS/IEC 61730-1:2004 — PV module safety qualification - Construction requirement
- IS/IEC 61730-2:2004 — PV module safety qualification — Testing requirement
- IEC 61800:2017 — Adjustable speed electric power drive systems
- IEC 6210 -1:2010 — Safety of power converters used in PV systems
- IEC 62305:2010 — Protection against lightning

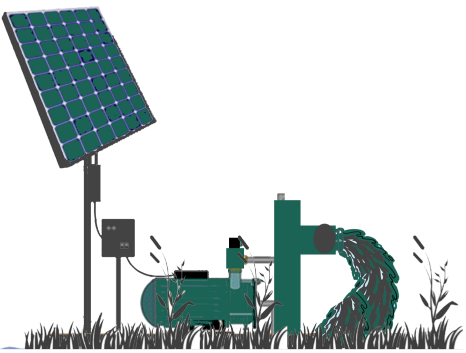
For any organization, it is always recommended to be certified under ISO 9001 quality management practice, not just to avail benefits of the government schemes and adhere to export requirements, but also to smoothly manage activities of the organization using best practices followed around the globe. Practicing the usage of ISO/IS/IEC codes in regular requirement analysis would also elevate the organization's trustworthiness. Any organization built on the mission to adhere to certain quality standards has higher possibilities of being successful in achieving its goals.



Quality Check Report Format

Site Inspection / Quality Checking Report	
Solar Power Plant Capacity	
Solar Power Plant Type	
Site Address	
Contractor Name and Contact	

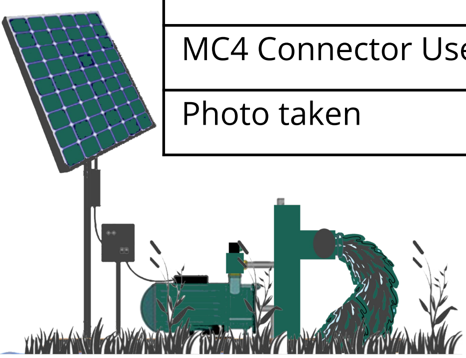
Check List Of Solar Power Plant Inspection			Remarks
Points TO BE Checked			
Solar Panel			
Array V_{oc}		V	
Array V_{mp}		V	
Array I_{sc}		A	
Array I_{mp}		A	
Photo taken	*Yes*	*No*	
Array to Array Distance		meter	
Manufacturer Stickering	*Yes*	*No*	
Photo taken	*Yes*	*No*	
Earthing Connection all array	*Yes*	*No*	
SPV cleaning arrangement Done	*Yes*	*No*	
Photo taken			
Array Joint Box (AJB)			**Remarks**
All AJB Fuse are Ok	Yes	No	
AJB Connection Properly Done	Yes	No	
Manufacturer Stickering	Yes	No	
Danger Stickering	Yes	No	
Photo taken	Yes		



Structure & Grouting			Remarks
All nut bolt washer fixing Properly	*Yes*	*No*	
Photo taken	*Yes*	*No*	
Grouting Dimension		mm×mm×mm	
Grouting Specification			
Curing Properly Done	*Yes*	*No*	
Neat cementing Done	*Yes*	*No*	

Lighting Arrester (LA)			Remarks
LA Height	*Yes*	*No*	
LA Mount in	*Yes*	*No*	
		mm×mm×mm	
Photo taken	*Yes*	*No*	
Earthing			
Total No. of earthing		*nos*	
Earthing Type	Pipe Earthing		
	Plate Earthing		
	Chemical Earthing		
Earthing Connected through			
G.I.Strip	*Yes*	*No*	
Wire	*Yes*	*No*	
Earthing Pit Cover Installed	Yes	*No*	
Earthing Pit Cover Dimension		mm×mm	
Earthing Pit Distance		metres	

Wiring			Remarks
PVC pipe use	Yes	No	
SPV to AJB Cable Tray use	Yes	No	
PVC Saddling Properly	Yes	No	
Cable Tray Use	Yes	No	
Ground Clearance of PVC pipe		inches	
MC4 Connector Use	Yes	No	
Photo taken	Yes	No	

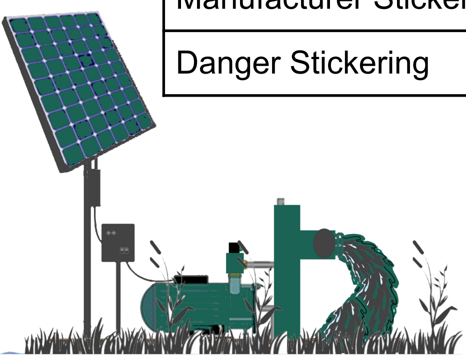


Cable Gland & Lug use			Remarks
AJB	Yes	No	
ACDB	Yes	No	
DCDB	Yes	No	
Inverter all terminals	Yes	No	
Battery Terminals	Yes	No	
Earth Terminals	Yes	No	
Photo taken	Yes	No	

DCDB			Remarks
All connection Properly Done	Yes	No	
Manufacturer Stickering	Yes	No	
Danger Stickering	Yes	No	
Photo taken	Yes	No	

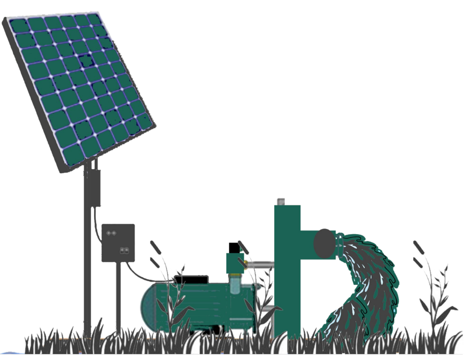
ACDB			Remarks
All connection Properly Done	Yes	No	
Manufacturer Stickering	Yes	No	
Danger Stickering	Yes	No	
Photo taken	Yes	No	

Inverter			Remarks
Inverter Mounted Properly	Yes	No	
Inverter connection Properly Done	Yes	No	
Ground Clearance of inverter		inches	
Insulated safety mat use in Inverter	Yes	No	
Inverter Earthing Done	Yes	No	
Manufacturer Stickering	Yes	No	
Danger Stickering	Yes	No	

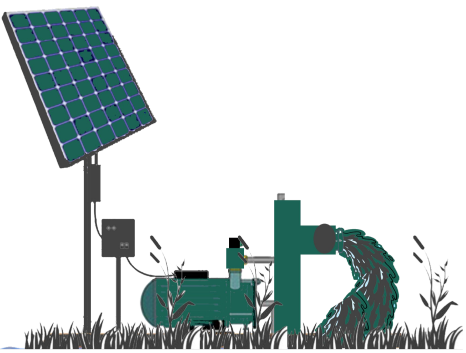


Battery			Remarks
Battery Voltage		Volt	
Battery Charging current		Amps	
Battery Dis- Charging current		Amps	
Battery Water level (if require)	*Yes*	*No*	
Battery Rack installed properly	*Yes*	*No*	
Battery mat provided	*Yes*	*No*	
Battery Terminal Clean and Use Petroleum gel	*Yes*	*No*	
Battery Terminal wire connected properly	*Yes*	*No*	

Plant Safety Equipments			Remarks
Fire Extinguisher & Sand Bucket Placed in proper location	Yes	No	
Photo taken	Yes	No	
Require Spare Tools Placed in proper location	Yes	No	
Photo taken	Yes	No	



General Check			Remarks
Solar Plant All direction photos collect and submitted	Yes	*No*	
Plant Handover Certificate collect	Yes	*No*	
Solar Plant operational properly	Yes	*No*	
Solar Plant connected load operational properly	Yes	*No*	
End Customer / Beneficiary Educated by the contractor to operate the plant	Yes	*No*	
Contractor Sign with Date :	Manufacturer Site Coordinator Sign with Date :		
Rating By Manufacturer Site Coordinator	Rating By Sr.Project Coordinator	Rating By Sr.Project Coordinator	
		1 - Beyond Expectation	4 - Average
		2 - Very Good	5 - Below Average
		3 - Good	6 - Poor
Senior Project Coordinator Name & Sign with Date ::			



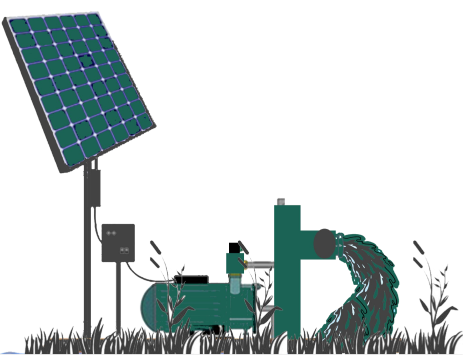
Commissioning

Once all the system components are installed, system commissioning occurs. Following are the steps to follow while commissioning a system:

- **Electrical connections:** Check all the physical cables if they all are securely fastened and also check the electrical system for continuity.
- **Water connections:** Examine all the pipes and the connections between these pipes and the pump to make sure everything is well connected without leakage and well supported. Make sure enough water is available in the water source
- **Pump**: Check that the pump and motor are correctly aligned. Check if the pump is properly lubricated and inspect if all the seals are perfectly closed.
- **Pump priming (if required):** Some of the pumps will require being primed when used for the first time which means filling water in the casing. Centrifugal pumps need to be primed every time they are turned on.
- **Check water level :** Never switch on the motor if enough water is not available in bore well/well and make sure enough sunlight is present at the location
- **Check VFD Configurations**
- **Check grid input voltage** (for grid-connected hybrid systems)

The following steps should be followed to start the solar pumping system:

1. **Turn on array**: Check if the output voltage and current of the solar array are correct.
2. **Turn on the control systems:** Check if the system readings are matching the manufacturer's specifications.
3. **Turn on the pump:** Start the pump according to the manufacturer's instructions. Monitor its pressure and water flow to confirm that the system is operating correctly.
4. **Observe pump operation**: Check if there are any leaks and monitor system readings while the pump is in operation. If needed conduct a bucket test to determine the flow rate and assess the system performance.



Common Errors

- **Connecting pump directly:** Never connect pump directly to the SPV panels as they may give higher or lower voltage than required by the load equipment and this may damage the equipment permanently.

- **Switch on controller**: Never switch on controller switch during installation.

- **DC Isolation:** All DC wiring should be completed prior to installing a PV array. This will allow effective electrical isolation of the DC system while the array is installed; and effective electrical isolation of the PV array while the inverter is installed.

- **Loose connection:** If there is no output, then the problem may be with cable, connector, junction box or charge controller. Check for defects or loose connection and replace if necessary.

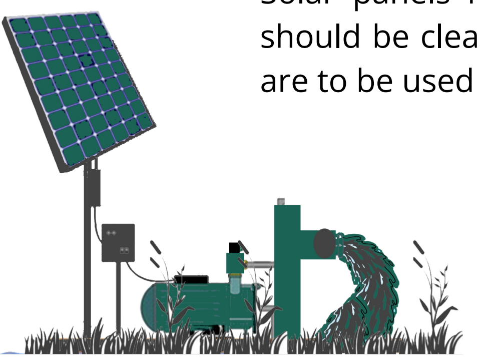
- **Internal damage:** If output voltage is okay but there is no current, then the possible failure is cell interconnections. It is due to the internal damage, and should be returned to the factory if within the warranty.

- **Dirt accumulation on PV module:** If there is no charging indication on the charge controller, the possible failure may be in the module or charge controller. If in the module, it is due to shading or dirt accumulation or corrosion or damage or module cable. In this case, change the location of the module and clean regularly. Replace cable or charge controller accordingly.
- **Low output voltage:** If output voltage is not available in less duration. It is possibly because of shading, dirt or improper installation or cable/charge controller damage. Remove shades and clean for maximum voltage output. If the cable or charge controller is damaged, then they should be replaced.

- **Shadow of Fencing:** Solar Photovoltaic Panels are installed facing south with proper angle of tilt where there is no shadow on any part of the panel at any time of the day to get maximum power.

- **Fencing:** As far as possible SPV modules should be fenced to protect it from cattle or from any damage or theft.

- **Cleaning agents:**
  Solar panels require no maintenance; however, the surface of the panels should be cleaned regularly to remove the dust. None of the cleaning agents are to be used except for water.



- **Distance of controller:**
  Install the controller close to the PV array to minimize cable length and cable losses on the input side and reduce the risk of lightning damage. Mount the controller on a solid board/wall in a shaded, well ventilated location.

- **Improper earthing:**
  It is important for the system (pump, controller, PV generator) to be correctly grounded and earthed for safety of both the installation and users. Lightning protection should also be installed.

- **Improper motor wiring:**
  Check that the motor wires are in the right order to prevent reverse rotation of the motor which could damage the pump. The correct rotation direction for submersible pumps is counter-clockwise, viewed from the top.

- **Electrocution/shock:**
  Always remember that even a single solar module is a live circuit that can result in electrocution.

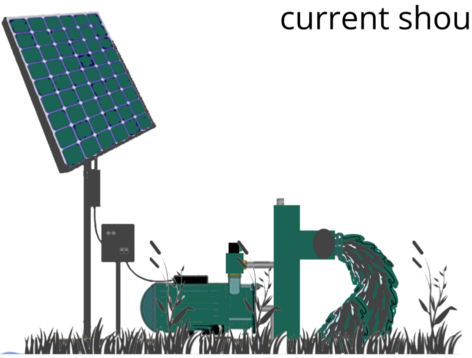
- **Improper module connection**:
  Two or more modules connected in parallel or series if connected incorrectly to a pump can damage or destroy the equipment.

- **Mishandling of PV Modules:**
  Your solar module consists of glass which can easily break. Do not throw objects at the solar module, stand or step on the module or try to repair your solar module if it breaks.

- **Unnecessary connections:**
  Do not carry out modifications on your system without technical guidance from your system supplier or a qualified technician.

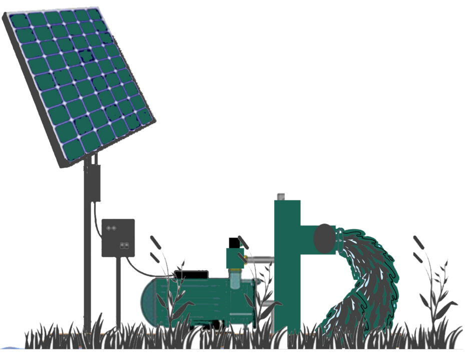
- **Cover the module during installation:**
  Fix all modules securely onto the support structure before doing any wiring and minimize the risk of accidents by covering and shading modules with their packaging until the installation is complete.

- **Mismatch of PV modules:**
  Modules that have different characteristics in model, power, voltage and current should not be connected together in the same system (mismatching)



Annexure

Grades of Concrete	Mix Ratio(Cement : Sand : Aggregates)	Compressive Strength
Lower Grade of Concrete		
M5	1:5:10	5 MPa
M7.5	1:4:8	7.5 MPa
M10	1:3:6	10 MPa
M15	1:2:4	15 MPa
M20	1:1.5:3	20 MPa



Evaluation

1) **Float Switch Is used to measure water output** (b)
   a) True
   b) False

   a)

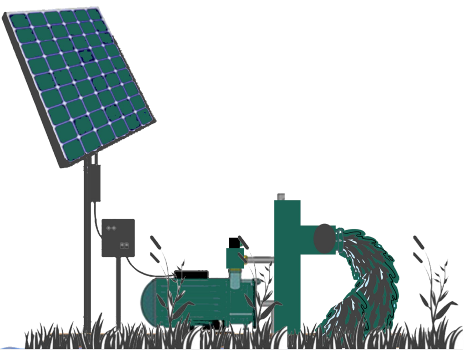
2) **If motor is moving in reverse direction, what action should be taken** (b)
   a) Check the earthing
   b) Check the connections
   c) Change the controller

3) If 300 Wp of solar panels are available for typical 1 HP solar pump (C)
   a) Connect 2 panels in parallel combination to get maximum output
   b) Connect 2 panels in series combination to get maximum output
   c) Connect 3 panels in series combination to maximum output
   d) Connect 4 panels in parallel combination to maximum output

4) **Surface pumps are preferred for bore wells and tube wells** (b)
   a) True
   b) False

5) **For optimal performance which type of tracker should be used** (b)
   a) Single axis tracker
   b) Dual axis tracker

6) **Standard structure are designed considering wind speed of** (c)
   a) 50 m/s
   b) 100 m/s
   c) 150 m/s
   d) 200 m/s

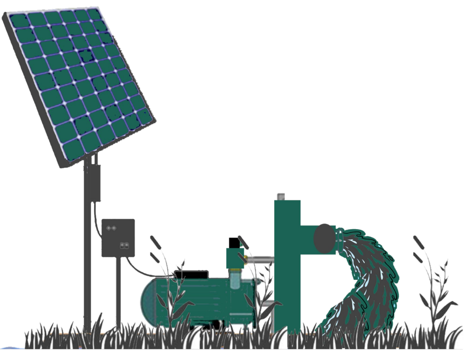


8) **In which direction solar panels be faced**
(b)

a) North
b) South
c) Northwest
d) Northeast

9) **What type of mixture is used in earth pit**
(c)

a) Salt
b) Sand
c) Charcoal
d) Cement



Evaluation

1 **Float Switch Is used to measure water output**

a. True

b. False

2 **If motor is moving in reverse direction, what action should be taken**

a) Check the earthing
b) Check the connections
c) Change the controller

3 **If 300 Wp of solar panels are available for typical 1 HP solar pump**

a) Connect 2 panels in parallel combination to get maximum output
b) Connect 2 panels in series combination to get maximum output
c) Connect 3 panels in series combination to maximum output
d) Connect 4 panels in parallel combination to maximum output

4 **Surface pumps are preferred for bore wells and tube wells**

a) True
b) False

5 **For optimal performance which type of tracker should be used**

a) Single axis tracker
b) Dual axis tracker

6 **Standard structure are designed considering wind speed of**

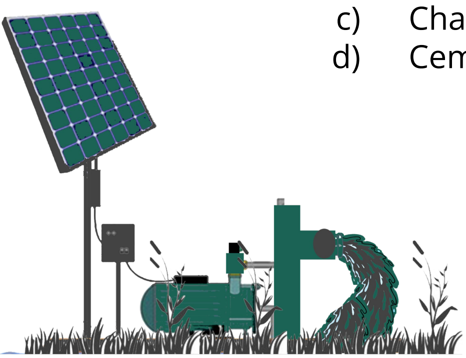
a) 50 m/s
b) 100 m/s
c) 150 m/s
d) 200 m/s

7 **In which direction solar panels be faced**

a) North
b) South
c) Northwest
d) Northeast

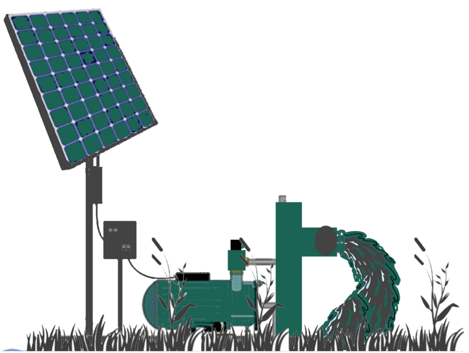
8 **What type of mixture is used in earth pit**

a) Oil
b) Sand
c) Charcoal
d) Cement



Answers

1	b.	2	b.	3	c.	4	b.
5	b.	6	c.	7	b.	8	c.



Operation and Maintenance of Solar Pumps

TOPICS COVERED

Inspection of Components - with checklist

Maintenance of solar pumps

Warranty

Step wise System Diagnosis Process

Troubleshooting

Inspection of Various Components

Every system regardless of type, must be inspected periodically. It is an important aspect for good operation of the system. System inspection should be conducted at least once a year depending on the size and intricacies of the system. Planned inspection prompt timely maintenance, and in some cases inspection and maintenance can be carried simultaneously especially when the inspectors also double up as maintainers. It also highly recommended that the inspectors also triple as repairmen of the system.

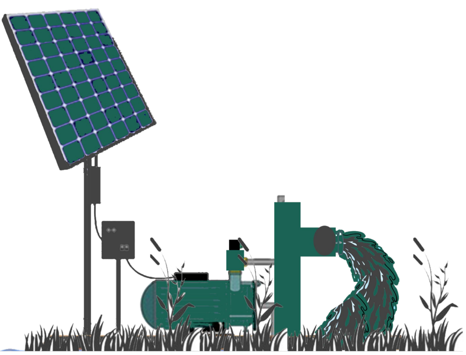
Solar Panels

- Check the solar panels for dirt and cracks,
  - dirt accumulates on the solar panels over time, as they are exposed to the environment. Cracks may be due to vandalism or heavy hailstorm.
  - If there are cracks on the panels, one should consider replacing those panels
  - Dirt can be cleaned off the surface using clean water and cloth, Soap should not be applied.
- Electrical cables
  - Check to see if all electrical cables are still intact, loose cables should be tightened up.
- Tilt Angle
  - In fixed solar array this may not be necessary, unless there is suspicion of tilt on angle if inclination. This should be corrected, to avoid dust accumulation of flatter inclines, and reduced solar absorption on steeper inclines.

Submersible Pump

In most cases, three major components should be inspected in submersible pumps.

- Alarm monitoring
- Pressure Flow checks
- Visual Inspection
  - Inspect for clogging debris on suction inlet
  - Check pump exterior for dents, corrosion and abrasion



Pipelines And Fittings

The inspection procedure outlined here, is a visual inspection. The procedure includes all fittings and accessories associated with pipelines.

- Identify the pipeline section to be inspected and note it down on the checklist book.
- Inspect the pipeline for labels, if any are visible on exposed sections.
- Inspect the pipelines for leaks, if leaks are spotted repair should ensue
- Inspect backfilling on pipelines
- Check or inspect pipelines for erosion after events of rainfall
- Inspect pipe supports, for loose brackets, pipe support if they are still intact.
- Inspect pipeline for vibrations, if excessive schedule for attendance
- Inspect pipe insulation against corrosion, pipes especially steel pipes usually corrode when they leak.

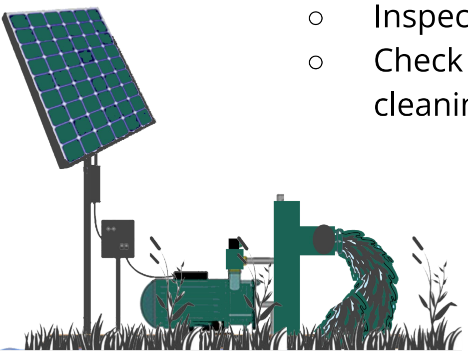
Valves

These are classified as part of system appurtenances. They are used to isolate certain sections of the system, from the rest. Isolation is usually done when there is ongoing maintenance in one section, where water flow is not required at the time.

- Leaks
  - Valves should be inspected for leaks, that is if they are still water tight, leaks on valves should be attended to, to curb prolonged leakages on the system.
- Blockages
  - Debris collection in the system may cause valves to let water through even though they are shut. All debris should be cleaned off valves, especially gate valves.
  - Grit collection also affects operation of gate valves, hence they should be stripped during preventive maintenance and cleaned off.
- Corrosion
  - Inspect valve threads for signs of corrosion, all corrosion when spotted should be attended.

Storage Tanks

- Tank
  - Inspect for leak on the tanks, if leaks are spotted schedule for repairs
  - Inspect leaks on pipes and fittings connecting to tank/reservoir
  - Check for accumulation of algae inside tank, and schedule for cleaning if spotted

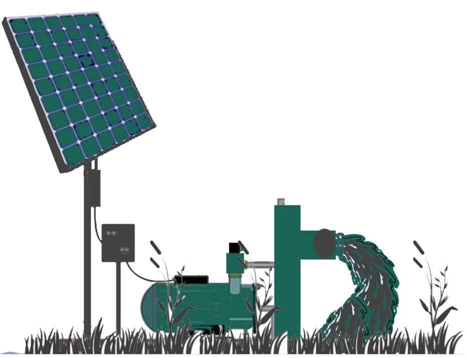


- Valves and Fittings
  - Inspect for leaks and breakages on valves. consider changing valves or repairing them leaks are spotted.
  - Inspect for dirt collection inside valve chambers, and clean overgrowth of grass in chambers.
- Float Valves
  - Inspect float valves for function, adjust float valves accordingly

Inspection Check List

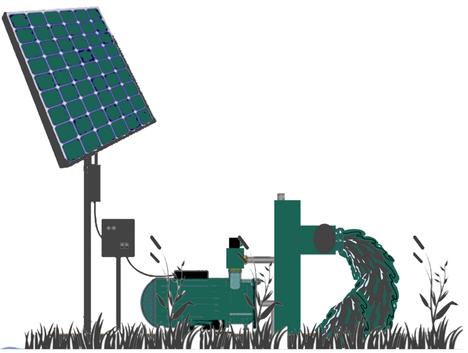
Submersible Borehole Pump

- Check electrical condition of insulation on power cable(s) and on all phases of the motor.
- Check for any loose or faulty electrical connections within the control panel.
- Measure resistance between stator windings (in ohms).
- Check voltage supply between all phases of the electrical control panel.
- Check voltage balance between all phases on the load side of the pump / mixer control panel with pump / mixer running (vac).
- Check amperage draw on all phases of the motor (in amps).
- Check condition and operation of the motor thermal protection control system (if equipped).
- Remove pump / mixer from the lift station for physical inspection.
- Check condition of upper and lower shaft seals (inspect condition of motor / stator housing, if applicable).
- Check condition and operation of leakage and bearing sensors (if equipped).
- Check for worn or loose impeller or propeller.
- Check impeller wear rings (rotating & stationary)
- Check for any unusual noise in the upper and lower bearings.
- Clean, reset and check operation of the level control system (if equipped).
- Check for physical damage of power and control cables.
- Check for correct shaft rotation.
- Check operation of valves and associated equipment.



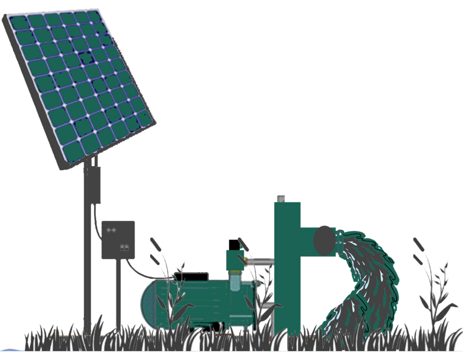
Storage Tanks

Storage Tanks Inspection Checklist			
System Name			
Inspector Name			
Date of Inspection			
Installation Date of Tank			
Commissioning Date of Tank			
STATUS			**ITEM**
Yes	**No**	**Comment**	**Item Description**
			Reservoir dirty
			Reservoir leaking
			Valves leaking
			Threads coroded
			Float valve closing properly
			Level Indiator not functioning
			Tank Stand coroded
			Tank Stand shoowing signs of structural failure
			Welds on stands coroded
			Tank stand needs painting
			Tank
Summary of Inspection Comments			



Pipeline

PIPELINE INSPECTION CHECKLIST					
IDENTIFICATION					
System Name					
Section number		Pipeline Number name		Date	
Date of Inspection		Pipe Specification		Contact Nmuber:	
Inspectors Name					
Comments					
IDENTIFICATION		YES	NO	COMMENT	LOCATION
Does the pipe have a label					
Is the pipe adequtely identified					
Are labels readable					
LEAKS					
Are any leaks observed					
Are any valves leaking					
Any leaks on fittings					
Any leaks on clamps					
Any recurrent leaks					
PIPE SUPPORTS					
Any loose supports					
Any uprooted supports					
Any corrosion on supports					
VIBRATION					
Any obseved vubration					
Any pipe distortion observed					
INSULATION					
is insulation still enough					
Any exposed insualtion					
Any bulging observed from insulation					
Any patternal discolouration on insulation					
Any missing insulation					
CORROSION					
Any corrossion observed on Joints and Fittings					
Any coating deterioration					
Any corrosiion in threads, flanges and valves					
SUMMARY OF COMMENTS					
Inspector:					
Were any deficiencies observed					
Deficiencies of concern were reported to Client					
Deficiency category:		leaks			
		Corossion			
		Vibration			
		Insulation			
		Pipe supports			
Qualified Inspector					
Clients Signature					



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Maintenance of solar pumps

Weekly Checks

Proper maintenance of any machinery or equipment ensures it's long life. There are a few weekly maintenance checks that can be easily done by farmers themselves to ensure smooth running of the solar pump:

Solar Panels

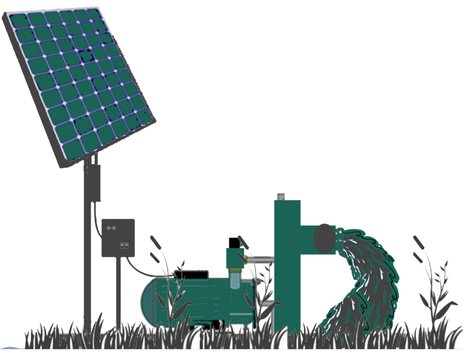
- Clean the Solar Panels to keep the system in a healthy condition and give better water output. Normal water needs to be used for cleaning the modules using clean water and wiper or wet cloth.
- Clean early morning and late evening and avoid cleaning during day time as it hinders the production of electricity and may also lead to glass damage.
- Remove any shadow falling on the solar panels

Cables and Connections

- Keep the Controller, wiring and connections all clean and intact.
- Inspect any kind of leaks in Pipes, tanks and valves for water supply. If any leaks are found, that needs to be repaired or replaced.
- Check if the motor cable of the pump is heating by touching the insulation by hand. If it is heating, then it needs to be replaced.

Other Checks

- Regular monitoring of power generation and Water output by using a Remote Monitoring system needs to be done to monitor the system performance.
- If water output has reduced, the pump needs to be checked for any blockage due to accumulation of mud, and that has to be cleared



Monthly Checks

A number of parameters need to be checked monthly to ensure the components are running smoothly.

Module Mounting Structure

- Check the structural integrity of the module mounting structure. Tighten the nut bolts on the mounting structure and solar modules. Also, replace any damaged or rusted nuts and bolts during the monthly check.
- The module mounting structure needs to be painted once a year with corrosion proof GI paint in order to prevent damage due to rust or corrosion.

Surface pump

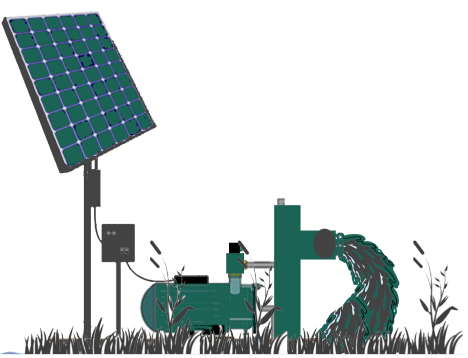
- Inspect the oil seal and packing of the surface pump for any leaks. This is not required if a mechanical seal is used for the surface pump.
- Inspect the tightness of couplings in the surface pump to ensure no leakage as well as for vibration during operation. If there is vibration during operation, then the pump needs to be fixed properly using nuts and bolts.

Submersible pumps

- Monthly cleaning of filters is a good practice, but not feasible for most farmers. However, cleaning of filters needs to be done after every cropping season, that is, every 3 to 4 months to keep the system healthy.
- Remove mud and other external blockages from the access points and joints of the pipes.
- Lubrication of the motor and pump bearing needs to be done as per the manufacturer's guidelines after every cropping cycle. The pump should not be over-lubricated. The vent cap of the bearing needs to be removed before lubrication and the pump should be run for 30 minutes before reinstalling the cap.

Controller

The pump controller box should be kept in a clean and dry area, and regular dusting should be done. The electrical connections need to be checked monthly by touch and feel. Before any checking or maintenance work, the MCBs for the module and grid and the operating switch of the pump should be turned off in the pump controller.



Cables and Connections

- The important connections that need to be monitored are connection between solar array and solar MCB, connection between pump and pump controller and connection between pump controller and earthing. Also, the MC4 connectors in the solar modules need to be checked for any loose connections.The cable junctions and junction boxes should be intact. If any break or damage is noticed, the junctions need to be repaired or replaced.
- Insulation is important during conducting any maintenance repair work, and insulation of all wires need to be checked during the maintenance. If any damage is noticed, that needs to be repaired immediately using insulation tape.
- While carrying out electrical maintenance and repair work, it is essential to use insulated tools and safety gears like rubber gloves and shoes to prevent electrical shocks.

Did you KNOW?

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Warranty

It is common for communities to establish comprehensive maintenance contracts with suppliers during warranty periods, and it is a good practice to extend such contracts beyond the warranty period.

1. Monitoring

System operation can be optimized by closely monitoring and recording key system parameters (data logging), enabling operators to assess system performance or demand changes.

2. Defect liability period:

Under the defects liability period of 1 to 2 years, any items that fail, are not installed to standard, except for any damaged by natural calamities must be corrected on site at cost to the contractor/supplier/ installer (depending upon the contract).

3. Product Warranty:

Every manufacturer defines their own warranty period. During the warranty period, the supplier is also expected to check system components and perform preventive maintenance at least quarterly (in any case, neither pumps nor panels require heavy maintenance, with panels only needing periodic cleaning) to attend to user complaints within a reasonable period of time, and to resolve any system breakdowns.

Product	Typical warranty period
Solar Panels	10-15 years*
Motor-Pump Set	2-5 years*
Inverters	5 years
Remaining components	1-2 years

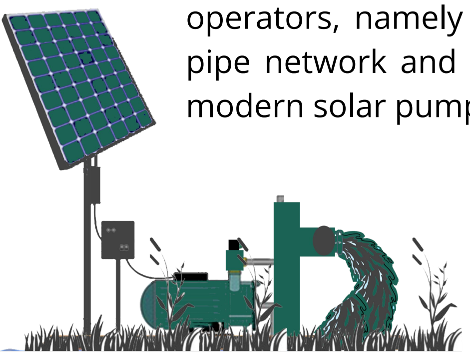
***varies according to the manufacturer**

4. Performance warranty:

In addition to component warranties, the supplier may also provide a performance warranty on the system as a whole, ensuring that it will meet or exceed the design performance for a number of years. Solar panels generally come with a total performance warranty of 25 years.

5. Training:

Suppliers should further secure system sustainability by training system operators, namely on basic plumbing skills useful for repairing leakages in the pipe network and on handling the advanced inverters and sensors common in modern solar pumping systems.



Step wise System Diagnosis Process

A technician of a solar water pump is like a doctor treating a patient. Just the way a doctor asks for the symptoms to his/her patients and then prescribes a medicine. Similarly a technician is required to ask for the problem and then follow the steps to understand what could have gone wrong and where. A step by step process of diagnosing makes the process of maintenance easy and fruitful.

Step 1

Check the voltage and current of the solar array using a multimeter, keeping in mind the weather conditions. The VMP and IMP should be checked in closed circuit only.

If the Voltage rating comes below the overall solar array VMP rating, a few things need to be checked.

1. Check if there is dust accumulation on the panels. The panels need to be cleaned regularly to ensure optimum energy output.
2. Check if there is any shadow falling on the solar modules, and remove the obstruction. Sometimes due to wrong installation, there can be obstructed sunlight, which can be fixed by repositioning the modules.
3. Check for any loose connection in wiring or MC4 connectors. If any loose connection or faulty connector is found, it needs to be repaired or replaced.

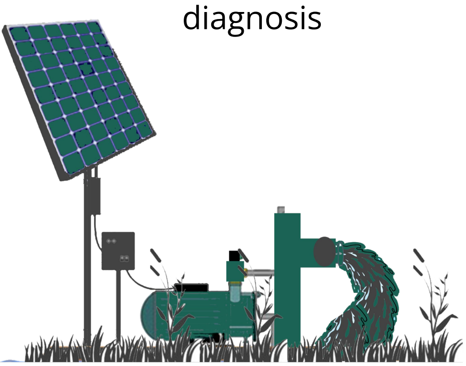
If the problem still persists, then individual modules need to be checked using multimeter and the faulty module or modules need to be replaced

Step 2

Check the condition of the Miniature Circuit Breaker or MCB inside the pump controller box. If any current or voltage surge occurs, inside the system the MCB will trip and disconnect the circuit.
The solar module MCB, Grid MCB and the pump MCB must be turned on. If the MCB is burnt, it has to be replaced with an MCB of the same rating.

Step 3

Check for the continuous Power output from the solar array by using a Multimeter. If there is a big fluctuation in Power output, it must be the issue of the controller. The servicing technician must modify the controller setting to ensure the constant power output is restored, otherwise if there is an internal issue of the pump controller, then it has to be dismantled and taken to a servicing centre for further diagnosis



Step 4

The water level is checked for Submersible pumps usage.
If the water level goes down from the minimum head range of the Pump, the column pipe length can be increased by approximately 10 feet. This will ensure a water flow, even though the pressure of flow might reduce.Also, groundwater recharge is recommended to be done in the region to bring up the water table.

Step 5

The pump condition needs to be checked.

For surface pumps, the motor and pumpset are opened separately and checked.

1. The motor winding is checked for any wear and tear and damage
2. The pump must be checked for any blockage or jam that needs to be cleared.

Once checked, the pump and motor must be joined and lubricated. If an oil seal is used in the pump, then that has to be checked for any leakage and then placed back on the pump.

For submersible pumps,

1. The pump is taken out from the borewell and then the same diagnostic checks are done like surface pumps.
2. During reassembly, water must be added into the pump before re-inserting the pump into the borewell.

In case the winding coil of the motor gets more than 50% burnt due to long usage or accident, then the whole coil has to be replaced. Otherwise just the burnt portion can be replaced.

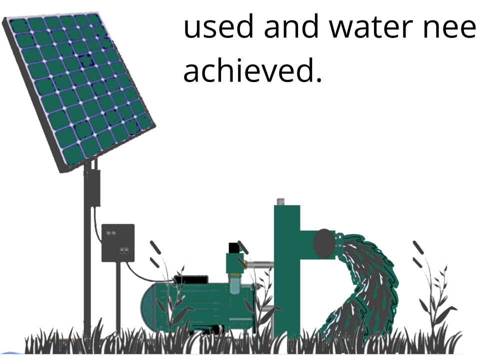
Pump lubrication is good practice during System Diagnostics.

Step 6

Check if there is any insulation failure by using an insulation tester. If it's showing any current at the joining points, it's very risky to operate the solar Pump. Shut Down the system immediately and insulate all the connecting points using insulation tape. Also, any damaged wire needs to be replaced or repaired.

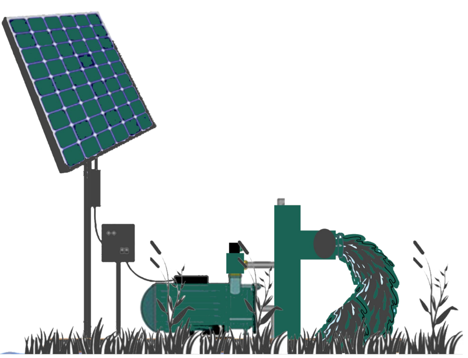
Step 7

Ensure that the controller is properly earthed and checked using an earth meter. The earth meter reading should be less than 1 Ohm. If the earth meter reads more than 1 ohm, then earthing chemical compounds need to be added in the ground where the earth wire is inserted. Otherwise, a mixture of salt and charcoal can be used and water needs to be poured on it till a reading of less than 1 ohm is achieved.



Diagnostic Checklist for solar pump

Check	What to do?
Check 1 - Check the voltage and current of the solar array using a multimeter	If the Multimeter reading is normal, then the system is running fine. If the reading is less than normal range, then clean the panels and check the MC4 connections and remove shadows on the panels. If the reading is more than normal range, then check the earthing connections and add repair it if damaged
Check 2 - Check the condition of the Miniature Circuit Breaker or MCB inside the pump controller box	If the MCB is connected and working fine, then the system is also running fine.If the MCB is tripped, then check for the fault, repair it and then restart the MCB
Check 3 - Check for the continuous Power output from the solar array by using a Multimeter	In case fluctuations are observed, then the pump controller needs to repaired
Check 4 - Water level is checked for Submersible pumps	In case the water level has gone down below pump level then stop the pump usage and ensure groundwater recharge In case water is less than 10 feet above pump, ensure groundwater recharge and regularly check water level to prevent dry run
Check 5 - Check pump condition	In case the pump winding coil is burnt more than 50%, it needs to be replaced In case there is dirt and debris, they need to be cleaned
Check 6 - Check if there is any insulation failure by using an insulation tester	In case of insulation break, the pump needs to be shut and the broken portion needs to be fixed.
Check 7 - Check Earthing using an earth meter.	In normal conditions, the reading of the earth meter should be less than 1 ohm. In case the reading is more than 1 ohm, then earthing chemical compounds need to be added in the ground where the earth wire is inserted till 1 ohm value comes



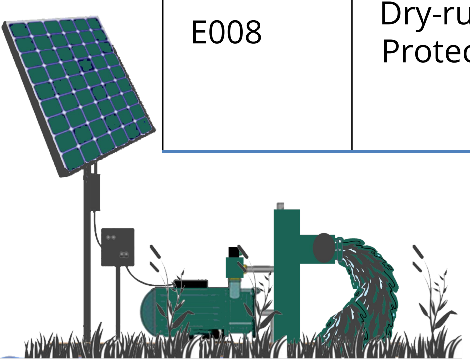
Major fault conditions for Pump Controller

If the controller has stopped to indicate a fault code on the display, the associated time-out delay will vary depending on the nature of the fault. The number following the "E" symbol corresponds to the error code for the offending condition. Every controller manufacturer can have their own nomenclature.
Electronic monitoring gives the controller the capability to monitor the system and automatically shut down in the event of:

- Dry well conditions
- High Voltage Surge
- Low Input Voltage
- Short circuit
- Over heating

Major fault conditions are highlighted in following table:

Fault code	Fault description	Possible Causes	Remedy
E001	Motor overload	• Too-low input voltage	Check input power supply or wiring
E002	Output phase loss	• Broken wires in the output cable • Broken wires in the motor winding • Loose output terminal	Check the wiring and installation
E003	Controller overheat	• Too-high ambient temperature • Cooling fans of the controller stopped or are damaged.	Decrease the ambient temperature if possible
E004	Well Level Fault	• Dry well or slow water recover	Wait for water to recover or reinstall the pump
E005	Over-current at constant running speed	• Sudden change of load • Too low input voltage	Check the load
E006	No power input	• Insufficient radiation • Improper connections	Check if sunlight is sufficient Check for connections
E007	Earthing or short circuit	• Improper earthing	Check the earth wire connections
E008	Dry-run Protection	• There is no water in the water tank waiting for water, it will restart	Restart the pump only if water is available. Running the pump without water can damage the motor windings.



Troubleshooting

Problem 1: Surface pump is vibrating during operation.

Reason: The surface pump is not fixed properly with the mounting structure or ground.
Solution: Fix the pump using nuts and bolts and tighten the joints. Once the loose joints are fixed, then the vibration stops during pump operation.

Problem 2: Water not coming out of the pump even though voltage reading is optimum on pump controller.

Reason: This happens due to inoperative pump, which is caused by various reasons -

1. pump being jammed by mud and dirt
2. wiring or connection problem
3. damaged pump motor winding

Solution:

- If the pump is jammed, then it has to be cleaned by a technician and reoperated
- If there is faulty wiring or loose connection, then the wiring needs to be repaired or replaced.
- If there is damaged winding in the motor coil, then the damaged portion needs to be replaced.

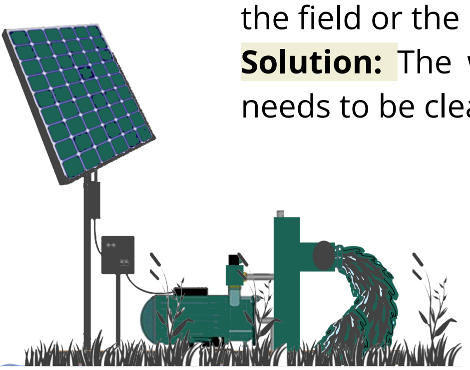
Problem 3: Short-circuit in pump.

Reason: Short circuit happens due to improper or damaged insulation of cable connections. Short-circuit and jammed pump impeller is shown in the pump controller display.
Solution:

- The location of the short circuit needs to be identified.
- Then, that particular portion of the cable needs to be replaced with a new cable.
- If the short circuit happens in the winding of the motor coil, then the coil needs to be changed.

Problem 4: Reduction In water supply through delivery pipe

Reason: The pipe has too many turns or cascades before delivering water to the field or the pipe has some blockages due to accumulation of mud or dirt
Solution: The water delivery pipe needs to be straightened. The pipe also needs to be cleaned to remove blockage due to accumulation of mud and dirt.



Problem 5: FIlter obstruction of borewell and water is not being pumped out

Reason: Debris gets accumulated on the filter to protect the pump from blocking
Solution: Remove the debri from the pump filter and reposition the hose to start pumping again.

Problem 6: Water flow pressure is low

Reason: The delivery pipe diameter is larger than the pump output pipe diameter or nozzle diameter
Solution: Use a delivery pipe of the same diameter as the output pipe or nozzle.

Problem 7: Delivery pipe is over bulging or bursts

Reason: The delivery pipe diameter is smaller than the pump output pipe diameter or nozzle diameter causing friction loss
Solution: Use a delivery pipe of the same diameter as the output pipe or nozzle.

Problem 8: Motor is running in opposite direction

Reason: Water pumps are designed to operate with the impeller going in one direction. If it is going the opposite direction, then there is an opposite connection between the controller and the pump.
Solution: The direction of connection needs to be changed.

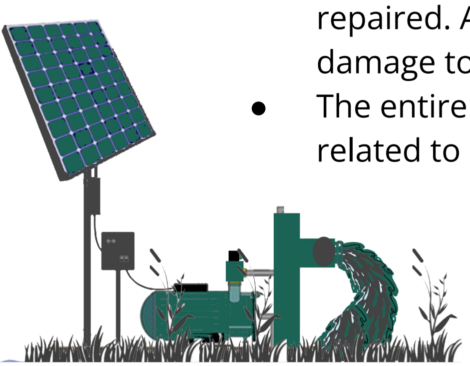
Problem 9: PV system not producing power, controller not turning on

Reason: The fault can be caused by either of the following reasons

1. PV module failure
2. Pump controller out of order
3. Wire or loose damaged by birds, rodents or during soil preparation

Solution:

- In case of complete module failure, individual modules are checked and the faulty modules are removed. Also, the MC4 connectors need to checked for loose connections
- In case the pump controller is out of order, the wires in the controller need to be tightened or reconnected if they have fallen out. If the controller still does not work, it has to be taken to the service centre.
- In case of damage to the cable connections, they need to be replaced or repaired. Also, care should be taken to ensure minimum physical damage to cables due to these external factors.
- The entire PV system is down/does not produce power; this may be related to a problem with the inverter.



Problem 10: The PV system output is less than expected, Water coming in bursts from delivery pipe

Reason: There can be several reasons for PV system output being lesser than optimum levels

1. If Module not properly cleaned
2. If there is shadow on the PV module
3. If there is any loose connection in MC4 connectors
4. Controller settings were adjusted wrong.

Solution:

- Clean the modules every week with clean water
- The modules should be placed such that no shadow falls on them. In case shadow is persistent, the modules need to be relocated elsewhere.
- In case one panel is damaged in parallel connection, that module needs to be replaced
- Loose connections need to checked and replaced in case of any damage
- Lastly, pump controller settings need to be checked and adjusted such that solar PV output remains optimally used.

Problem 11: Pump controller or controller box giving out electric shocks

Reason: Improper earthing or earthing connection

Solution:

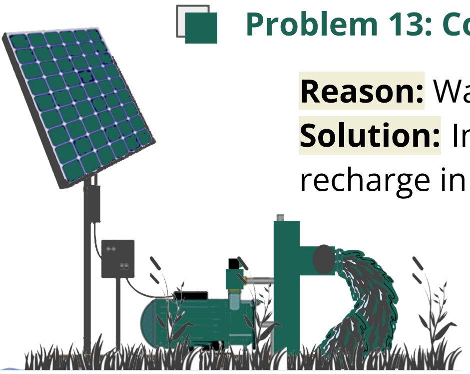
- Check the wires and insulate them properly, ensuring no naked wire is touching the controller box
- Check earthing connection, that is, whether the earth wire is properly inserted in ground
- Check the earthing using an earth meter, and if the reading is more than 1 ohm, add more earthing chemical compounds and water till the reading reaches below 1 ohm.

Problem 12: Controller does not show all parameters correctly

Reason: Loose wiring or Display fault
Solution: Open the controller and check for loose connections, and tighten loose wirings. If problem still persists, the controller may need to be replaced

Problem 13: Controller shows dry run indicator

Reason: Water level lower than pump
Solution: Increase depth of pump borewell and/or practice groundwater recharge in long term



Reference Materials

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