Nigerian Journal of Renewable Energy Research
Volume 1, Number 4, pp. 204-249, 2025

eISSN 1597-8907: pISSN 1597-8877

ANALYSIS AND EVALUATION OF PHOTOVOLTAIC SOLAR WATER PUMPING SYSTEMS AS A SUSTAINABLE APPROACH TO IMPROVE WATER UTILISATION EFFICIENCY

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https://doi.org/10.5281/zenodo.17931243
https://njrer.org/download/analysis_and_evaluation_of_photovoltaic_solar_water_pumping_systems.pdf

ARTICLE INFORMATION

Article history:
Received 18 Jun., 2025
Revised 28 Sep., 2025
Accepted 15 Oct., 2025
Available online 30 Nov., 2025

Keywords:
Photovoltaic Solar Water Pumping System, Sustainable Solution, Renewable Energy, Irrigation Technology

ABSTRACT
Present paper aims to discuss scope and limitations of photovoltaic solar water pumping system. Components and functioning of PV solar pumping system are described. In addition, review of research works of previous noteworthy researchers has also been done. Irrigation is well established procedure on many farms in world and is practiced on various levels around the world. It allows diversification of crops, while increasing crop yields. However, typical irrigation systems consume a great amount of conventional energy through the use of electric motors and generators powered by fuel. Photovoltaic energy can find many applications in agriculture, providing electrical energy in various cases, particularly in areas without an electric grid. In this paper the description of reviews on a photovoltaic irrigation system, is presented. Since various irrigation points of organization are located in areas without an electric grid, photovoltaic cells can provide the necessary power for the operation of this automatic irrigation system. To further enhance the daily pumping rates tracking arrays can be implemented. This system demonstrates the feasibility and application of using solar PV to provide energy for the pumping requirements for sprinkler irrigation.

1. INTRODUCTION
Diesel-powered pumps are widely employed in farming and grassland irrigation. However, there can be problems of reliability and availability where fuel supply is erratic and expensive, high maintenance cost, and short life expectancy. These and recent concerns for the environment associated with the diesel engines call for a viable alternative source of power for irrigational water pumping. Renewable energy sources have gained a lot of attention as a replacement for fossil fuels or as a supplement in hybrid systems. Solar-powered (photovoltaic)

systems are one of the viable alternatives that have attracted considerable attention in this regard. They have been deployed in many remote regions for various applications, ranging from rural electrification and community water supplies to irrigation and livestock water supplies. Although photovoltaic (PV) systems generally have a high investment cost, it has many features which make it attractive as an alternative source of power for water pumping. It is clean, as it produces no carbon emission, it generates no noise, and it has low operational and maintenance cost. This manuscript presents a detailed intensive review of solar-powered water pumping systems as reported in the literature to serve as a quick reference to researchers and engineers who are working or interested in the subject.

Photovoltaic water pumping system is one of the best alternative methods for irrigation. The variation of spatial and temporal distribution of available water for irrigation makes significant demand on water conservation techniques. Hence solar powered Automated Irrigation System provides a sustainable solution to enhance water use efficiency in the agricultural fields using renewable energy system removes workmanship that is needed for flooding irrigation. Environmental pollution is prevented with renewable energy and energy production from local resources is encouraged. The use of this photo-irrigation system will be able to contribute to the socio-economic development. It is the proposed solution for the present energy crisis for the Nigerian farmers. This system conserves electricity by reducing the usage of grid power and conserves water by reducing water losses. Proposed system is easy to implement and environment friendly solution for irrigating fields. The system was found to be successful when implemented for bore holes as they pump over the whole day. Solar pumps also offer clean solutions with no danger of borehole contamination. The system requires minimal maintenance and attention as they are self-starting. Solar energy is the most abundant source of energy in the world. Solar power is not only an answer to today's energy crisis but also an environmental friendly form of energy. Photovoltaic generation is an efficient approach for using the solar energy. Solar panels (an array of photovoltaic cells) are now a day extensively used for running street lights, for powering water heaters and to meet domestic loads. The cost of solar panels has been constantly decreasing which encourages its usage in various sectors. One of the applications of this technology is used in irrigation systems for farming. Solar powered irrigation system can be a suitable alternative for farmers in the present state of energy crisis in India. This is green way for energy production which provides free energy once an initial investment is made (Harishankar et al., 2014).

Nowadays, as the increasing shortage of water resources, promote water saving irrigation technology and has become the inevitable choice to fill the water crisis. Today the generation is heading towards ultra-technologies. Water pumping has a long history; so many methods have been developed to pump water. People have used a variety of power sources, namely human energy, animal power, hydro power, wind, solar and fuels such a diesel for small generators.

The most common pumps used in remote communities are:
- Hand pumps
- Direct drive diesel driven borehole pumps
- Electric submersible pumps with diesel generator
- Solar submersible pumps

2. LITERATURE REVIEW

Photovoltaic (PV) technology generates power from solar radiation. Numerous efforts have been undertaken to assess, monitor, and enhance the performance of various components of a photovoltaic (PV) system: a PV module (Abdallah, 2004; Vick and Clark, 2004; Huang and Sun, 2007; Hansen et al., 2000; Lorenzo, 1994), a controller (Hohm and Ropp, 2003), a battery (Copetti et al., 1993; Gergaud et al., 2003; Achaibou et al., 2012), a pump (Vick and Clark, 2011), and a pump motor (Bhat et al., 1987). Such research have been beneficial in enhancing the efficiency of photovoltaic system components. Nonetheless, various parameters must be evaluated for optimal photovoltaic system design to ensure the needed reliability in a certain area. This entails a comprehensive examination of all interacting physical (plant and soil types, irrigation system specifications, PV system dimensions, site characteristics), meteorological (solar radiation, air temperature, relative humidity, wind velocity, precipitation), and managerial (irrigation scheduling) variables to attain the desired reliability of the PV system. A technique that integrates the characteristics of the centre pivot irrigation system, daily crop water requirements, soil moisture conditions, irrigation applications, photovoltaic array output, load demands, and energy storage is essential for assessing the reliability of a solar-powered centre pivot irrigation system. This comprehensive method could significantly enhance the system's effective sizing. External environmental variables will adversely affect photovoltaic performance. Key factors to consider include insolation, ambient temperature, and wind speed (Van Dyk et al., 2005).

The configuration of a photovoltaic system is highly adaptable. The optimal use of solar energy occurs when the panels are directly linked to the load. The efficacy of water pumping is partially attributed to the removal of the intermediary phase, specifically the battery bank, for energy storage. A direct connection between the photovoltaic array and the pump enables water to be pumped during daylight hours. The most efficient direct-connect systems involve pumping water to an elevated storage tank, wherein electrical energy from the panels is transformed into the potential energy of the elevated water, available for on-demand usage, typically by gravity (Hamidat et al., 2003). The whole efficiency, from sunshine to water flow, has been documented to surpass 3% (Daud and Mahmoud, 2005; Pulfrey et al., 1987).

This method is a straightforward and environmentally sustainable alternative for irrigating land. The technique proved effective when used to boreholes, as they operate continuously throughout the day. Solar pumps provide a clean solution without the risk of borehole contamination. The system demands minimum maintenance and oversight, as it is self-starting. To optimise the monitoring of daily pumping rates, arrays can be employed. This system illustrates the viability and implementation of solar photovoltaic technology to fulfil the energy demands for pumps in sprinkler irrigation. Despite the substantial capital expenditure necessary for the implementation of this system, the overall advantages are significant, rendering it economically viable in the long term (Harishankar et al., 2014).

Economic analysis indicates that photovoltaic pumping systems for irrigation in Bangladesh are more viable than diesel engine pumping systems. From an economic perspective, the cost of a photovoltaic (PV) pumping system for a single season of irrigation is somewhat greater than that of a diesel engine pumping system, attributable to the elevated expenses associated with PV modules and their components (Haque 2001). The automation of an irrigation system will significantly diminish the disparity between energy requirements and consumption, consequently conserving resources and minimising waste. The primary benefit of this initiative is the optimisation of power consumption via water resource management, as well as the conservation of the government's subsidised electricity. This demonstrates an efficient and economical method of irrigation that will automate the agricultural sector (Yalla et al., 2013).

In Nigeria, establishing a grid system is typically prohibitively costly due to the considerable distance of rural settlements from existing grid lines. Although fuel is accessible domestically, the transportation of that fuel to isolated rural areas can pose significant challenges. Numerous isolated settlements lack roads and related infrastructure. Renewable energy is advantageous for water pumping applications in distant regions of numerous developing nations. The transportation of renewable energy systems, such as photovoltaic (PV) pumps, is considerably more straightforward than that of other types, as they can be disassembled and reassembled on-site (Khatib, 2010). The life cycle cost analysis conducted on both systems demonstrates that the photovoltaic water pumping system is the more cost-effective option compared to the diesel water pumping system (Narale et al., 2013).

Cuadros et al. (2004) assert that this method was appropriate for assessing the dimensions and consequently the viability of solar-powered irrigation systems, given the substantial expense associated with photovoltaic (PV) systems. The feasibility is assessed not only in terms of the cost of photovoltaic systems but also regarding the land area necessary for implementation. Glasnovic and Margeta (2009) examined the maximum regions that might be economically watered. Kelley et al. (2010) indicated that photovoltaic irrigation was both technically and economically viable, contingent upon the availability of sufficient acreage for the solar array. A primary difficulty regarding solar panel utilisation for power generation is the quantity of panels needed and the space they would occupy. In agriculture, this is particularly significant as it directly affects the land available for cultivation. This study demonstrated that only a minimal percentage of the two-acre plot would be necessary for the panels. This illustrates the viability and implementation of solar photovoltaic systems to meet the energy demands for drip irrigation pumping.

Several factors were considered to determine the pumping requirements and, consequently, the solar panel area, including the selected crop, the dimensions of the planting area, the number of peak sunlight hours, the efficiency of the solar array and its electronics, the elevation for pumping, and the efficiency of the pump. Consequently, these considerations would influence the viability of such systems. This study demonstrated promising outcomes regarding the spatial requirements for solar panels utilised to generate power for the drip irrigation of hot peppers on a two-acre plot (Persad 2011). Particular studies have examined the application of photovoltaic systems on small farms (Roul, 2007), whereas prior feasibility analyses assessed either the economic or technical viability of photovoltaic irrigation. The majority of the investigations were unique to system size and location. Research examining systems with power demands about 1 kW has been performed in Namibia, Jordan, and India (Mahmoud, 1990; NAMREP, 2006; Meah et al., 2008). The majority of the literature indicates that photovoltaic irrigation is theoretically viable for diminutive systems of one acre in size (Kelley et al., 2010). Solar pumps have been a topic of discussion in India for some time. A 2005 estimate by Purohit and Michealova indicated that approximately 7,000 were already operational in the field. Nevertheless, solar-powered tube wells currently utilised by farmers are difficult to locate. As the cost of photovoltaic (PV) cells continues to decline in accordance with Moore's Law, while diesel prices escalate, solar-powered pumping has become a financially viable concept.

Water pumping has historically been the most dependable and cost-effective application of solar-electric (photovoltaic, or PV) systems. Most photovoltaic systems depend on battery storage to power lights and other appliances at nighttime or when sunlight is unavailable. Most photovoltaic pumping systems operate without batteries, as the photovoltaic modules directly power the pump. The photovoltaic pumping system is exceedingly straightforward in the absence of batteries. It comprises three components: the solar array, a pump controller, and the pump. The sole component in motion is the pump. The solar modules are guaranteed to generate power for 20 to 25 years. The anticipated lifespan of the majority of controllers is 5 to 10 years. Pump lifespan can range from 5 to over 10 years, with many built for field repairs. Maintenance often necessitates cleaning the solar modules every 2 to 4 weeks, provided the pump or controller does not malfunction. This task can evidently be performed inexpensively by unskilled local labour (Aligah 2011). Recently, Hammad (1999) conducted a study on the utilisation of photovoltaic-generated electricity for pumping water from 13 wells located in the eastern and southeastern desert, distant from the national grid, as well as in the southern regions of Jordan, characterised by complex topography. These pumps can independently deliver 40–100 m3 of water per day to satisfy the daily requirements of residents in those regions. A fully automated irrigation system has been conceived, constructed, and tested with solar photovoltaic cells and a digital controller. The system is cost-effective, dependable, mobile, and compact. Reductions in electricity and water costs can substantiate the initial expenditure, which may exceed that of conventional systems, over time. It inflicts minimal harm on the environment and alleviates the public utility of an additional burden. It is applicable in both small and large farms, gardens, parks, and lawns. It can also function as a universal solar-based controller for managing building doors, water heaters and air conditioning systems (Ali 2001).

Solar water-pumping technology is commercially available, has an established track record of reliability, requires minimal specialised staff during operation, and incurs low and cheap operation and maintenance costs. Photovoltaic pumps offer numerous advantages, including their operation on freely accessible sunshine, resulting in no fuel or electrical expenses. They are environmentally sustainable, dependable, and possess an extended operational lifespan (Yingdong 2011). The benefit of utilising solar energy for water pumping is that substantial volumes of water are needed during daylight hours, coinciding with peak solar intensity, when photovoltaic panels generate optimal energy and, consequently, water output. These solar pumps can be put in areas that are not linked to the national power grid (Ahmet 2012).

Photovoltaic systems for groundwater pumping are utilised in Upper Egypt, demonstrating that the cost per unit of water pushed by these systems is considerably lower than that of diesel systems (Yingdong 2011). In India, 9 million diesel-powered pump sets for irrigation operate out of a total of 21 million pump sets, each with a capacity of 3.73 KW (5 HP). Of the 9 million diesel pump sets, 75% are expected to be located in solar resource regions, resulting in a total of 6.75 million diesel pump sets in these areas. Of the 6.75 million diesel pumps, 70% possess land suitable for the installation of photovoltaic (PV) systems; hence, the total number of pump sets in solar resource regions with land available for solar PV installation amounts to 4.725 million, equating to 16,785 MW, which is only half of the diesel pumps. The substitution of 4.5 million diesel pumps conserves 223.8 billion litres of diesel and reduces carbon dioxide emissions by 469.98 billion kilogrammes annually (Arora 2013). The aforementioned procedures indicate that the optimal nominal electric power of the PV generator, based on reference parameters in the Arilje region, with a decade average daily water requirement of 12.8 m3 ha–1 day–1, would adequately meet the irrigation needs of raspberries throughout the entire observed period (Gajic et al., 2013). At an annual operation of 2000 hours, Claro Energy's 8.5 kW solar pumps, priced at Rs. 1 million, will conserve approximately 17,000 kWh of power annually, valued at Rs. 85,000 per year (Mukherji, 2007).

3. 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. Two types 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. Solar energy has been applied to various areas including Water heating, Drying of vegetables, Agricultural drying and water pumping for households and for agricultural purposes.

3. PHOTOVOLTAIC CELLS

Photovoltaic cells are devices which 'collect the light and convert it into electricity. The cells are wired in series, sealed between sheets of glass or plastic, and supported inside a metal frame. These frames are called solar modules or panels. They are used to power a variety of applications ranging from calculators and wrist-watches to complete home systems and large power plants. PV cells are made of thin silicon wafers; a semi-conducting material similar to that used in computer chips. When sunlight is absorbed by these materials, the solar energy knocks electrons loose from their atoms, allowing the electrons to flow through the material to produce electricity. This process of converting light (photons) to electricity (voltage) is called the "photovoltaic effect".

4. PHOTOVOLTAIC APPLICATIONS

Solar panels are used in a variety of applications. The applications vary from small simple lanterns to large elaborate power plants.

- Rural and urban households for domestic purposes like lighting.
- Communities, small industries and institutions like schools, for lighting as well as for powering television sets, computers, etc.
- Water pumping systems.
- Telecommunications, as these systems are often installed in isolated places with no other access to power.
- Health center vaccine refrigeration in rural areas. Such solar refrigerators are also utilized to store blood plasma. WHO supports programmers that install solar power for medical purposes

5. SYSTEM COMPONENTS

The whole system of solar pumping includes the panels, support structure with tracking mechanism, electronic parts for regulation, cables, pipes and the pump itself.

5.1 Solar Panels or Modules

Solar panels are the main components used for driving the solar pump. Several solar panels connected together in arrays produce DC electricity, interconnections are made using series or parallel combinations to achieve desired voltage and power for the pump.

5.2 Solar Pump

Centrifugal or submersible pumps are connected directly to the solar array using DC power produced by the solar panels. Solar pumps are available in several capacities depending upon the requirement of water.

5.3 Support Structure and Tracking Mechanism
Support structure provides stability to the mounted solar panels and protects them from theft or natural calamities. To obtain maximum output of water, a manual tracking device is fixed to the support structure. Tracking increases the output of water by allowing the panels to face the sun as it moves across the sky.

5.4 Foundations (Array and Pump)
Foundations are provided for support structures and pump.

5.5 Electrical Interconnections
A set of cables of appropriate size, junction boxes, connectors and switches are provided along with the installation.

5.6 Earthing Kit
Earthing kit is provided for safety in case of lightning or short circuit.

5.7 Plumbing
Pipes and fittings required to connect the pump come as part of the installation.

6. FUNCTIONING OF PV SOLAR PUMP SYSTEM
A 50-watt photovoltaic solar panel can power a 12-volt pump, which can move 1,300–2,600 liters per hour (or 350– 700 gallons). Standard plastic fittings and half-inch piping connect these elements to a water saving tank of 500–1,000 liters. A sturdy stand should be built for the water tank to provide gravity flow, and a frame should also be constructed to provide the best angle for the solar panels. Multiple filters are needed to protect the life of the pump and minimize clogging in sprinkler emitters and tubes. A solar pump combined with affordable drip irrigation kits can be used with a wide variety of high-value crops to increase water efficiency, minimize fertilizer loss, and irrigate hilly terrains.

6.1 Key Aspects of PV Pumping System
In general, the investment required for a PV pumping system is Rs 250-300/Wp (where Rs is the Indian rupee and Wp is watts peak). For example, the cost of a 900 Wp unit would be Rs 225,000-270,000, but with subsidies, this will be reduced to Rs 50,000. To make the best use of solar energy, the PV system, the groundwater pump and the water distribution system have to be well matched. The PV power provided must cover the power demand of the pump adequately. This is determined by the relationship between the required discharge flow, the total head and the pump efficiency. This depends on the type of pump, which in turn depends on the depth of the available water source. Although positive displacement pumps are preferred for large heads, centrifugal pumps are most commonly used. Photovoltaic (PV) panel electrical outputs are rated according to industry Standard Test Conditions (STC) of 1000 W m^{-2} incident solar radiation at an operating cell temperature of 25^{o}C and under an absolute air mass of 1.5. Environmental conditions met outside the laboratory will cause a decrease in PV performance from the STC rating, the magnitude of which depends on the module technology. Many additional losses are incurred due to the inefficiencies in transferring energy from the PV panels to a load, such as a pump or battery bank, thus resulting in a secondary decline of performance. Though there have been studies measuring outdoor performance of PV modules, there is a great need for further field studies of complete PV systems.

Another important aspect would be the ability to model the potential solar radiation, PV power output, and subsequent water output for the purpose of irrigation scheduling. Photovoltaic powered water pumping systems (photo- irrigation) have been studied by researchers in many years. Studies mostly concentrated on DC motors cause of energy obtained from solar panel is DC (Lawrance et al., 1995, Dursun et al., 2005). These are shown that better results were obtained for performance analysis (Kolhe et al., 2004., Kolhe et al., 2000). Photo-irrigation system has advantages than flooding irrigation. Some of these are, bringing utilization of water sources more efficient, preventing erosion and growing of weeds only by irrigating the requested areas (Cuadros et al., 2004), decreasing moisture stress (Pande, et al., 2003), no operation cost, providing opportunity for local energy sources and exhibiting a parallel point of view with water requirement (Ghoneim, 2006). In terms of automation, developed wireless technologies, researches focused on automatic irrigation with sensors in agricultural systems (Kim 2009, Stone, et al., 1985, Zhang 2004). In this connection, research works of some other noteworthy researchers Alyu and Sambo (1989), Bajpai et al. (1991), Maurya et al. (2013), Maurya et al. (2013; 2014), Okanta et al. (2003; 2004a; 2004b) and Porsoki (1996) are worth mentioning. The advantages of using wireless sensor is to reduce wiring and piping costs, and easier to install and maintenance especially large areas (Dursun et al., 2010). Energy of pumps used for the agricultural irrigation is generally provided from electrical energy or fossil fuels. Since fossil fuels commence to annihilate besides its increasing of prices and hazards to environment alternative energy seeking efforts has become inevitable also in agricultural sector. Solar energy that is sensitive to environment, clean and requiring no maintenance is an alternative renewable energy source especially for countries like Turkey having a high amount of annual solar irradiation rate. When it is considered by means of requirement for irrigation the advantage of PV pumping systems is that water demand and increasing for sun shining are compatible characteristically (Anis et al., 1994). In summer months obtained solar energy increases and also naturally water requirement of trees increases.

The cost of solar PV has come down and cost of diesel has been regularly increasing. At present the cost of solar PV is very much less to diesel, solar PV cost shall be half of diesel within three to four years, since approaching towards grid parity. 400,000 telecom towers are associated with diesel generating sets having capacity 3 to 5 KW. 60% Telecom towers located in urban and semi urban areas and 100% located in the villages are run by diesel generating sets. Recently in 2013, Maurya et al. (2014) focused their attention to capital cost modeling. In fact, off-grid potential is unlimited in India and is about 20 to 25% potential of the world (Arora, 2014). Solar water pumps are often thought of as being an expensive technology, which is not able to pump enough water and which is not durable. However, solar water pumps have come a long way in 25 years and today there are solar pumps on the market which have improved on previous technology, e.g.: Submersible pumps which can pump up to 200m heads; Pumps that are able to pump larger volumes of water, e.g.: At 100m, about 10,000 litres per day; At 50m, about 20,000 litres per day; Above performance can be doubled through dual systems (if the borehole allows this).

- Low maintenance requirements (3 to 5 years);
- Good performance which means fewer solar panels to pump the same amount of water;
- Some of the pump models can be backed-up by a genset to pump additional water with the same pump during the night or during overcast days;
- Good quality and reliability
- Simple to install

Furthermore, solar pumps are well known for having the following features:

- Require minimal attention as they are self-starting;
- Solar pumps are “good” for boreholes as they pump over the whole day;

- Weak boreholes can be used effectively with a low volume pump due to pumping 8 to 10 hours a day;
- In most cases, a solar pump offers an ideal solution to the diesel option which requires operating funds (with uncertainty about future diesel prices), time investment for operating pump (manual starting etc.) and logistics for fuel, maintenance, installation and de-installation;
- Tracking arrays can be used to increase daily water pumping rates;
- Solar pumps offer clean solutions with no danger of borehole contamination.

6.1 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.

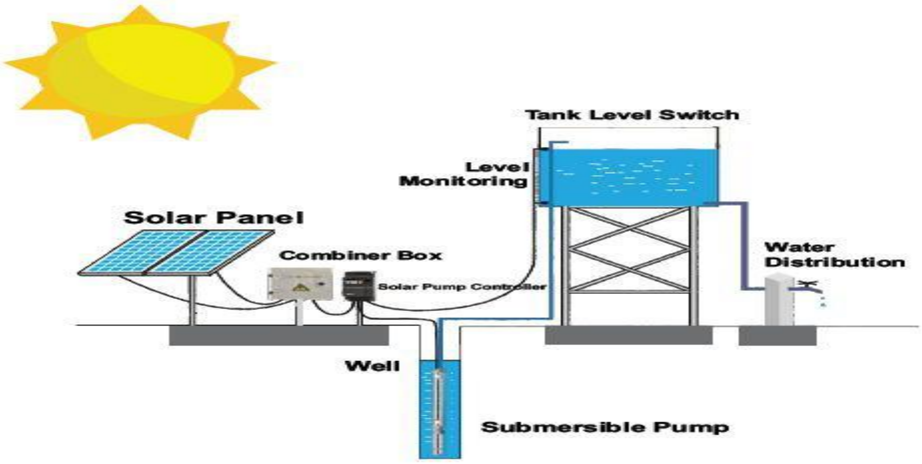


Figure 1. Diagrammatic representation of solar pumping water system

6.2 Applications of Solar Pumps

The potential applications of solar pumps include:

- Irrigation (individual farmers or cooperatives)
- Portable water supply for Institutions (traditional niche market for schools and health clinics)
- Community-scale watersupply 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.

6.3 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%.

6.4 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.

6.5 Advantages andLimitations

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 Nigeria 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 presented in Table 1.

Table 1. Limitations of solar pumps

Limitations	Solutions
High initial investment cost	Government subsidies and easy bank finances are available through bank of Agriculture though bureaucracy processes sometimes hamper the process
Output fluctuation due to varying solar isolation (weather	Use of VFD and battery can ensure a constant supply without voltage fluctuations
dependent)	Grid connected solar pumps use grid energy to run the pump when solar energy is not available
Vandalism and theft	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:

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

6.6 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.

6.7 Components of the Solar Pumping System

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.

7. SOLAR PV CELLS AND SOLAR ARRAY

7.1 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 $15 \times 15 = 225$ 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.

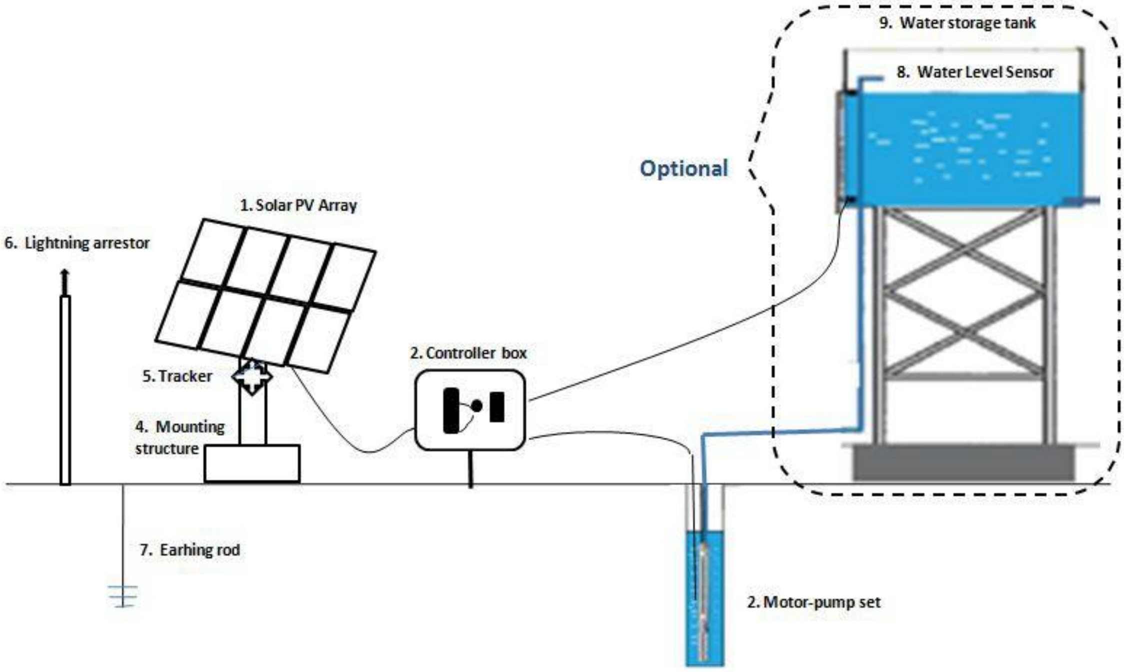


Figure 8. Solar-powered borehole system

7.2 Solar PVmodules

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.

7.3 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.

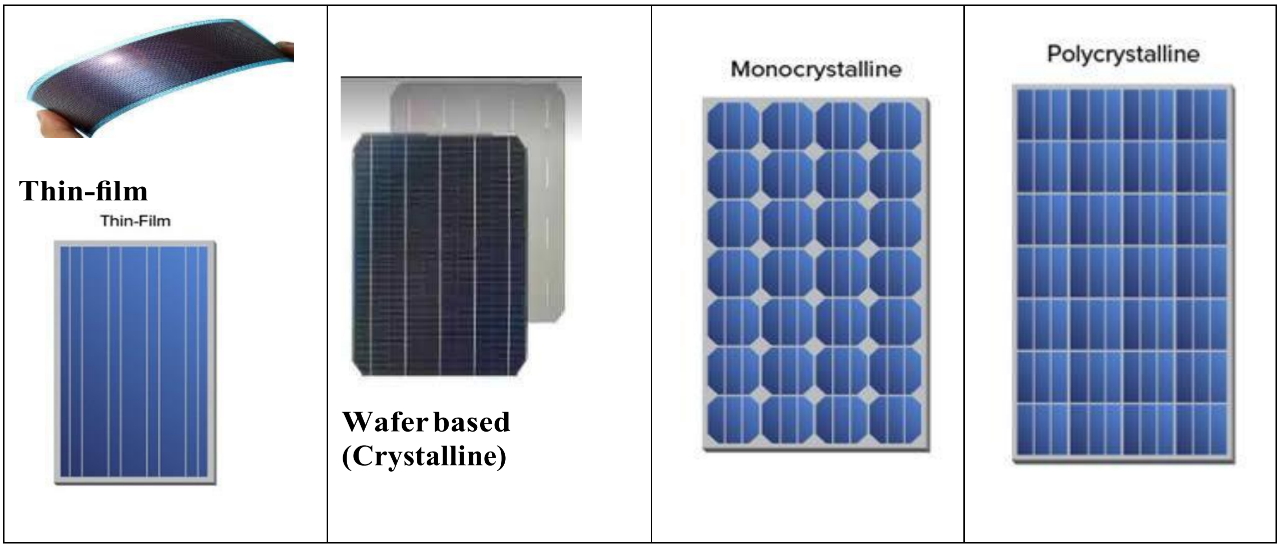


Figure 9. Types of solar panels

7.3.1 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.\

7.3.2 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%.

7.3.3 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. The advantages and disadvantages of each type of solar panels are presented in Table 2.

Table 2. advantages and disadvantages of each type of solar panels

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

7.4 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. Many cells make a module. Many modules make an array. This is demonstrated in Figure 1.

Figure 10. From cell to array

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.

7.5 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 up to 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

7.6 Common Features of Module Mounting Structure

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

- 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.

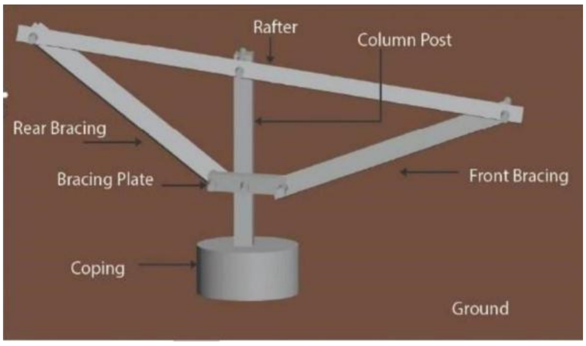


Figure 11. Load Carrying Components of Module Mounting Structure - Column and Rafter

- 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

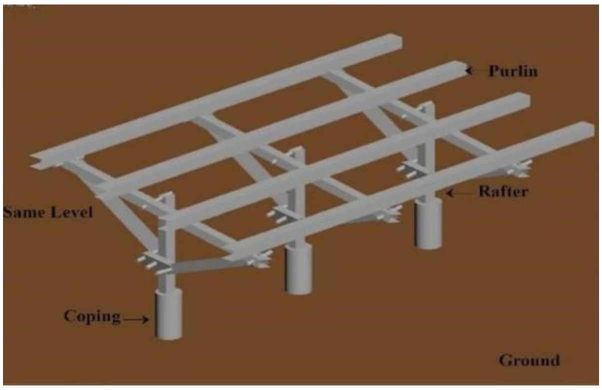


Figure 12. Purlin over rafter for module housing

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 solarpump. 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.

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

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.

7.7 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.

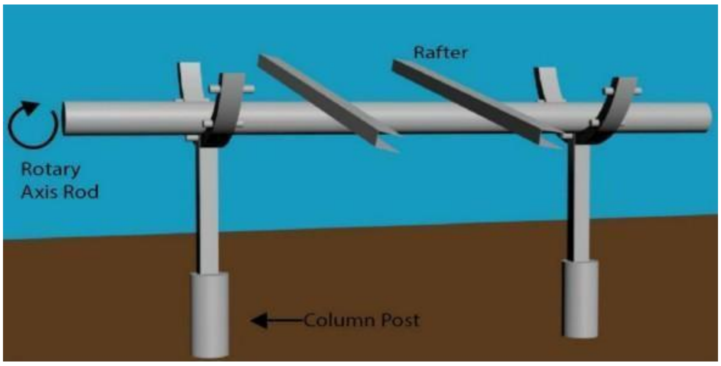


Figure 11. single axis mechanisms

7.8 Double Axis Tracker

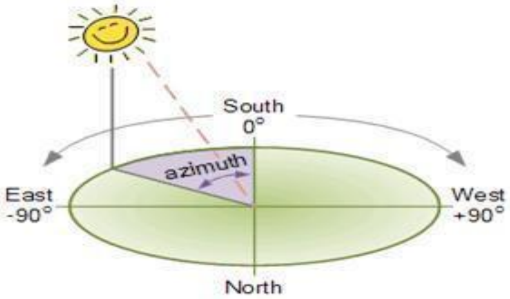
These rotate the array on an east-west axis and also can tilt it on a second axis in south-north direction, so that it is angled directly towards the sun at all parts of the day. The strength of dual-axis trackers is their ability to maximize energy production. A motor controlled by a programmed microcontroller, 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.

Figure12. Mounting Mechanism

7.9 Azimuth Angle

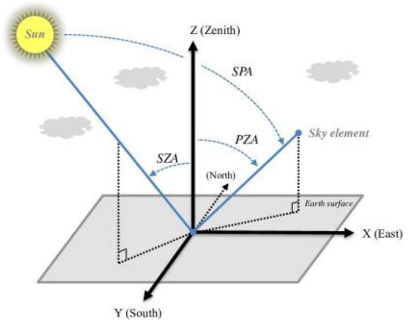
The angle between true south and the point on the horizon directly below the sun. Azimuth angle of the solar module is an indicator of alignment of the module with respect to (true) south. For modules facing (true) south this angle is 0° and for module facing (true) north this angle is +/- 180



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 e a s t 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.

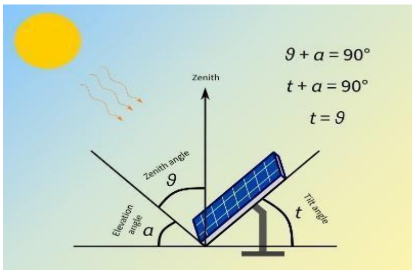
7.10 Zenith Angle

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.



7.11 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.

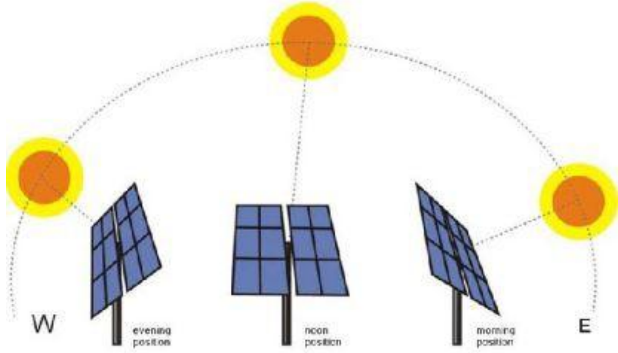


The panels need to be facing south since the installation is being done in the northern hemisphere. In case of the southern hemisphere, the solar modules should be installed facing the north direction.

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 Nigeria, the tilt angle usually varies between 10° to 17°, based on the latitude of the installation location.

7.12 Trackersforsolarpanels *(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.



7.13 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. It can be said that 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.

7.14 SubmersiblePumps

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.

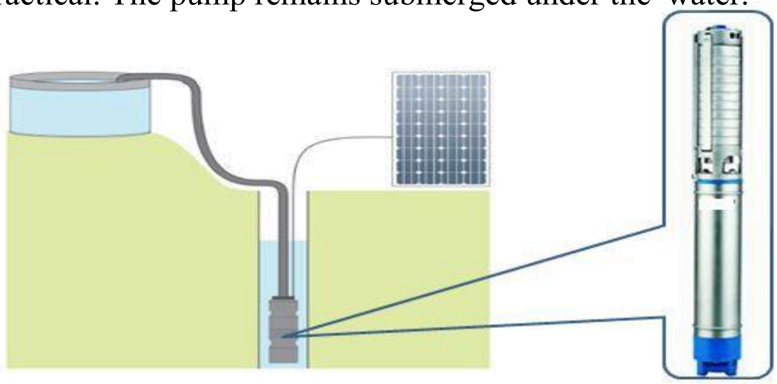


Figure 3. SubmersiblePump

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.

7.15 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.

7.16 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.

7.17 Components of Submersible Pumps

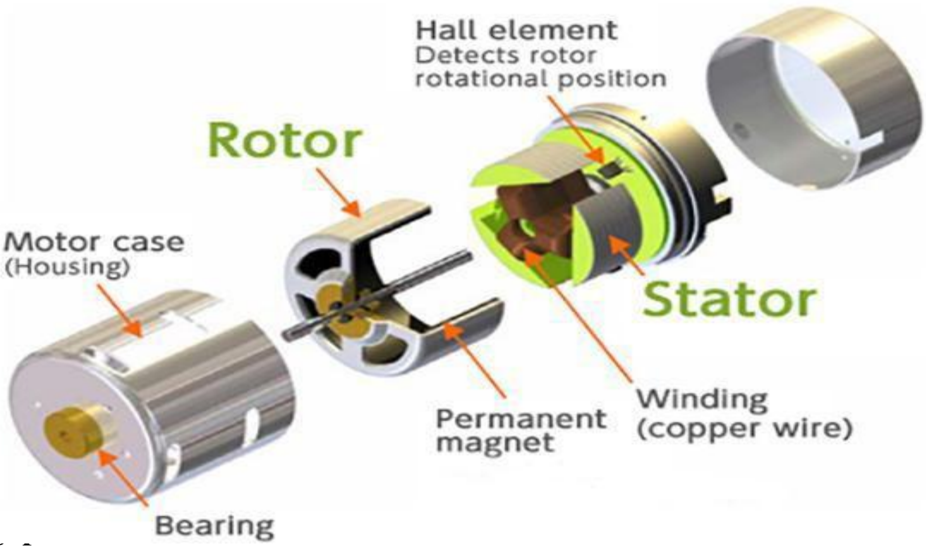


Figure 4. Parts of a Submersible Pumps

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.

7.17.1. 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.

7.17.2. 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.

7.17.3. 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.

7.18 SurfacePumps

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.

Figure 4. Pictural of a surface ;pump

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.

Surface pumps 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.

A disadvantage is that 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.

7.19 Components of Surface Pumps

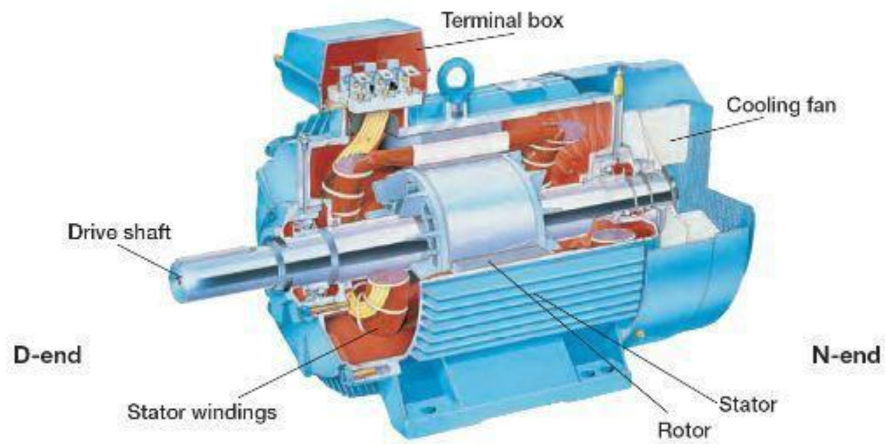
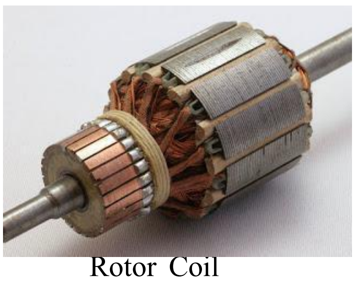


Figure 5. Parts of a Surface Pump

 Stator / Armature Coil	 Rotor Coil	 Main Shaft

 Bearing	 Pulley Drive	 Motor Housing

9.19.1. 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.

9.19.2. 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.

9.19.3. 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.

9.19.4. 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.

9.19.5. 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.

9.19.6. 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.

10. Classification of pump-motor set based on current

10.1 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.

10.1.1 Advantages

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

10.1.2 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.

10.2 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.

10.2.1 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

10.2.2 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

11. 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.

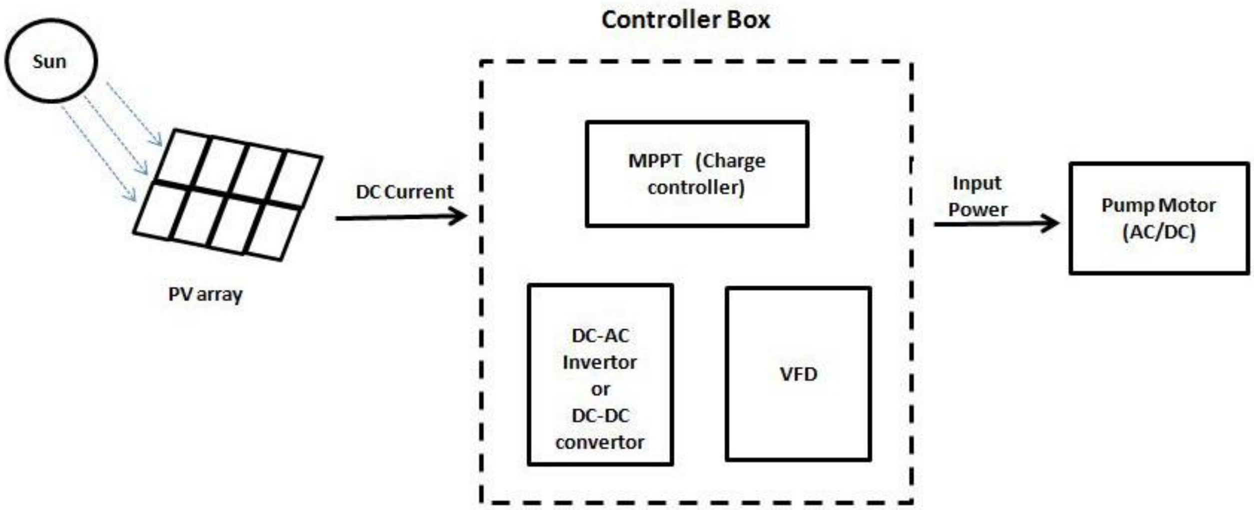
Grid connected solar pumps are becoming popular gradually. Here, the pump can switch its source of power from solar energy to grid connected electricity in the absence of sunlight. Also, excess energy produced by the solar panels during the day can be directed to the grid, which is sold and acts as a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

11.1 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.

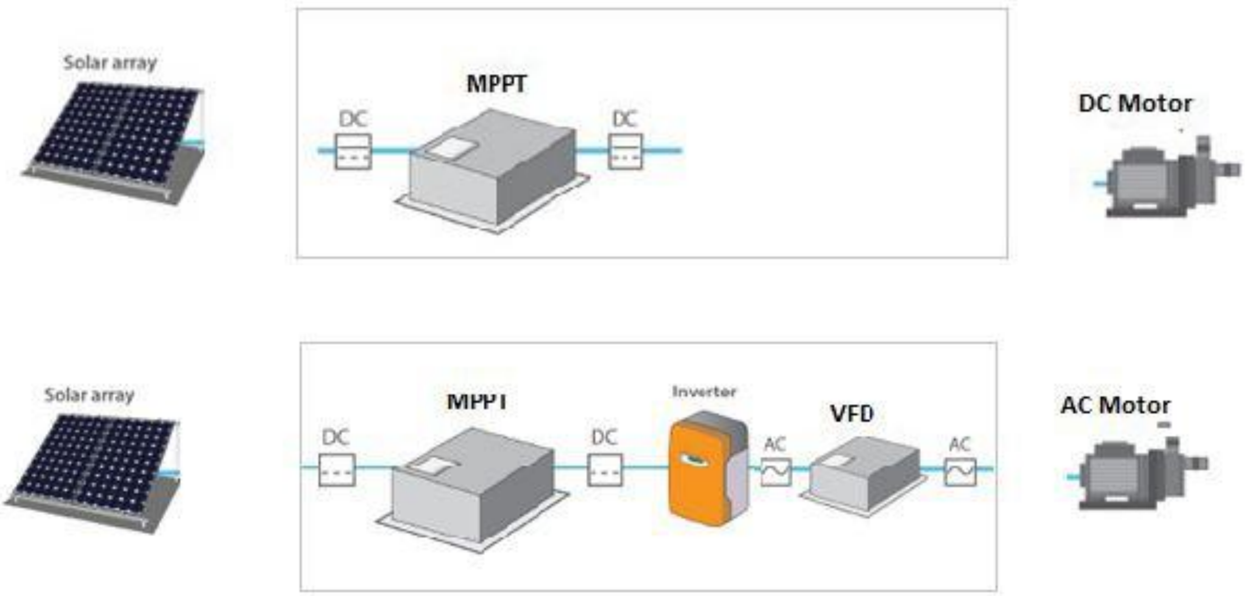
The main functions of the pump controller are:

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 increase its lifetime and reduce 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.

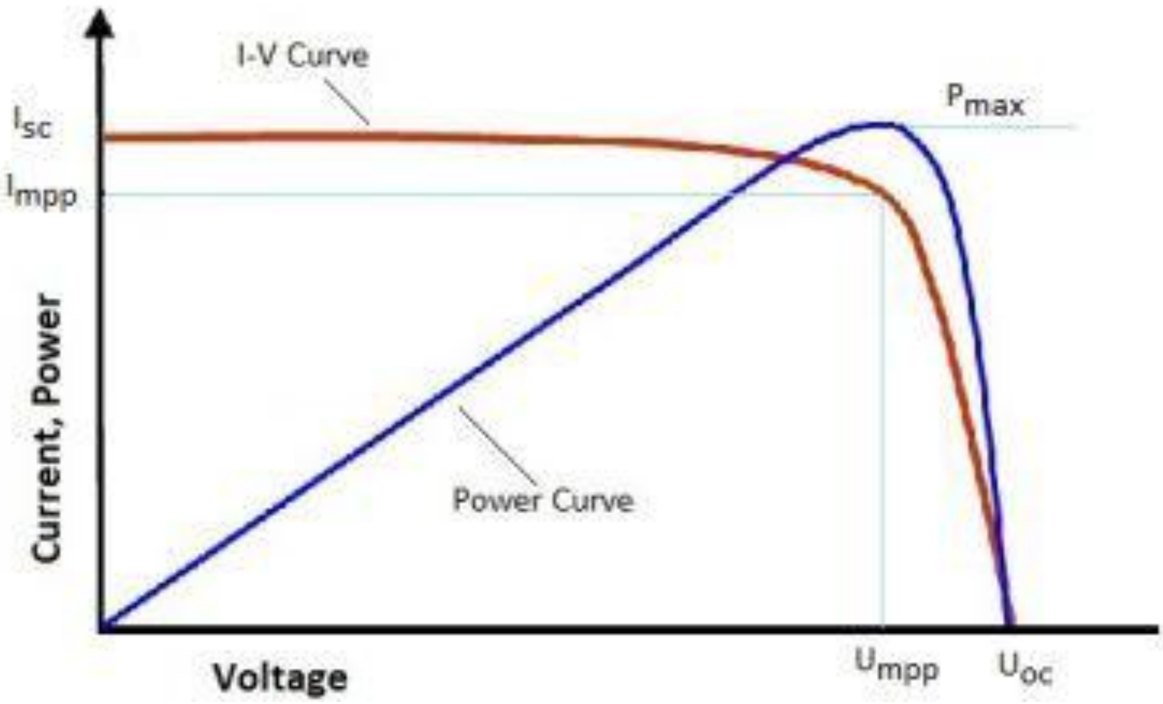


The inverter and controller must have IP54 protection or must be housed in a cabinet having IP54 protection to protect the controller from dust and water. Hybrid controllers are used sometimes too, when grid connected solar pumps are used. These controllers switch between solar power and grid power intelligently.

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)

11.2 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.

12. Advantages of using a VFD

12.1 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.

12.2 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.

12.3 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

13. 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 solarpanel 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.

13.1 Types of Solar Pump Inverters

13.1.1 StringInverters

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.

13.1.2 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.

13.1.3 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.

13.1.4 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.

The various types of battery-based inverters are:

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.

13.2 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.

14. 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.

14.1 Types of Batteries used in Solar Pump

14.1.1 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.

14.1.2 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.

14.1.3 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%.

14.1.4 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%.

14.2 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:

Units or kWh = (Volt x Ah) ÷1000 or (Volt x mAh) ÷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.

14.2.1 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.

15 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.

15.1 EarthingCompound

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.

15.2 Earthmeter

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.

16. 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.

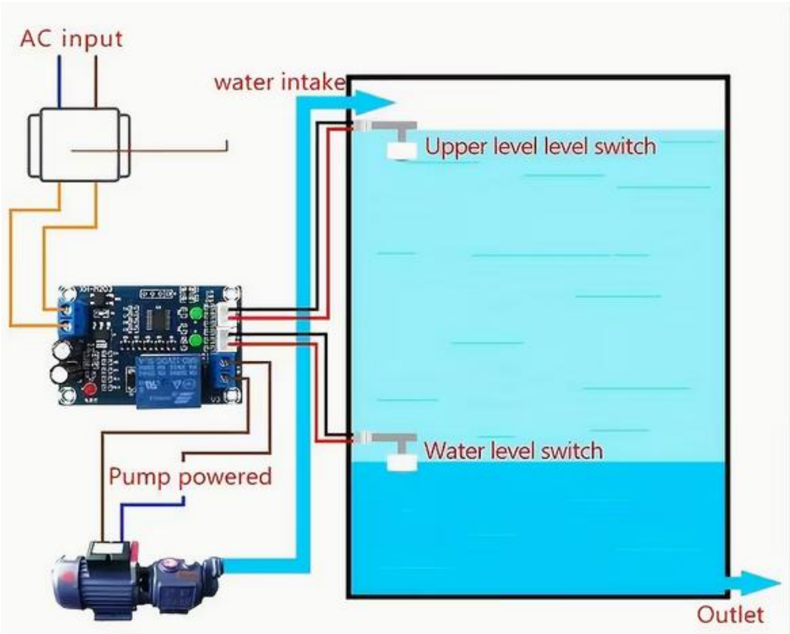


Figure 6. Pump with water storage tank

16.1Water 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.

16.2 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.

16.3 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.

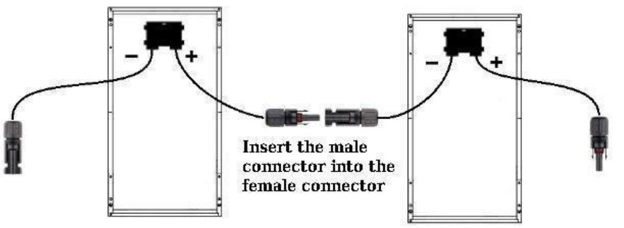
17 BALANCE OF SYSTEM

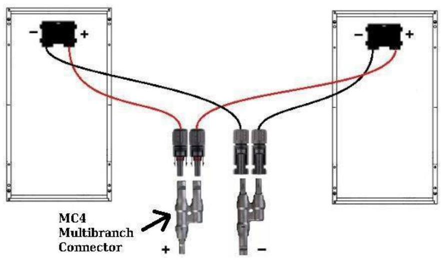
17.1 Electrical Equipments

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.

17.2 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.

17.3 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.

17.4 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.

Table 5..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.affotdable-solar.com/learning-center-tools/wire-sizing

17.4.1 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.

17.4.2 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 heavyvoltage.

17.4.3 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.

17.5 WiresandWiringSize

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.

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.

17.6 MechanicalEquipments

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).

17.7 SafetyEquipments

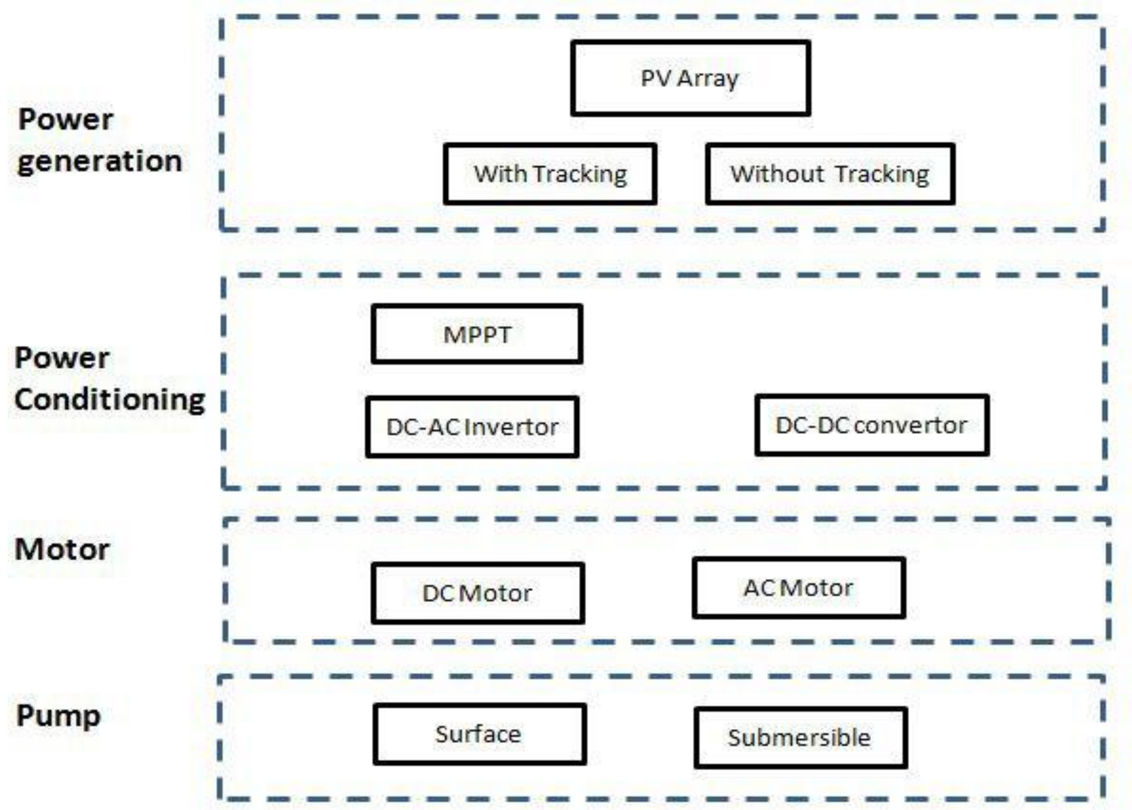
Safety equipment including earthing materials and personal protection gears. For full protection against open circuit, accidental short circuit and reverse polarity, the components need to be Earthed using an earthing rod. For personal protection, rubber gloves, boots and insulated tools are to be used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

17.8 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).



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.

18. CONCLUSION

The analysis and evaluation of photovoltaic (PV) solar water pumping systems confirm their viability and superiority as a sustainable approach to improve water utilization efficiency. Key Conclusions to this article include:

Environmental Sustainability: PV systems are highly environmentally friendly, producing nearly zero greenhouse gas emissions or pollutants during operation, unlike fossil fuel-based pumps. This aligns with global Sustainable Development Goals (SDGs) related to clean water, clean energy, and climate action.

Economic Viability: While initial capital costs can be high, the life-cycle cost (LCC) of PV systems is significantly lower than diesel alternatives due to minimal operating expenses (zero fuel cost) and low maintenance requirements. Payback periods are often short, making them a cost-effective long-term investment.

Technical Reliability and Efficiency: PV water pumping systems are technically reliable, especially in off-grid or remote areas with abundant sunlight. Their performance is directly correlated with solar radiation, naturally matching periods of peak water demand for applications like irrigation. Advances in technology, such as Maximum Power Point Tracking (MPPT) techniques and optimized system designs (e.g., using water storage instead of batteries), further enhance their overall efficiency and stability.

Improved Water Utilization: By providing a consistent and reliable water supply, these systems support efficient irrigation practices (like drip irrigation), which minimize water losses and enhance crop yields, thereby improving overall water utilization efficiency.

Socio-Economic Impact: The adoption of these systems can lead to positive socio-economic impacts in rural communities by reducing labor burdens, enhancing food security and economic independence for farmers, and promoting resilient rural development.

Photovoltaic solar water pumping is a robust, efficient, and sustainable solution for water management, particularly in regions with limited infrastructure. Successful implementation depends on proper system design and sizing tailored to local conditions and water demands, with ongoing monitoring and supportive policies to maximize their impact.

Acknowledgement

The authors wish to acknowledge the funds provided for this research and publication by TETFund Centre of Excellence for Renewable Energy, Kaduna Polytechnic, Kaduna, Nigeria. The funds were provided by the Tertiary Education Trust Fund (TETFUND), Nigeria, under the TETFUND Special Intervention for Establishment of Centre of Excellence (TETF/ES/DS&D/KADPOLY/COE /2021/VOL11).

Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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