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A Comprehensive Review on Development of Solar Pump Operated by PV Module

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Abstract: Water is the need of life, it is currently pumped by the use of the electric and fossil fuel based pump. The rising price, depleting nature and polluting nature required some other alternative methods of pumping the water in local and remote location. Among different renewable energy sources, solar energy-based solar pump technology driven by Photovoltaic (PV) cells can be efficiently used for pumping water in different commercial, irrigation work, domestic use, and in remote areas. Solar energy is nonpolluting in nature and freely available in the atmosphere in abundant amount. The large-scale use of the solar pump in all fields of society enhances its demand. Put these things in mind, in this research article a review on the development of the solar pump operated by PV module has been presented. In this article, the main covering points are the development of the solar pump from the past era, the present study, types of motor and pump, uses of batteries, solar tracking, and various applications of the solar pump. The solar photovoltaic system is cost-effective compared to other pumping methods like diesel pumps, gasoline pumps, etc. The solar pumps require negligible fuel and maintenance costs. It requires only timely cleaning of solar panels. The photovoltaic solar pump is a clean and green energy source for the environment, and it will not produce any harmful gases like fossil fuels.

Keywords: Solar pump; solar tracking; solar flux; photovoltaic module.

1. Introduction

In the present scenario pumping of water from the earth, river, canals, and ponds for domestic use and irrigation of fields are dependent on conventional fuels like diesel, natural gas, etc. These fuels are exhaustive, very costly, and harness the environment. At present world is facing a lot of problems due to the excessive use of fossil fuels for fulfilling the growing energy demand. In between 1775 to 2020, the carbon content in the atmosphere has been increased from 0 to 39 billion tons, and the carbon percentage increase from 260 ppm to 415 ppm[1]. From 1900 to 2020 the average surface temperature of the earth has been increased by 1°C [2]. The increased carbon content and the increased average surface temperature in the environment have created the problems like acid rain, global warming, and greenhouse gas, etc.

So, it is the need of the world today to develop the alternatives of pumping the water by some other energy source. One of the energy sources is photovoltaic (PV) cell technology which will be used for pumping the surface, river, earth water for commercial and irrigation purposes. The PV cell technology converts the solar energy available in the atmosphere into electrical power. The total amount of solar energy available in the atmosphere is 10000 times the energy demand of the earth at free of cost[3]. The good thing about this technology is that solar energy available in the environment according to the requirement of water. So, PV cells will be a good link to supply the water to the community as per requirement by converting the available solar energy on the earth. The water requirement in India is varied according to the variation of seasons, the maximum amount of water is required in the summer season and a huge amount of solar energy is available these days[4]. So, in the future PV cell will fulfill the energy demand of the world. The solar pump is an interesting research area for researchers for the last 50 years due to its applicability in remote, domestic, agriculture, and industrial uses[5]. The solar pump technology operated by PV cell is the same in all respect to the diesel or electrical energy power-operated pump. The main difference is the source of energy and the control unit for supplying the constant power to the pump. The huge availability of solar energy in India at remote locations gives the opportunities to use PV cell technology in different sectors like agriculture, domestic and industrial purposes.

The PV cell technology which converts the sunlight into electricity gives sustainable growth to the world for fulfilling the energy demand and gives long-term solutions to the environmental crisis. This green technology gives the security of water, energy, and the environment to society. The limited non-renewable energy resource will replace with this environment-friendly green technology.

In this paper, a compressive review on current research on solar pumps and utilization of solar water pumping technology from the past long time is presented. The study focuses on the thermodynamic performance analysis, optimum size, simulation and experimental analysis, economic analysis, environmental aspects, and uses of solar water pumps in different sectors of society in remote locations.

2. Solar Pump Technology

2.1 Present Technology

A simple solar photovoltaic system consists of a PV module, electronic controller, and motor-pump unit. The PV module converts solar energy into electrical energy. it is mounted on the manually and automatically operated frame. The controller helps the motor-pump system for smooth running. The motor pump system may be AC or DC operated. It is run by electrical energy supplied by the controller and its size is selected as per the requirement of head and discharge. The simple solar pump system pumps the water only in the daytime and its efficiency is low in cloudy weather conditions. It has been modified by adding a storage facility that will supply the water in the night time and cloudy weather with one- or two-days backup. It is either battery storage or tank storage[6]. The battery storage system is very costly for farmers because it increases the total cost of the investment, the maintenance, and the replacement cost after a fixed time. So, it is replaced by a simple water storage tank[9], .

The one drawback of the solar pump is that it requires the large surface area to install the solar panel. This problem has been solved by using the concept of solar tree in which, the solar panel are mounted on the branches of the tree as shown in Fig. 1. The outline of the storage system with the battery bank and the water tank is representing in Fig. 2.

The directly coupled DC-operated centrifugal was introduce in the solar pump in 1970. The directly coupled centrifugal pump operated by DC supply is simple and very reliable but it cannot work at the Maximum Power Point Tracking (MPPT) due to variation of solar flux throughout the day[10]. After the addition of MPPT and controller improve the popularity of solar pumps.

The PV water pump has shown a lot of advancement last decades. The first-time centrifugal pump was used operated by direct current and alternating current (AC) with good stability and efficiency around 23% to 32%. For improving the efficiency researcher uses a positive displacement pump in place of a centrifugal pump and gets a good efficiency of more than 65%. The screw pump was also used in the solar pump but the main drawback of the screw pump is that it is used in applications where the low head and discharge are required [11]. The current solar pump has a lot of improvement by the addition of a controller in the system. It will supply the optimized power to the pump by controlling the input current and voltage accordingly. The controller gives the input to the

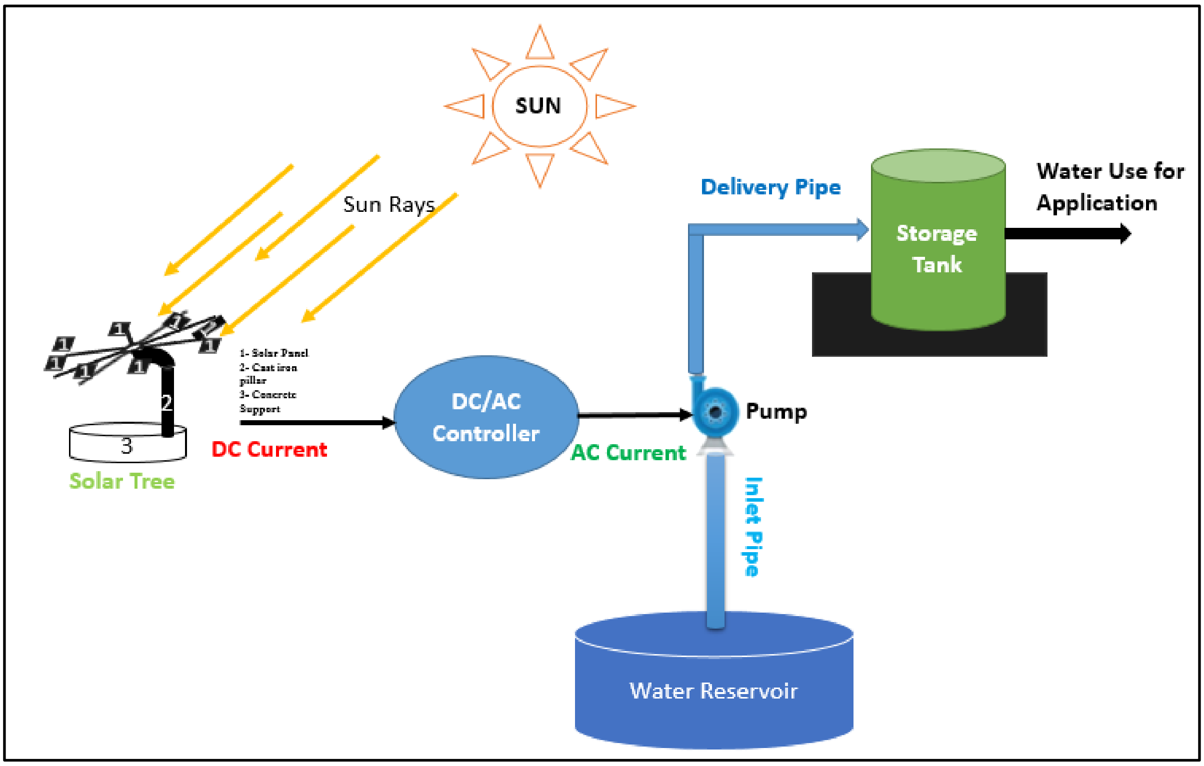

Fig.1: Solar tree use in solar pump

speed of the motor, level of the tank, and with the addition of MPPT gives the maximum discharge of the pump. in subsequent years with the help of microcontroller programming of dual-axis tracking and automatic tracking improved the performance of the system and reduce the size of PV modules. Tracking also improved the peak hours of the sun at which the output of the PV module is maximum.

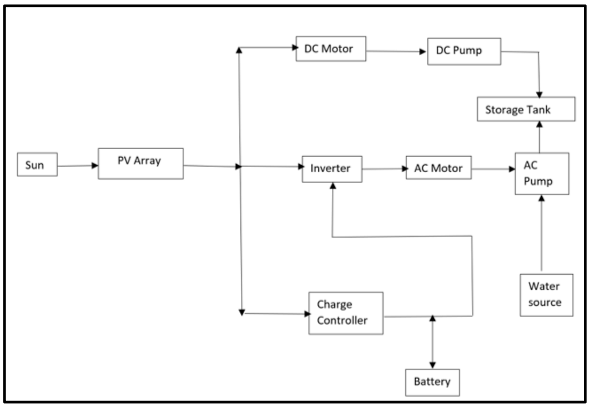

Fig. 2: Solar pump with battery and water tank storage

Due to the development of technology over the past few years helical rotor pumps are used in place of centrifugal pumps in the submersible motor. The screw pumps require no regular maintenance. The most solar pump requires this type of design.

The main problem with the solar pump is the low efficiency of the solar panels and its high manufacturing cost. The low efficiency of the solar pump is due to a lot of losses that occur from the solar panels to the pump[12]. The following are the main losses that occur in the solar pump presented schematically in Fig. 3.

(a) **Shading Losses: -** The shading loss occurs due to the presence of trees and buildings near the structure of PV modules. The partial and complete shading have reduced the output power produced by solar panels[13]. The shading is of two types (1) Shading due to mountains and hills and structures present near PV modules (2) shading due to misalignment of PV modules on the frame or ground. The misalignment of PV modules gives the shadow on each other in the same system. it has reduced the diffuse radiation factor which reduced the overall solar flux.

(b) **Temperature Loss:** - The new PV modules are tested in the company at the test conditions of 1000W/m^2 solar flux, 1m/s wind speed, and 25°C cell temperature. The selected temperature for the test is 25°C and it is called the Nominal Operating Cell Temperature(NOCT). So, if the PV module's temperature crosses the NOCT then the efficiency of PV modules is go down. In a day the temperature of PV modules is increasing from morning to evening and has reached a maximum level at 1 to 2 pm[14].

(c) **Losses in inverter:** - The invert converts the Direct Current (DC) into the Alternating Current(AC) as per the requirement of motor pump set. The efficiency of the inverter is reduced from 0.1 to 1% in every 150V DC input power supply[10]. A total 5% losses have occurred inside the control unit due to power consumption at low radiation and high DC input[15].

(d) **Loss of Reflection:** - The PV modules convert solar energy into electric energy. The energy conversion efficiency of solar panels is very less due to a lot of amount of solar energy is lost in the atmosphere. When solar flux reaches the surface of solar panels some parts of energy are reflected back in the atmosphere and some are absorbed and converted into electricity. For avoiding reflection and increasing absorption the outer surface of the solar panels is covered by the anti-reflective coating material. In normal conditions solar panels reflect the 4% of the total radiation[12].

(e) **Losses due to atmospheric pollution, suspended particles:** - The number of pollutants, particulate matter, and water vapor remain suspended in the atmosphere when the temperature of atmosphere falls below the condensation temperature of water in the morning time. All the suspended particles and snow have been collected on the top surface of the solar panels. The collected material on the top surface does not allow to absorb solar radiation due to that the power production of PV panels is reduced. The studies concluded that due to accumulation of suspended particles, snow, dust particles, and bird beats reduces the 15% of power production of PV modules[16].

(f) **Losses due convection and radiation:** - The solar flux in the atmosphere increases from morning to evening and due to that, the temperature of solar panels is also increased. The radiation loss is governed by the Stefan Boltzmann equation in which radiation loss is directly proportional to the fourth power of the temperature. So at higher temperatures, radiation heat loss is very high.

(g) **DC/AC Cable losses:** - The cable loss occurs due to the presence of resistance in the cable wire material. The cable loss depends on the type of current flow from PV modules to the motor pump set. The DC losses are more than the AC losses[16]. DC loss has to be reduced by using an inverter that converts the DC current into AC current.

(h) Mechanical Losses: - Mechanical losses occur due to relative motion between the shaft and bearing of the motor and pump. The mechanical losses vary in a range of 5%-15% depends on the size of the motor pump set[17].

(i) Hydraulic Losses: - The hydraulic loss is considered to be the loss in discharge. The discharge loss is due to slip and the gap between the pump blade and the outer disk.

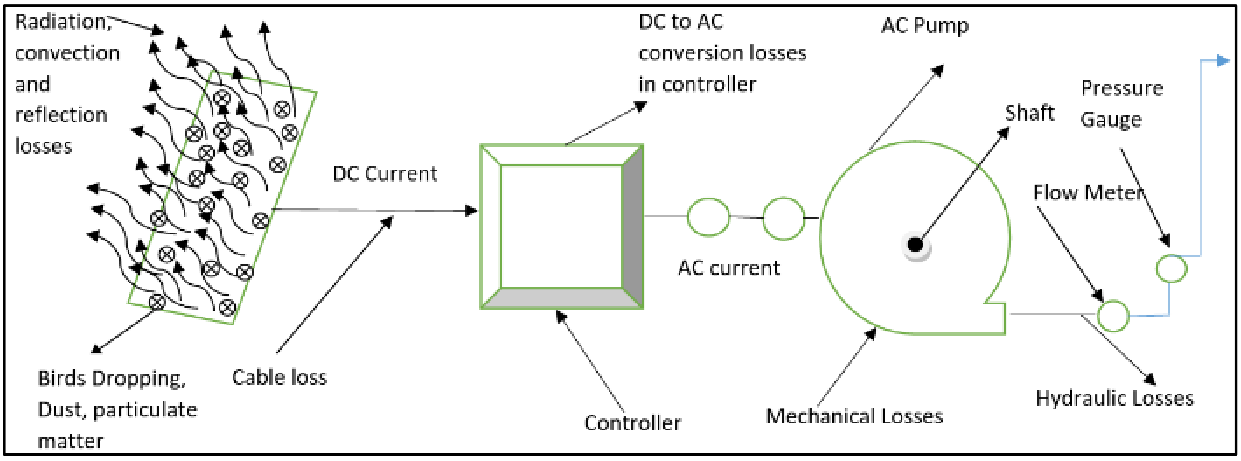

Fig. 3 Schematic representation of losses in the PV-operated solar pump

2.2 working of solar water pump

The solar pump irrigation based on PV cell technology converts the sunlight into electricity. The solar panel converts the sunlight into the DC, and with the help of the inverter and controller, it is further converted into the required voltage and current to drive the (DC or AC) motor. The motor coupled with the submersible pump pumped the water for irrigation purposes and remaining stored in the tank. The pumped water has many uses for domestic application as shows in the Fig. 4. The work done by the pump is dependent on the sum of static and dynamic heads. The static head is the elevation difference of the level of two tanks and remains constant. The dynamic head is variable it is dependent on the discharge of the water passes to the suction and delivery pipe if discharge losses are neglected through the pump.

2.3 Solar water pumps

The various type of solar water pump arrangement is used worldwide on the basis of types of motor pump combination and storage of tank, use of batteries. The following arrangement explained below.

2.3.1. DC Motor- DC pump arrangement with storage tank

In this arrangement DC motor-pump is used, so no need of inverter[18]. This arrangement cannot use for high head, big size pump and long distance between PV module and pump due to high losses of electric power.

2.3.2 AC motor- AC pump arrangement with storage tank

In AC motor-pump arrangement inverter is used in between the PV module and AC motor for converting the DC current into the AC current. The AC motor pump arrangement is used for big size pump, high head pumping of water and for transfer of power for long distance.

2.3.3. AC motor- AC pump arrangement with Batteries

This type of arrangement is same for above explained system but in place of storage tank battery bank is designed for supply the electricity demand at the time of non-availability of solar energy. Battery bank system is not feasible for large capacity pump because no of batteries is increased and not economical for farmers. The above all three design structures are schematically represented in Fig. 2.

2.4 Availability of water for irrigation

For irrigation water source may be pond, river, stream, spring, deep drilled well. The water source must be recharged otherwise source can be dried, if recharge rate is less than the water pumping rate then the well is dried the pump can fail. The variable that can affect irrigation are the volume of reservoir, recharge time, cost of pumping system.

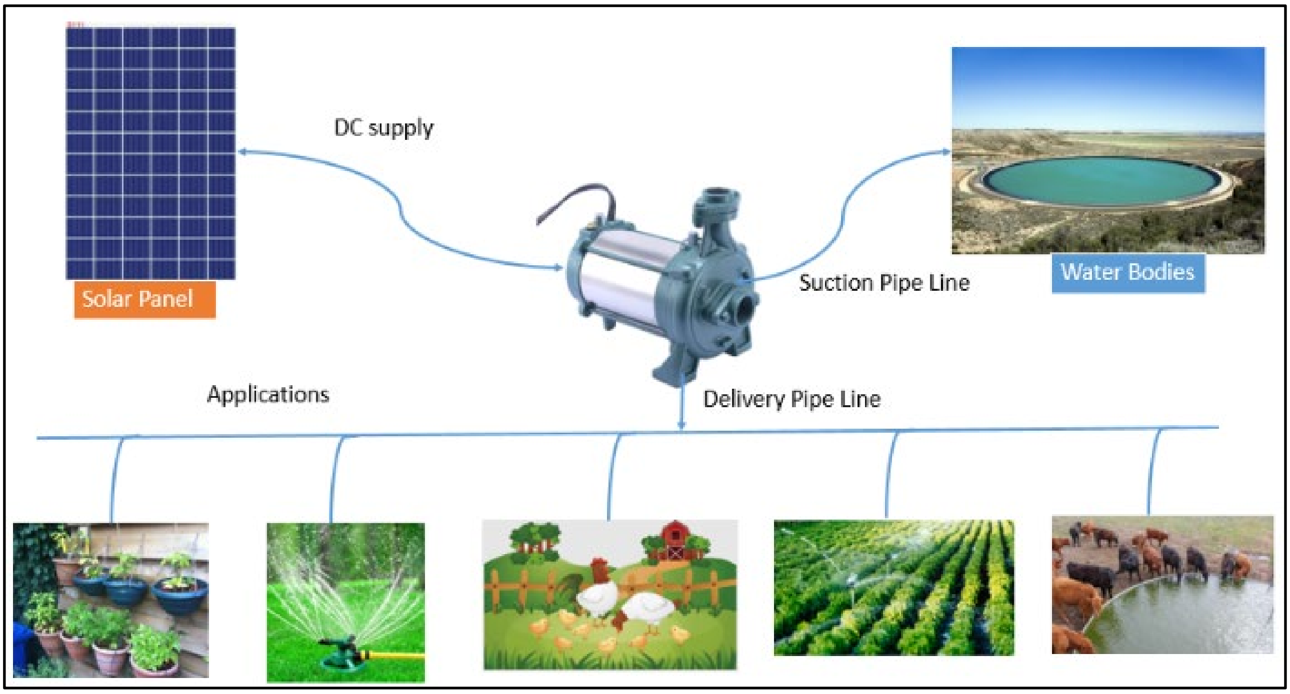

Fig. 4: Schematic representation of the solar pump technology operated by PV module[19)]

2.5. PV module Electrical Model

PV module of solar pump is the costly device so optimized arrangement of the plate is required according to the voltage and power of the motor. The designing of the solar panels is such that it should supply the optimum amount of electrical energy in all seasons of India as required by motor pump system. The total number of solar panels must be determine based on worst month of solar energy. The total number of panels are calculated by the multiplication of panels in series and parallel. The number of panels are in series and parallel are calculated according to the voltage and current required by the pump.

Number of panels in series = Required Voltage of the motor/ Voltage of one plate

$$N_S = \frac{V_R}{V_P} \qquad (1)$$

Number of panels in parallel = Total power consumed by motor/ output power of one plate*no of plates in series.

$$N_P = \frac{P_T}{P_S N} \qquad (2)$$

The electrical model of the solar cell consists of a P-N junction diode, it has its own series and shunt resistance with the photo current as represented in Fig. 5. The variation of current with the voltage in solar cells is

nonlinear exponential behaviour. The[20)] proposed a five-parameter model given as follows.

$$I = I_{PH} - I_o\left[e^{\frac{V+IR_S}{BV_T}-1}\right] - \frac{V}{R_{SH}} \qquad (3)$$

$$V_T = \frac{kT}{e} \qquad (4)$$

Where I is the circuit current, I_{PH} is the photon current, R_S is the series resistance, R_{SH} is the Shunt resistance, T is the cell temperature, B is a Constant, V is the circuit voltage.

Equation 4 gives the very good accuracy with five constants (I_{PH}, I_O, R_S, R_{SH}, B). These constants depend on the solar flux and the module temperature. It can be determined by five boundary conditions provided by manufacturers' data of solar cells. The boundary conditions are short circuit current, open circuit current, maximum power point, temperature coefficient for open-circuit voltage, and temperature coefficient for short circuit current. The model further simplified by neglecting series resistance and shunt resistance [21)]. When shunt and series resistance are neglected, the three constant are remaining and can be determined by three initial boundary conditions explained above. The three constant model equation is given as follows.

$$I = I_{PH} - I_o\left[e^{\frac{V+IR_S}{BV_T}-1}\right] \qquad (5)$$

Figure 5 shows the simplified electric circuit model of the solar cell which represents R_L is the load resistance, I current flow to the circuit, Isc is the short circuit current equal to the photon current depend on the solar flux reached on the surface of solar cell, I_J is the diode current[22)]. The photon current and diode current both are of the opposite nature.

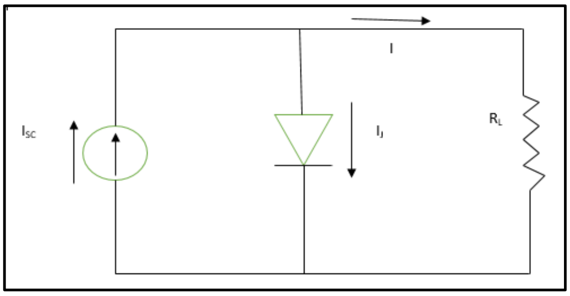

Fig. 5 Electrical model of solar cell

These are the basic equations for calculating the circuit current, in these equations, the short circuit current is directly proportional to the solar flux falling on the plate surface. The maximum voltage generated by the solar panel is directly proportional to the open-circuit voltage. The maximum voltage generated by the solar cell also depends on the energy band gap, higher energy bandgap material show higher maximum circuit voltage. The circuit current mainly depends on the solar flux, geographical location, and the temperature of the solar cell, etc. at the lower insolation, it may be possible that the solar module will not produce the required amount of power which will discharge any amount of water. The linear boost converter can be used in this situation which will help to increase the discharge at particular insolation. This month is considered to be the worst month of the year.

The above equations are non-linear in nature, the solution requires lot of iteration. Based on the above model equations, the number of the simulation techniques have been used in published work represented in Table 1.

Table 1: The performnace measurment studies on PV water pumping system

S. No	Author,s	Study site	Concluding points
1	Gad. H (2014)[23]	St. Catherine, South Sinai, Egypt	Simulation Software based on solar model equations have been used to evaluate the performance of solar pump.
2	Katan et al. (1987)[24]	Perth, Wetern Australia	Perfromance evaluation has been done by PSPICE software.
3	Loxsom and Veroj[25]	US Locations	Performnace evaluation has been done based on the algorthim.
4	Boukebbous et al. (2021)[26]	Algeria Sahara	Data monitoring system istalled to find the experimental data.
5	Mahmood Chhahartaghi et al. (2021)[27]	Isfahan City, Iran	Performance evaluation done by model equationas and experimental observation.
6	Mohammed Yachi et al. (2023)[28]	Southern Algeria	Sophistated verification methods to evaluated the solar pump performance.
7	Jose Angel et al. (2024)[29]	-	MATLAB SIMLINK has been used to determine the performance of the solar pump.
8	Richa Parmar et al. (2021)[19]	Haryana, India	Peroemance of the pump has been determined by determining the total quantity of the water discharged.
9	Albert et al. (2022)[30]	-	MATLA SIMULINK has been used to dermine the performnce of the solar pump at various coditions.
10	Naval et al. (2022)[31]	Spain	The performace has been determined at various tilt angle.

2.6. Types of Motors used in Solar pump

The motor selection is done on the basis of the size of the pump. If the size of the pump is less than 5 kw and distance beween solar pannel and sumersible pump is less then DC motors are preferably used. The one demerit with the DC motor is that its maintence is high , but due recent advancement in technology the induction mptor coupled with centrifugal pump is used in sumersible pump[4]. If induction motor is used then the inverter is used between the pv modules and the motor so AC current can supplied to the motor. The best thing with the induction motor is that it maintenance free and have good efficiency, reliability. The[32] used the Divided shaft pump (DSP) for improving the pump performance. The shaft is divided in to two parts and joined with the help of coupling and clutch arrangement. The engagement of the coupling with the help of clutch is fully automatic and operate at the different times of the day. The DSP shaft have been designed by taking the input data of motor pump by the manufacturer curves. According to the author conclusion the lower stage and high speed of shaft work when higher solar radiation in day time and higher stage and lower speed is used in morning and evening time of the day. The performance of DSP is compared with the traditionally manufactured pump with the help of theoretical data calculated on inclined plate at 20 degree tilt angle with horizontal. The comparison between electrical and hydralic performance of centrifugal and positive displacement pump have been concluded in[20]. The performance have caculated on the basis of metrological data avaialble at different location of Sahara and Algeria in Africa. The results shows the positive displacement pump is better than the centrifugal pump in term of efficiency and at high head. The load losses probability (LLP) method is used for optimized the size of the solar pump which consist of battery bank as well as the storage tank[33)]. The investigation is done on the four locatiion of south Africa Algeria and Oran in north as well as Bechar and Tamanraseset in South. The performance of synchronous reluctance motor system have been examined by vaying the insolation received by the solar plate[34)]. The paper concluded that the synchrous motor with photo voltaic generator give the better effiency than the brush type DC motor.

2.7. Types of Solar Pumps

The selection of pump is done on the basis of the availabity of water resource below the earth, available head and the head required to be developed by the pump. However three type of water source available on the eart ist is the water avalable at very deep well 2nd is the water avalable at in medium head well and 3rd is the surface water avalable in the river, pond and the canals. For deep well sumersible pumps are used. However in the sumersible the pump and motor both are attached in a single unit ,at the bottom motor is attached and the impelers are joined in series in number of stages as per the head required by the pump to raise the water. The floating water pumps used for surface water are combined in a single unit. These pumps floats above the surface of the pond, canal and river and then pump the water on earth surface so head developed by these pumps are very low. The third type of the pumps used for pumping the water from medium head. These pumps have motor and pumps both are separate unit and power is trasfered with the help of belt, pulleys and coupling etc. The above classification of the pumps are to be on the basis of use of the pumps. on the basis of working of solar pump the pump are classified in two types as shown in Fig. 6.

Ist is the dynamic pump and 2nd is the positive displacement pump. However, the dynamic pump is further classified in the axial flow pump and centrifugal pump. The positive displacement pump is considering the screw pump and volute pump.

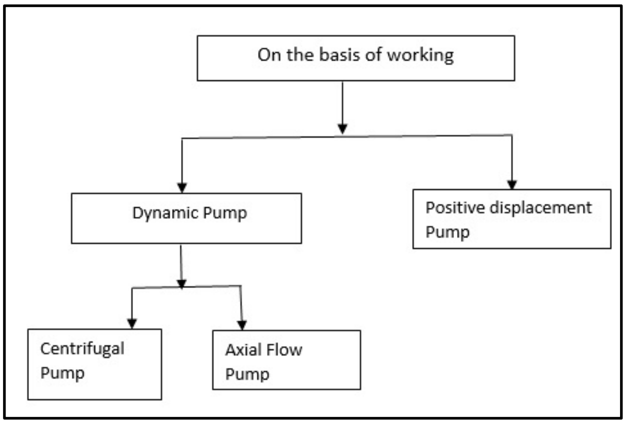

Fig. 6 Types of hydraulic pump

2.7.1. Dynamic pump

Dynamic pumps have an impeller on which blades are fixed. The two types of blades are provided on it one is movable blade and others are fixed blade. The movable blades work as a guide vane which guided the fluid at the blade angle of the rotor. The shape of the fixed blades is such that it will build the necessary pressure and velocity that is required to lift the waste from the surface. These pumps are two types.

2.7.1.a Centrifugal Pump

The centrifugal pumps lift the water by developing the pressure due to shape of the blades and the casing of the pump. The water entered at the eye of the pump at very high velocity and low pressure and left the pump at high pressure and medium velocity. So, change in centrifugal head due to rotation of fluid at different radius is equal to the manometric head required to lift the water[35)].

$$(U2^2 - U1^2)/2g = H_m \qquad (6)$$

Where $U2 = \pi D_2 N/60$ (m/s), $U1 = \pi D_1 N/60$ (m/s), H_m= Manometric head (m) and N= rpm of the rotor

The minimum starting speed

$$N_{min} = 84(H_m/(D_2^2 - D_1^2)^{1/2} \qquad (7)$$

The efficiency of the centrifugal pump is depending on the speed of the rotor so at very low insolation the due to reduced speed efficiency is less. This is considered to be the biggest disadvantage of the centrifugal pump when used with the solar application. These pumps are preferred for low to medium head up to 75 m but for high discharge. The pump performance has been improved by adding the Dividing Head Shaft[32)].

2.7.1.b Axial Flow Pump

In axial flow pump water flows in the direction of the axis of the pump and pressure is changed due to the aerofoil shape of the blade on which water flows. Mainly axial flow pumps are used for low head (40m) and high discharge. These pumps have specific applications in low head irrigation, spray application in irrigation etc.

2.7.2. Displacement Pump

The displacement pumps develop the pressure by displacing the water from a higher volume to a lower volume. These pumps have higher efficiency than the dynamic pump but the main draw back with these pumps are their low discharge rate. The discharge of the pump depends on the size of the piston and the speed of the pump but it is independent of the head of the pump. The displacement pumps are also called the positive displacement type of the pump. These pumps consist of the piston and develop the reciprocating motion inside the closed cylinder. The cylinder consists of an inlet and discharge valve at the cylinder head. When the piston moves from the bottom dead center to the top dead centre in the cylinder the low pressure is developed inside the cylinder. The low pressure allows the fluid to enter the cylinder. When the piston moves from the top dead center to the bottom dead center the piston creates high pressure in the cylinder due to the fluid discharging at high pressure from the discharge valve. The fluid is accelerated at the entry in the cylinder and decelerated at the time of discharge of the fluid. So, the minimum working speed of the pump is selected on the basis of the vapor pressure at the temperature of the fluid[36)]. On the other hand, a screw pump lifts the water with the help of a screw formed on the shaft of the pump. It sucks the water from the suction side and discharges at the outlet end. The benefit of these pumps is that it has in simple in construction and less moving parts. The one benefit of the displacement pump is that it works at a very low voltage range (24-48V) and high head up to 150 m[4)].

3. Literature review on solar water pumping system

In present scenario the solar pump is widely used in the agriculture, domestic and industrial application due to reduction in the cost as compared to conventional method of irrigation. The cost of fossil fuels is continuously increased and on other side the cost of solar panels are reduces due to development of advance manufacturing technique and government incentives. It is possible in near future the solar systems cover all areas of the energy because it is not harnessing the environment as well as cost effectiveness. In India the mixed farming is practised by the farmers in which they have livestock and agriculture both as a source of earning. However, the water needs for drinking, bathing domestic animals, sanitation, and for irrigation of farms can be easily fulfilled by solar pumps at very low maintenance costs[37)]. The lot of research has been published on performance calculation, optimization, design analysis, maintenance, economic viability, environmental effects, and the parameters affecting the efficiency of solar pumps. So, the following subheadings are explained in this book chapter.

3.1.Design of solar pump

The main design factors of solar pumps are based on the requirement of water for specific purposes, the evapotranspiration by crops, precipitation per annum, latitude of the place, and the variation of atmospheric temperature throughout the year. Other factors also counted for precise designing are the need for water, size of storage available, head of water depending on the location and up to which pump lifts the water, discharge of the pump, size of the panels, motor pump combined system efficiency[21)]. The overall design of each component of solar pump depends on the actual power requirement by the pump-motor system to raise the water from the earth. So, the following are governing equations which are required for designing the pump for each component of solar pump. the optimum sizing of the component determined by various optimization technique[38)].

3.1.1Design of Number of panels for solar pump

The solar panels are the first and most important component of the solar pump system, due to panels incurred the 60% of the total cost of the solar pump. The size of the solar pump is also depending on the number of solar panels used for irrigation. The total number of panels are calculating by simply energy conservation principle. As per the energy conservation principle the total energy required by motor is supplied by PV panels[39)].

$$N= [\rho g Q H_m/\eta_m * T_m / I_t * A * \eta_p * \eta_g * \eta_{bi} * T] \quad (8)$$

Where H_m= Manometric head

H_m = Static Head + inlet loss + exit loss + frictional loss

$$H_m = Hs + V_1^2/2g + V_2^2/2g + 4flv^2/D*2g \quad (9)$$

T_m= Time of working of Motor., V_1= Velocity in suction Pipe., V_2 = Velocity in delivery Pipe., f = Friction Coefficient.

$$f = 16/Re \quad (10)$$

Here Re= Reynolds Number, A= Area of solar module., N= No. of module. ,η_p= efficiency of solar plates. ,η_g= Battery Charging discharging efficiency. ,η_{bi} = efficiency of battery and inverter. , T = Total time of exposure of PV cell in a day (6 hr in a day).

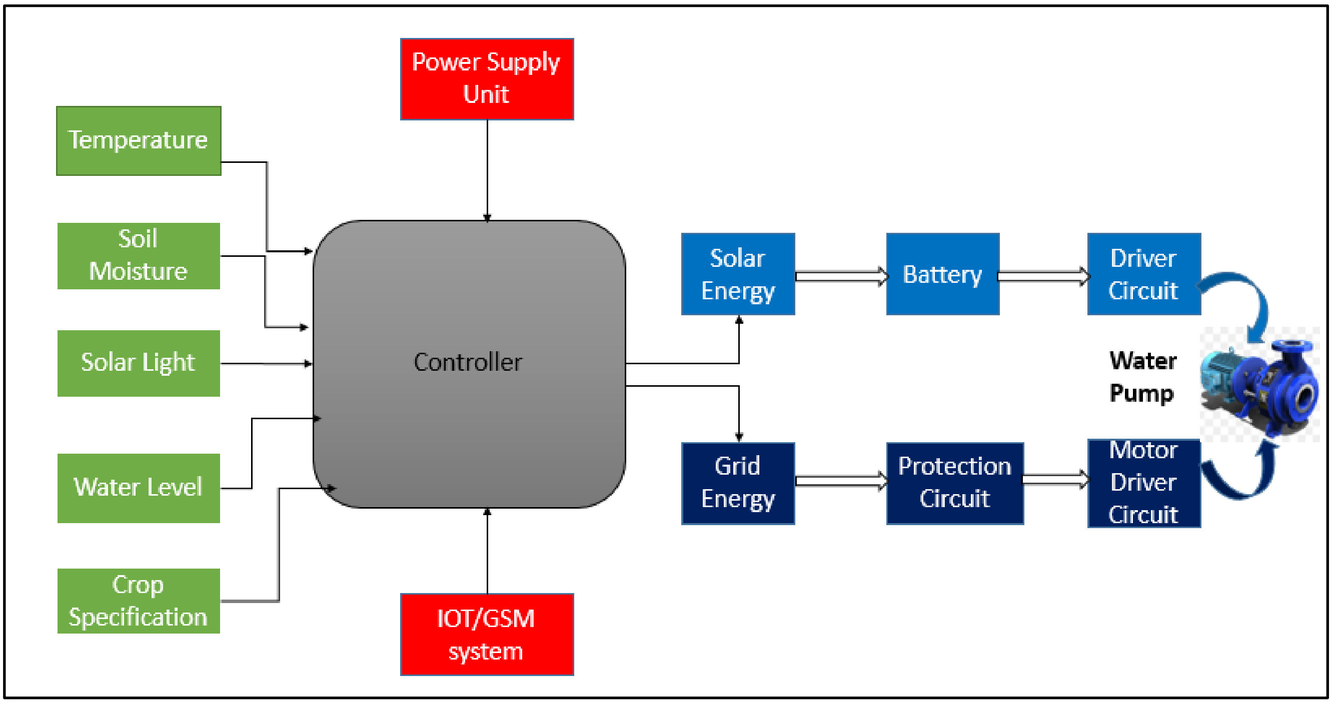

Fig.7: Solar pump components order [7)]

3.1.2Design of Number of Batteries for solar pump

The requirement of number of batteries are at the time of non-availability of solar energy due to cloudy weather or the night time. The main drawback with the battery banks is that it will increase the overall cost of the solar pump and not economically feasible for the farmer to maintain the battery bank. The battery banks are charged in the day time when the sun energy is available and it will use in night time when solar energy is not available[40)]. The number of the batteries are required on the basis of number of hours of operation of the solar pump without solar energy. So, number of batteries are.

N_B= T_B*Load on Motor (W)*/ (BAH*V*power factor) (11)

Where TB = Number of working hours of the batteries., BAH = battery ampere hour, V = volts of the batteries.

As per equation 11, the number of batteries are depending on the total load of the motor as well as the working hour of batteries at the time of non-availability of solar energy. So, use of batteries are not economical because the cost will be increased two times, if batteries are used for high load demand. Temperature, solar flux, moisture, crop specification and water level are the main input parameters of solar pump as shown in Fig. 7.

3.1.3Design of Control System

Basically, there are two types of the control systems used in the solar pump. Fist is the control system with inverter and second is the control system without inverter. If the DC motor is used for running the pump than no need of use of invert the direct current generated by solar panel can be directly used for pumping the water and extra power generated by solar panel can be stored in the batteries by the use of automatic charge controller. The automatic charge controller gives the safety of the battery bank at the time of charging and discharging of batteries at optimum current and voltage. The solar photovoltaic system with charge controller is also known as maximum power point tracking (MPPT) that will give the best efficiency at time of the availability of solar energy[41)]. The MPPT system maintain the optimum speed of the motor by supplying the maximum power required by motor and maintain the maximum efficiency of the solar pump system. The charge controller with inverter convert the direct current generated by panels in the alternating current required by AC motor as shown Fig. 8.

The very simple system without batteries and DC current motor can be used for small capacity solar pump. The main problem with the DC current is the high losses if the distance between the solar panels and motor is high.

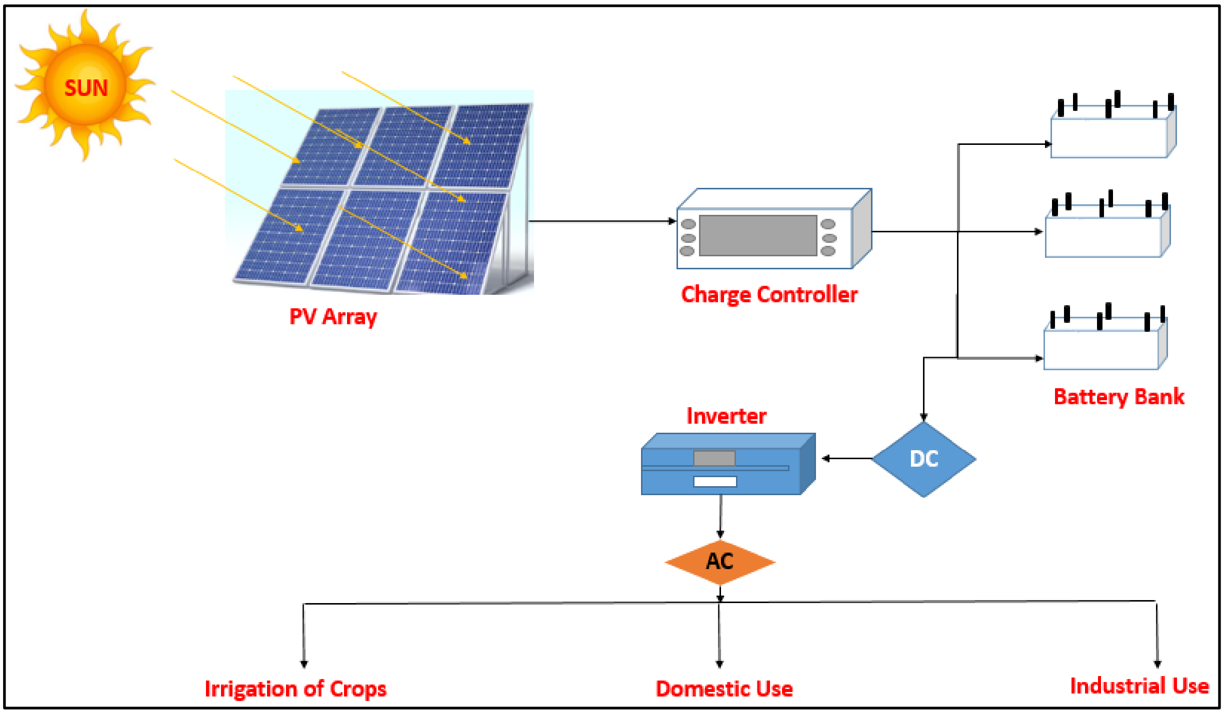

Fig. 8: Stand-alone battery storage solar pump

3.1.4Design and selection of motor pump system

The design and the selection of the motor pump system is depending on the required discharge and availability of water source (head). For high head and high head, the submersible pump is the best option but its life is less due to submersible pumps are installed below the earth dipped in water source. The corrosion and rusting of seal could damage the pump. The most important advantage of using of submersible is that it did not have any problem of cavitation at all head. At medium head and high discharge, the centrifugal pumps can be used but when the total dynamic head increased the cavitation create the big problem in the solar pumps. The priming is also required in the centrifugal pump at the time of starting the solar pump. For low discharge and high head, the displacement pump work very well. So, the solar pump can be selected on the basis of required head and discharge at particular site.

4. Performance of solar pump

As per[4] the performance of the solar pump is depending on following factors.

(a) The discharge of the pump.
(b) The total dynamic head.
(c) Availability of the solar flux.
(d) Seasons of the year.

The total dynamic head or manometric head is the sum of suction head (Elevation head difference between the suction water and discharge water) and total minor and major losses occur in the pipe section.

H_m = Static Head + inlet loss + exit loss + frictional loss

$$H_m = Hs + V_1^2/2g + V_2^2/2g + 4flv^2/D*2g \qquad (12)$$

Where Hm = Manometric head, V_1 = Fluid velocity in suction pipe in m/sec., V_2 = Fluid velocity in the delivery pipe in m/sec. f= friction coefficient between pipe wall and fluid flowing the pipe.

The friction coefficient f= 16/Re where Re = Reynolds number depends on the fluid properties and the average fluid velocity through the pipe section is given by[43].

$$Re = \frac{\rho V D}{\mu} \qquad (13)$$

Where ρ is the density of the fluid, V is the average velocity of the fluid through the pipe, D is the diameter of the pipe section and μ is the dynamic viscosity of the fluid.

The energy required by pump to the lift the water against the manometric head Hm is given by[43].

$$EL = \rho g Q H_m/\eta_m \qquad (14)$$

Where η_m is the motor efficiency or the mechanical efficiency. The mechanical efficiency is due to the mechanical losses occur between the shaft and the bearing in the motor. Q is the discharge of the pump in m3/sec.

Power produced by the solar panel is the input power which will supply the sufficient energy to the motor to the lift the water against the manometric head given by[34].

$$P_{SP} = S*A*N_P*\eta_P \qquad (15)$$

Where P_{SP} is the actual power produced by the solar panel, S is the solar flux falling on the solar panel, A is the area of the one solar panel, N_P is the number of the panels connected in series and parallel arrangement and η_P is the efficiency of the solar panel. The efficiency and maximum power produced by the solar panel is given by manufacturer catalogue. The actual power produced by the solar panel is quite less than the maximum power produced solar panel due to number of loss occur in the environment, cable loss and reflection and refraction losses given by[44].

$$P_{max(actual)}= [(1-L_T) *(1-L_C) *(1-L_B) *(1-L_M)] *P_{max} \quad (16)$$

Where L_T= Temperature loss factor, L_C= Cable loss factor, L_B= Battery loss factor, L_M= Mismatch loss factor and P_{max}= Maximum power produced by PV panel.

Temperature Loss factor is given by equation as per [45].

$$L_T= (P_T)loss/P_{max} \quad (17)$$

Now $$P_{max}= C_P*P_{max}*(T_m- T_{mref}) \quad (18)$$

$$Tm= Ta + (NOCT -20) *(I_T/800)\ ^{\circ}C \quad (19)$$

Where NOCT = Nominal operating cell temperature.

The total performance of solar pump is depending on the actual power produced by panel but due to the internal losses in the system and external losses in the environment due to temperature difference between absorber plate and environment reduce the performance of the solar panel. As the temperature of the solar panel is increases in a day time from 11.am to 3 pm the losses in the atmosphere is also increased. This will reduce the performance of the solar panel.

5. Factors affecting the performance of solar photo voltaic pump system

The solar photo voltaic pumping system performance depends upon the number of parameters like required discharge, total dynamic head, location, whether condition, height from sea level, size of the field etc. These parameters not only the constraints but also discourage the farmers to irrigate the field by solar pump. The main performance parameters, problems and their solution are given blow.

(a) As per data given in[21),46)] the conversion efficiency of solar panel is varied from 22.7% to 1.53% for singe crystal and multi-crystalline silicon material. Due to low conversion efficiency the size of the solar panel is very high. So, to full fill the energy demand of large-scale system increases the cost of solar pump is very high that is not fit for irrigation for the farmers. For getting the maximum output from solar panel it is required to fixed the solar panel at an optimum angle as per the location. Addition of solar tracking further increase the cost of solar pump. It will increase the payback period and not economical for public use[47].

(b) The selection of controller in solar pump is most important because it will affect the overall performance of the solar pump. It will track the maximum radiation to the Sun and convert appropriate current and voltage as required by motor pump system [48]. The charge controller controls the activity of charging and discharging of batteries and maintains the long life of the Li-Br batteries.

(c) There are different types and different power pumps have been used but the selection of right pump is done on the basis of discharge supplied by pump and total dynamic head. The right selection of pump not only increase the overall efficiency of the system but also reduce the cost and increase the life of system. It is also necessary to decide either used the DC or AC motor but when AC motor is used an inverter is required to convert the DC current into the AC current[47].

(d) System demand and performance both depend on its use at all 24 hours. The solar photovoltaic system is well used when sun light is available but during night it can be used by storage system. There are two type of storage system used in solar pumps fist is the battery storage system in which batteries are charge in duration of day when sun light is available and this stored energy in the form of Dc power can be utilised at night but these batteries increase the cost of solar pump around 30%[40]. Second storage system is water storage in a tank the tank filled upto the top in day time and stored water can be used when sun light is not available. This is a cheap way of storing the energy and require no running cost. The size of the tank is depending on the use of water at the time non availability of sun energy[49].

The main disadvantages of solar pump are the its low efficiency and low performance. So, following are the factors that affect the efficiency of solar photovoltaic system are given below. Table 2 shows the previous work published on the performance improvement of the solar pump.

Table 2: Various simulation and methods used for performance improvement of solar pump.

S. No.	Author's Details	Techniques Used	Research outcomes
1	Odeh et al. (2005)[9]	TRNSYS Simulation Modelling	The number of solar panels enhanced which increases the discharge of the solar pump and motor pump efficiency.
2	Abdolzadeh et al. (2014)	Spraying water on solar panels.	It reduced the module temperature and enhanced the pump performance.
3	Joao et al. (2012)[50]	Inductor boost converter and voltage source without battery storage	The maximum efficiency is 91% at the power output of 210 Wp.

4	Vikas Kumar (2023)[51]	Cooling of solar panel at dual axis tracking system.	Efficiency of the solar panel enhanced.
5	Umar et al. (2023)[52]	Self-cleaning and cooling system has been installed with solar panel	It enhanced the solar panel efficiency due to both dust accumulation and water spraying.
6	Vanaja et al. (2021)[53]	Modular Multilevel Inverter (MMI) has been used	Enhanced the solar pump performance.
7	Firoozzadeh et al. (2023)[54]	A cooling film has been developed for reducing the temperature of the solar panel.	The efficiency of the solar panel is enhanced due to this cooling effect.
8	Chadge et al. (2024)[55]	Various arrangement of the solar panel has been used for improving the performance of the solar pump.	The performance of the solar pump has been enhanced due to different arrangements of the solar pump.
9	Tiwari el al. (2020)[56]	Water cooling on solar panel.	Due to water cooling, the efficiency of the solar panel increased.

5.1 Effect of photo voltaic module adjustment

In different parts of the world the availability of sun light and environmental conditions are different. The need of water in India depends on the seasons the highest requirement of water in the Summer season but the good thing is that highest amount of solar energy is also present in the environment in the same seasons. So, it is required to choose a perfect angle of locating the panel, and size of the panels and fix or tracked the photo voltaic module accordingly. The main parameters which show the performance of solar cell are given as[32].

a. Maximum power produced by a solar panel under normal environment conditions[57].
b. The main parameter is the nominal operating cell temperature (NOCT) which affect the performance of solar panel drastically due to variation of solar flux [58].
c. The tilt angle of the solar panel will also affect the performance of the solar panel[23] and the latitude of the location. So, it is necessary select the optimum inclination angle at which solar flux is maximum thought day[59].

5.1.1 Effect of inclinational of photo voltaic plate

The PV tilt angle is very important factor it will decide the level of solar flux that reaches on the surface of the solar panel.[60] studied the performance of three different angles of tilt (L, L+15, L-15) of different seasons of the year[35]. Finally, they concluded that at the time of winter the angle of tilt (L+15), in summer time the angle of tilt (L-15), and in Autumn and spring time it is(L). where L is the latitude of the location on the Earth[61].

[62] invested the performance of solar pate at the at different tilt angle varies from -40^{O} to +40^{O}in steps of 10 degrees and finally concluded the maximum performance is obtained in between -10 degree to +10 degree[63].

In order to optimize the tilt, angle an algorithm is proposed by[64]. In which an optimized tilt angle is determined without any numerical problem. They used the metrological data from the years 1985 and 2001 at the location in Turkey with variations of angle 0° degrees to 90° degrees. The algorithm gives the theoretical results by variation of 1 degree of tilt angle. The radiation on the tilt surface is determined by[21),65].

$$H_T/H_g= (1-H_d/H_g) *R_b + H_d/H_g*R_d +R_r \quad (20)$$

Where H_d= Total diffuse radiation

Rb= Tilt factor find out by equation suggested by **liu and Jordan (1960)**[45] for a south facing surface.

$$R_b= (ws*\sin(\delta)*\sin(\varphi-\beta) + \cos(\delta)*\sin(ws)*\cos(\varphi-\beta))/(ws*\sin(\varphi)*\sin(\delta) + \cos(\varphi)*\cos(\delta)*\sin(ws)) \quad (21)$$

Diffuse radiation tilt factor

$$R_D= (1+\cos(\beta))/2. \quad (22)$$

Tilt factor for reflected radiation [66].

$$R_r= (1-\cos(\beta))/2 \quad (23)$$

Where Rr is the reflection coefficient, ws is the hour angle, δ is the declination angle, ϕ is the latitude of the place, β is the tilt angle of the panel.

In order to improve the effectiveness in optimization results a equation depends on the three variable is given by[67), 68].

$$G_{gt} = G_{bt} +G_{dt}+ Grt \quad (24)$$

G_{bt}, G_{dt}, G_{rt} are the direct beam flux, diffuse radiation flux and reflection radiation flux in W/m^2.

Actual power output from PV module is calculated by equation given by[69].

$$P_{actual} = \eta pv*A_{PV}*Ggt \quad (25)$$

Where ηpv is the efficiency of the photo voltaic module, A_{PV} is the area of the PV module and Ggt is the total radiation fall on the surface of the PV module.

In general, the specific design and photo voltaic tilt angle is given by[70] and shown in Table 3.

Table 3: Magnitude of tilt angle as per the use of water.

Water need as per requirement	Best Solar plate tilt angle
Nominal water demand throughout the year and maximum in summer.	(Φ- 20°)
The maximum amount of water requirement throughout the year.	(Φ- 10°)
If maximum amount of water required in summer.	(Φ- 20°)

(1) If solar pump is installed in a particular area for the domestic water need. The solar panel tilt angle should be near to 20˚.
(2) If the demand of water supply is more in summer and throughout the year it will remain constant, then tilt angle is chosen to be 10˚.
(3) If requirement of the water is highest throughout the year then tilt angle should be near to 10°.
(4) If your requirement is highest in summer, then the solar plate tilt angle should be latitude minus 20°.

5.1.2 Effect of Solar panel tracking

In order to find out the long-term performance of differen-2 configuration of PV module. the teste was conducted by[71]. The long-term performance was calculated by three different configurations are given as (1) fixed (2) Tracking by one or two axis (3) V-trough generators. In one and two axes tracking the maximum flux is captured by the photovoltaic array throughout the day. The tracking not only improve the efficiency of the plant but also reduce the payback period and improve the cost of the installation of the pump.

For reduction in cost and complexity in the tracking system[64] conducted a study on the solar photovoltaic module in three different tracking approach. In fist approach track the solar PV module in hourly basis in second methods used the tracking on month basis in third case the tracking is done yearly basis[72]. The system uses to be automatic and finally they concluded that hourly tracking is not advisable because it will improve the cost of installation several times as compared tracking in monthly and yearly basis[73]. The best way to use the tracking in month basis or the seasonal variation. The variation of solar flux in a day with respect the month basis on the basis of tracking on hourly basis, month basis and yearly basis[74].

Caton P.[75] investigated the results on ten different PV tilt angle at different frequencies. Some configurations are given below.

(a) For east-west axis the PV tilt angle slope should be in between 0˚ to 90˚.
(b) For better tracking in summer month in east-west direction the PV tilt angle should be in between 30˚ to 90˚.
(c) No need of the providing tilt angle in North to south direction.
(d) With vertical axis the angle of tilt should be 30˚.
(e) Two axis tracking was investigated in area of Ying of west Africa (9.7°N, 0.8°W).

[76] conducted experimentation on solar pump that is directly driven by photovoltaic module without use of any inverter and controller. They finally concluded that 25% efficiency have been increased by manual tracking done three times in a day[77].

5.1.3 Effect of PV module arrangement

The PV module arrangement in series, parallel is also affect the performance of solar panels and number of researchers proved this by experimentation.[78),79] conducted the experimentation on four different arrangement of solar panels. The four different arrangement of PV module are given as below[80].

1. In 1st arrangement total 18 modules used in which 6 modules in6 row series and 3 in parallel (6S, 3P)[81].
2. 2^{nd} arrangement total 24 number of modules have been used in which 12 modules are connected in series in one row and two rows in parallel(12S,2P)[82].
3. In third arrangement 24 modules are connected in a combination of eight in series and three in parallel[83].
4. In fourth arrangement total number of modules used are 24 in a combination of 6 in series and 4 in parallels (6S, 4P)[84].

Finally, they concluded that the third arrangement of 8panel in series and three in parallel give the best performance of all four arrangements. It produces the maximum power of 900W[85].

5.1.4 Effect of PV module size

For study the size of the PV module on the performance of solar panel 7 different size of PV module simulation is done throughout the year[9, 86]. The simulation results show that when size of solar panel increased then flow rate of water and subsystem efficiency increased while reducing the performance of the solar PV module simultaneously[87]. The increase in size of PV module increase the heat transfer area which will promote the heat loss. The over size of the PV module increases the cost of water while under size increase the overall cost of the irrigation due to low discharge of the system. So optimum size of PV module is required which will balance between the cost and the discharge of the water[88].

For optimum size of the PV module two important parameters have been selected by[89,90, 91].

1. Worst month of the year
2. Peak sun hour analysis.

The size of the PV module has been calculated on the basis worst month of the year. The worst month of the year is month of the year at which the solar radiation is minimum. If the modules are selected on the basis of worst month then solar system can supply the power throughout the year in peak hours of the day[92].

The peak hours of the sun are the hours of the sun in which solar radiation give the solar flux of 1000 W/m^2 [93].

5.2 Effect of Pumping head

[8] conducted the experimentation on different head and calculated the amount of power required. Finally, they

concluded that 288 w power required for head of 11m, while 56 W power required for 0.6 m head. The efficiency of motor and pumped reached the 26% and 12% at 11m and 0.6m head.

[78] installed a solar pump in a well of at the head of 120 m depth. The tests were performed on four different heads (80 m, 70 m, 60 m and 50 m) and shows the results on Fig. 7. The best efficiency has been represented by the 80 m head. At the time of the morning and evening when solar radiation is low; the low head pump gives the good performance. On contrary at the noon when solar radiation is high the highest head pump working well[94].

[95] conducted experimentation by simulation on four different size of submersible pump. The selected site for experimentation at four different areas of the Kairouan (36.5^{O}N, 10.11^{O}E). for getting the suitable head simulation was performed by varying the head from 60 m to 85 m. The results clearly show that at 2840 rpm the efficiency of the pump was 30%, at the head of 65 m and discharge 2.12 m^3/h. The total power supplied by inverter to motor was 1252 Wp .

5.3 Effect of Pump-Motor combination

The right selected motor pump system can several times increase the performance of the solar pump. The type of pump and their working principal is given in Table 4.

Table 4: Working principle of the pumps.

Type of pump	Working Principle
Centrifugal pump	The head developed against the total dynamic head is provided by the centrifugal force developed over the runner blade.
Displacement Pump	The water is displaced from inlet valve to outlet valve by the reciprocating piston.
Screw pump	The screw pump has higher efficiency than the centrifugal and displacement pump but it has low discharge.

[32] investigated the effect of number of stages of the pump at variable speed on the discharge and the system efficiency. They use the three pumps at different stages (46, 33 and 24) at speed range of the 50 Hz and 40 Hz. They focused on the highest volume at the different combination of stages and speeds. Finally, they concluded that in the afternoon when solar radiation is high low stages at high rpm and in morning, evening time high stages at low rpm give the best performance.

[16] performed the experimentation on two type of the system arrangement. In first type multistage centrifugal pump combination with three phase AC motor have been used. In 2nd type a positive displacement pump with DC brushless motor was used. Finally, they concluded that positive displacement pump has large efficiency than the centrifugal pump particularly at large head. They obtained the maximum efficiency of positive displacement pump 45% and in the centrifugal pump was 14%.

In another research they performed the experimentation on again two combination of motor- pump system. First, combination consist of centrifugal pump with three phase AC motor. In other combination system consist of positive displacement pump with DC motor. They concluded the summary in Table 5.

Table 5: Comparison between the centrifugal pump and Reciprocating pump.

Parameters	Centrifugal pump	Reciprocating pump
Head	At high head, medium discharge and total efficiency low	At high head, medium discharge and high efficiency.
Losses occur	High energy losses occur	Low energy loss occurs

5.4 Effect of atmospheric conditions

The atmospheric variables like temperature, velocity and solar flux affect the performance of solar pump. So, these conditions are required to considered at the time of designing the solar pump. Some factors are described below.

5.4.1 Solar Flux

Solar flux is the most important parameters for designing the solar pump system.[19] performed the one-year simulation up to 28 m optimal pumping head for studying the effect of the solar flux. They concluded that below 300 W/m^2 the solar pump gives no discharge but at higher solar flux it will give the large amount of volume flow rate[96].

[76] observed that for good designing of solar pump require the exact analysis of the solar irradiation. They collect the large data between the year 1985 to 2004 for making good correlation of solar irradiation data and atmospheric temperature. They compared the three empirical relation of early research paper on the basis of this data and find the most optimized empirical relation with its correlation coefficient. The comparison is shown in table 4.

As per table 4 the most optimized correlation is given by Liu and Jordan[75), 97]. The theoretical calculated results given by[75] shows the good match with the measured solar radiation in the afternoon time. On the basis of these theoretical results output variable of solar pump can also be determined by good accuracy but this correlation give the error in remaining hors of the day. The absolute error reached to be 40% to 70% in morning and evening time.

5.4.2 Effect of the PV module temperature

The photovoltaic module performance and efficiency are varied with respect to the temperature of the cell material [98]. After a certain limit that is called the nominal temperature of the solar cell beyond this temperature the efficiency of the solar cell has been reduced [99]. This also cause the thermal destruction of the cell material. So, maintaining the optimum performance the cooling of the solar panel can be done either by the water or air[100], [101].

5.4.3 Effect of the geographical location

[16] studied the effect of the geographical locations on the output parameters on the solar pump. The four different locations have been selected for experimentation at the Sahara, Africa. The two selected sites were Tamanrasset and Bechar have Sahara environment located at the in the south Africa. The two other sites were at Algiers and Oran; these sites have Mediterranean environment located in the north of Africa[102]. The relative difference was found on these selected four sites on the basis of the total power output by solar panels and the head developed by the pump. Finally, they concluded that at 250 Wp, 40m head difference occurred in between the northern and the southern side[103].

6. Applications of solar water pumping system

The most important application of the photo voltaic technology is as a solar pump in domestic and agriculture applications[104]. The PV pump have reduced lot of pollution because it is not consumed anything that burn and produce the pollutant[76), 105].

In year 2013 the USA (United states of America) produce 10% of the total energy required by PV cell technology[106), 107]. In china the energy produced by the pv cell technology was 30% of the total energy demand of the china[108), 109].

In the advancement in the solar technology, peoples are focusses towards research in the solar cell for replacing the fossil fuel technology[38]. It is the green source of the energy as compared to fossil fuels. it will not produce any harmful pollutants and greenhouse gases that give the bad effects on the environments[16]. It is the cheapest way of irrigation and pumping of water for domestic use in the area which have lot of amount of solar energy[110]. Solar power is also used in desalination plant located near to the sea coast[26].

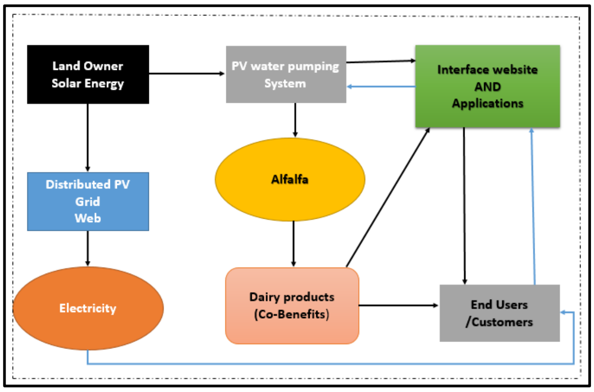

Fig. 9: Schematic representation of solar cell applications[111].

The Figure 9 represents the number of ways by which solar cell technology can be used. As per Figure 9, the solar cell technology can be used for water pumping system, dairy products and remaining can be sale to the power grid[112].

The solar pump can also be designed on the basis of the total static head, water need on the basis of population and metrological profile[108),113),114]. The angle of inclination by solar panel is 15 degrees and the depth of the well was 40 m. They used the centrifugal pump with combination with three phase AC motor. The total installed capacity of the solar pump was 3000 Wp[115].

[43] design and develop a solar pump in an area of Kuwait for fulfil the demand of 300 people water need. The pump capacity per day 12 m^3 discharge have been designed on the basis of the per person water need of 40 Litres per day. The installed pump has capacity of develop the head of 15 m and pump power 210 Wp**.** The floating solar panel power plant can also be used in all over the world[116]. The application of solar pump in compiled form is represented in Table 6.

7 Advantages of solar photovoltaic water pump system

The solar photovoltaic system is cost effective as compared to other methods of pumping the water like diesel pump, gasoline pump etc[117]. The solar pump required no fuel for running as well as its maintenance cost is negligible, only time to time cleaning of panels is required[118]. The photovoltaic solar pump clean and green energy source for the environment it will not produce any harmful gases like fossil fuels[119].

The life of the solar pumping system is around 20-30 years[120]. The payback period of the solar pumping system is around 2 to 5 year, so around 20 years it will run without any investment either in the fuel and other maintenance cost required as in the diesel pump[121]. In India solar pump is very economical as compared to diesel operated and electricity operated water pumps[64]. the payback period is 4 to 5 years and life of the solar pump in India is around

20-25 years[4]. As per the study conducted by[24],[122] the reliable life of 1.5 kw solar pump is around 15-20 years[123].

As per the conclusion given by[124],[125] on horticulture crop irrigation by solar pump[126]. The solar pump is very cost effective as compared to the diesel-based water pump. The experimental data is collected to the whole cycle of the horticulture crop.[37] investigated the performance of solar water pumping system economically and conclude that 7-8 MWh electric power saving is done by installation of single 4.48 kw DC solar water pump[60].

Due to reduction in the cost of PV modules compared with last 10 years and increase in the price of petrol and diesel fuel 250% attracted the world to full fill the energy demand by PV module[127]. Now a day's government provides a lot of subsidies to farmers for solar pump irrigation[128],[129].

8 Economic Feasibility and optimization of Solar Pump

The economic feasibility study is very much required in the case solar pumps due to the high price of PV modules and availability of solar energy in a day. A new approach of optimization had been developed by[46],[131] by consideration of initial cost of investment, revenue cost and take as a constraint the availability of solar energy and head of the groundwater level[132]. The paper concluded that the proposed model deducts the total cost to be around 18.8% in a photo voltaic water pumping system[133]. The sensitivity study shows the effect of the total cost of crop and the total cost of the photovoltaic module[134].

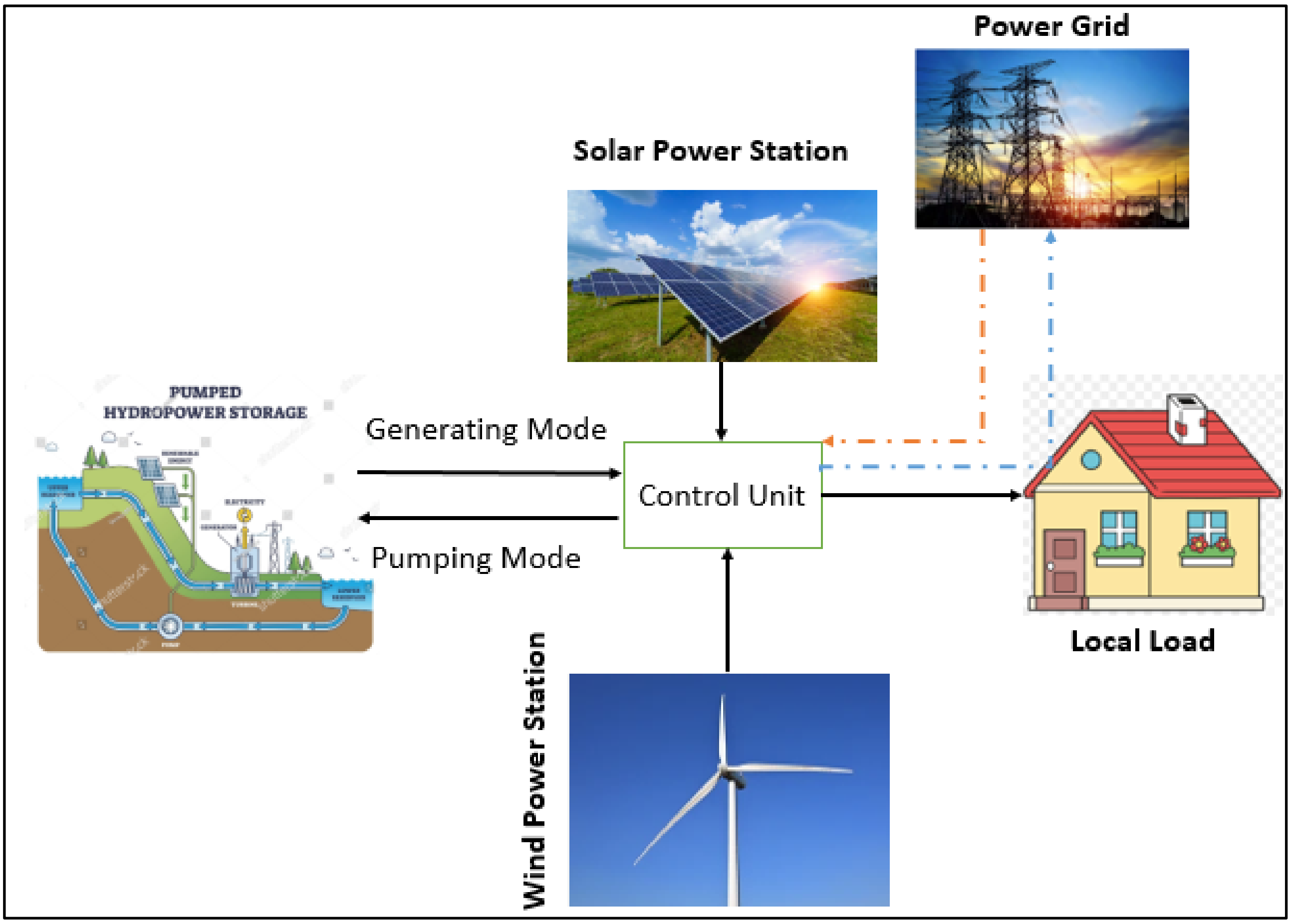

Fig. 10: Solar and wind energy for the pumping of water[130]

The simulation results on the differents case study are also performed on the solar pump by putting MPPT (Maximum power point tracking) and VRFB (Vanadium Redox Flow Battery) in[34],[135]. They also conclude that pump characteristics parameters like current, voltage, and torque have been fluates in absence of VRFB when directly connect the PV module with MPPT[96].

The optimization of solar pump have also big contribution in the term of motor pump system efficiency [136],[62].

If the wind energy is included with the solar energy in the solar pump then its cost of generation of the power further reduced[137].

The Figure 10 depicted the use of the wind power with solar power to drive the solar pump which made it standlone and have the capability to pump the water 24 hrs[138),139)].

The research optimized the daily discharge of the solar pump by maximizing the solar pump efficiency at all times of the day[140)]. The author minimizes the mechanical losses and electrical losses by put the system on the field control and also incorporated the MPPT system in between PV module and the inverter[141)].

A different approach of optimization has been used in[147)] in which the output of hydraulic energy that depends on the input energy received by PV module is maximized and it is considered to be a objective function[148)]. The model had been validated on two locations in Croatia in one was Split and other was Osijel[149)]. The economic feasibility between PV water pump and diesel engine is checked in[7)]. The comparison made among different capacity solar water pump and the diesel engine size vary from 2.8 KWp to 15kWp. The sensitiviy of the systems to be proved at different location and different conditions of the enviroment[150)].

The solar pumping system have been installed in Faculty of Engineering and Technology (FET) in Jamia Milia[151)]. The reaserch focused to the comparison between solar water pumping system and existing system run by conventional energy source[152)]. The total cost of SPV system is around 10 lac that will return in 4 year of payback. However the total life of the pump was 20 year thaen it will supplied the water upto 16 years without spending the any cost[153)].

Table 6 Application of the solar pump in various fields of society

Authors	Solar Panel	Motor/pump type	Head Developed	Use
108)	2995 Wp	Centrifugal pump with three phase supply	35- 40 m	-
142)	Inclination angle of solar panel 15° 210 Wp	-	15 m	Daily basis discharge of the pump 12 m^3.
143)	The total power supplied by the solar panels was 3200 Wp	Two pumps (Submersible type)	218 m	Maximum discharge obtained to be 0.9 l/s.
144)	Power of solar panel was 409 Wp.	AC three phase centrifugal pump (400 Wp)	20 m	5.29 m^3/day.
145)	Power of solar panel 195 Wp	150 Wp centrifugal pump	100 m	1 m^3/day
146)	Power output of the solar panel 900 Wp.	0.5 hp submerisble pump	-	Domestic applications
146)	Power output of solar panel 1200 Wp	1 hp centrifugal pump	-	Irrigating the crops

It will also save the cost of 3 lac per year which was early spend for running the conventional diesel operated pump. The solar pump are located in remote area of sahara Africa[16),] . This paper shows the performance of three pv array sizes (1040, 1400 and 1750 watt peak power) and compare the economic feasibility analysis with the conventional diesel engines[154)].

The average yearly flow rate is around 60 m^3/day and the cost is 0.04 dollar per m^3 for three pv array sizes. Theexperiemtal investigation on 610wp pv generator have completed and also enviromental factor to be studied[155)]. The authors finally concluded that solar pump setup run with 10% reduced electrical losses. The enviroment friendly validity is also proved In the paper. The financial study carried out in[156),157)]. It will more economical for the farmers if the solar and wind energy combined to pump the water for the irrigation[130),158)].

This paper consider all the fiancial factors (initial investment, internal rate of return and the cost of water discharge, depreciation with time and the incometax benefit) in solar pump and finally evalute the results in India[159)]. After evaluation author concluded that the higher cost solar pump is not viable for potential india. However the lot of incentives and subsidies provided on the solar pump by the govrment of India. In[126)] the solar pump installed on 130 types have been studied in eight states of Mexico range vary from few kilowtts to 2 kWp[93)].

This study provide the big data for finncial study of the solar pump technology and give a comparision between pv technology with the traditionally used methods of irrigation. The reference[160),161),40)] have been used the solar pump technology in place of diesel engine and find out the saving in diesel fuel in annually. The author also found the reduction in amount of CO_2 emission and cost due to installtion of the solar photo voltaic pump in India. Author also sumrized the data between solar flux and cost of diesel fuel according to that if dailly solar flux supplies is around 5.5 kWh/m^2 for 1.8 kWp solar photo voltaic pump US 405.06/ton cost saving. The Table 7 reresents the reduction in cost due to use of new techniques in solar pump.

Table 7: Cost reduction in solar pump due to new techniques

Authors Details	New Concepts	Outcomes of study
162)	A concentrating solar panel of 300 to 500 Wp.	Electricity production reduced upto half.
163)	Replace the motor by linear actuator	Cost has been reduced due to replacemnt of motor
164)	Used induced flow by external device	Itreduced the cost and comlexity
165)	Used Linear actuator	Linear actuator gives the maximum efficency of 90%.
32)	Used divided shaft concept.	9 to 10% yearly water yield increased.
166)	Addition of the effective booster reflector.	Output power of the solar panel enhanced.

9 Conclusion

A compressive review on the current status of PV cell technology is presented. It is focused on the design, development, applications, and advantage of the solar pump. Based on the above study following are the main conclusion.

1. Solar photovoltaic technology is the economical and reliable solution for the replacement of fossil fuels in near future. In future solar pump for irrigation is beneficial for farmers due to government is providing a lot of incentives on a solar pump.
2. The remote locations like deserts and the mountain the availability of electricity grid supply is not possible. The solar pump can be used for both domestic and agriculture use.
3. The high initial installation cost can be reduced if the government provides the high incentives so that in the future solar cell technology can replace the diesel pump and electrical driven water pumping systems.
4. There is a lot of research gap available in the selection of materials for maintaining the best efficiency at high temperature, efficiency-improving techniques, factors affecting the performance and degradation of PV generator. If the efficiency of the solar panel increased then it can reduce the cost of solar panels and reduce the cost of the solar pumps.
5. The life of the solar pumping system is around 20-25 years. The payback period of the solar pumping system is about 4 to 5 years, so around 20 years, it will run without any investment either in the form of fuel cost and maintenance cost as required in the diesel pump. Therefore, solar pumps are very economical as compared to diesel-operated and electricity-operated water pumps[4)].
6. Due to the reduction in the cost of PV modules compared with the last ten years and the increase in the price of petrol and diesel fuel by 250%, the world will have focused to full fill the energy demand by PV modules in the near future. Now a day's government provides a lot of subsidies to farmers for solar pump irrigation[128)].
7. Due to the development in recent technology and the working of PV modules on Maximum Power Point Tracking, the solar pump is very useful for supplying water for agriculture and domestic use. In the mountain, hilly and desert areas, these pumps effectively provide water.

Solar pump irrigation is very attractive in areas of Asia, Africa, China, and some other Asian countries located in tropical region. These areas are rich in solar energy, a lot of population of these areas are also located in the remote side which require water for daily use and farming.

Nomenclature

N_S	Number of solar panel in series.
V_R	Required voltage of motor (V)
V_P	power (V)
N_P	Number of plate in parallel.
P_T	Total power consumed by motor (W)
P_S	Output power of one plate (W)
I	Circuit current (Amp)
I_{PH}	Photon Current (Amp)
R_S	Series Resistance (Ohm)
R_{SH}	Shunt Resistance (Ohm)
T	Cell Temperature (K)
B	Constant
V	Circuit Voltage (V)
K	Boltzman Constant
e	Electron Charge (Coulomb)

Greek symbols

δ	Declination Angle(°)
β	Slope Angle (°)
φ	Angle of latitude (°)

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