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SOLAR ENERGY IN IRRIGATION

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ABSTRACT

Farmers always have a significant role to provide food for growing population. However, to meet the growing food demand, farmers require large agricultural land and sustainable irrigation system to produce surplus food products. In developing countries, farmers do not have access to electricity for irrigation systems in remote areas, therefore, renewable energy can play a major role to fulfill their electricity requirement. Even the areas having grid access, don't get regular and reliable electricity. Farmers may generate electricity from wind, sun and biomass etc. to use in their farms. Country like India, about 18% of produced electricity is consumed in agricultural activities, hence, renewable energy can be significantly used for farmer's activities. As abundance of solar and long sunshine hours in almost every region of country, the solar energy might be one of the best possible ways for electricity generation. The use of solar pumps by farmers for irrigation purpose is the easiest way to harness the solar energy and also contribute to clean and green energy generation. In this paper, solar photovoltaic based water pump (SPVWP) and solar thermal energy based water pump (STEWP) for irrigation purposes are discussed. Apart from this, the use of solar photovoltaic (SPV) panels in greenhouses and irrigation/farm managements is discussed. And now these days, scarcity of freshwater is putting pressure on scientific communities to think of alternative ways to providing water supply for irrigation purpose. Therefore, new and exciting techniques are evolving in the field desalination of seawater so that freshwater can be supplied for agriculture activities, hence, the use of solar energy in desalination also described in this article.

Keywords: *Solar water pumps, solar thermal water pump, SPV based greenhouse, desalination*

INTRODUCTION

In developing countries, the crop production is mainly dependent on rain and adversely affected by uneven distribution of rainfall. However, the availability of solar energy can be used as power source for pumping systems to lift water from canals and rivers for supplies in rural and urban areas. At present, most of the water pumping systems around the world are used the fossil fuel generated electricity or other conventional energy sources. Consequently, it has severe impact on environment and contributes to air pollution. Apart from impact on climate change, they are also depleting at faster rate which is serious cause of concern in near future. Therefore, solar energy can reduce the dependence of water pumping system on the fossil fuel sources. The use of solar water pumping systems also minimizes the overall operation and maintenance cost and upfront cost and replacement of solar water pumps are 2-4 times lesser than diesel pumps (Robert, Ghassemi et al. 2009).

Keeping in view the rare availability of grid electricity in rural and remote areas, deficit of electricity and high fossil fuel cost severely affect the irrigation activities resulting in low crop production. Hence, the utilization of solar energy for pumping and irrigation purpose is emerging technology and can also serve as the best the alternative to fossil fuel powered pumping system. The solar energy can be used for irrigation in two ways; thermodynamic method like solar thermal energy based systems and photovoltaic (PV) based systems. SPVWP is based on PV technology that converts solar energy into electrical energy to run a DC or AC motor based water pump. In recent years, SPVWP have gained enormously in acceptance, reliability and performance due to rare availability of electricity in remote and rural areas. Installing of SPVWP at pumping site has many advantages such as it can work in harsh climate including high temperature and cold temperature area (Ghoneim 2006). A properly designed SPVWS can be proven as cost saving in long-term scenario as compared to fossil fuel powered pumping systems.

Solar thermal energy based water pumps are also developing in same pace along with PV technology based water pumps. STEWPs are based on the principle of thermodynamics where incoming solar radiation is collected through solar concentrators to heat the working fluid at high temperature and pressure. And then high pressure fluid can be used in two ways to drive conventional or unconventional pumps; first, Rankine or Brayton cycle and second, Stirling cycle where solar energy is converted to mechanical energy. The reliability and performance of STEWPs may be enhanced by using thermal energy storage methods (Bataineh 2016).

Apart from above discussed methods, these days the use of seawater for irrigation purposes is also gaining popularity due to shortage of freshwater for drinking and other purposes. The seawater covers approximately 75% of earth area so it is an inexhaustible and most sustainable water source. In natural state, seawater is unsuitable to use for irrigation and human consumption due to presence of salinity. Therefore, to address the issue of shortage of freshwater, it needs to be desalinated using promising desalination techniques such as vapor compression (VC), reverse osmosis (RO), multistage flash desalination (MSF), electro-dialysis (ED) or membrane distillation (MD) (Qiblawey and Banat 2008). The desalination facilities consume huge amount of energy, hence, the large scale solar based desalination process can make these facilities more viable (Palenzuela, Alarcón-Padilla et al. 2015).

SOLAR PHOTOVOLTAIC WATER PUMPING SYSTEMS (SPVWP)

The SPVWPs are photovoltaic based technologies which convert sun energy into electric energy and then this electric energy is used to drive AC or DC motors which convert electric energy into mechanical energy. Pumps used in motors converts this mechanical energy into hydraulic energy to lift water.

A direct coupled SPVWP is shown in Fig. 1 consists of PV array as power source, storage tank to store water for 24 hours working of the system, maximum power point tracking (MPPT) system to extract the maximum power from the PV array and a DC surface mounted/submersible/floating motor pump set. The mounting structure of PV array can be fixed or sun tracking which is dependent on the consumer requirement and cost. To operate the pump set in day, night and cloudy condition either battery can be used for electricity storage or water tank to store water. The pump set and components used in the SPVWP system must be compliance with national or international standards (Chandel, Naik et al. 2015).

In late 1970, direct coupled SPVWP system was first introduced and till then it has seen considerable improvement in its reliability and performance. Initially, it was costly due to high cost of SPV panels but the steady fall in prices of SPV panels made this system economically viable. Direct coupled SPV water pumps are very simple and reliable because PV array generates only DC power which is directly connected to DC motor pump set (Kou, Klein et al. 1998). The electronic systems are being used in the current SPVWP systems which have further enhanced the performance, efficiency and output power of the system. The electronic controller used in the system; can automatically adjust the flow rate of pump, can extract maximum power using MPPT , can monitor the water

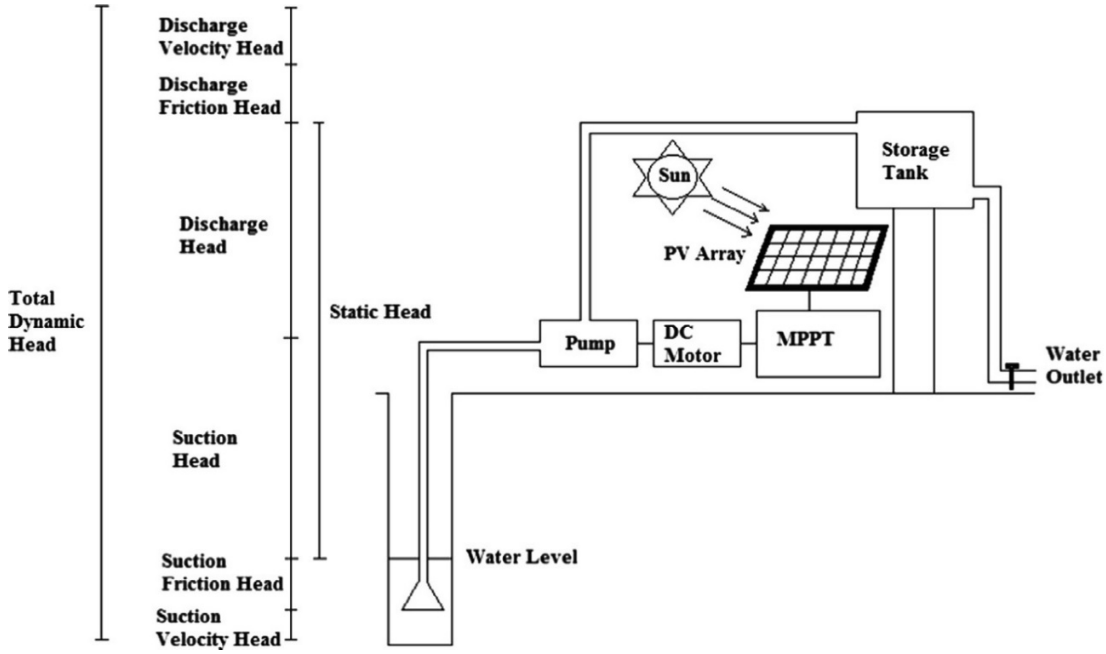


Fig. 1: Schematic of a direct coupled solar photovoltaic water pumping system with MPPT (Chandel, Naik et al. 2015).

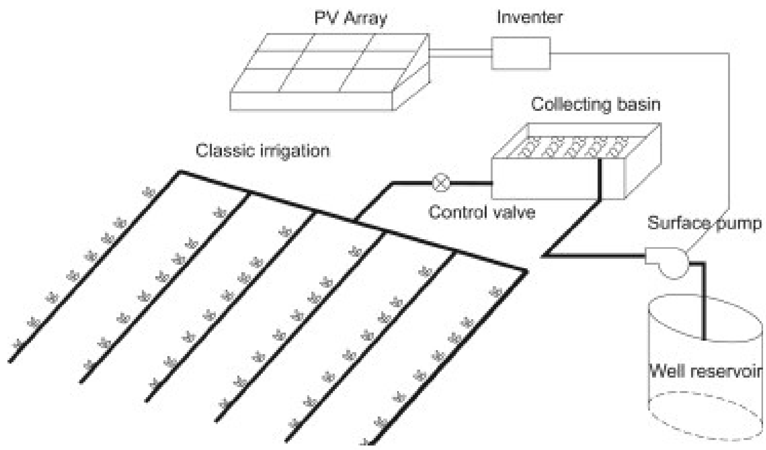


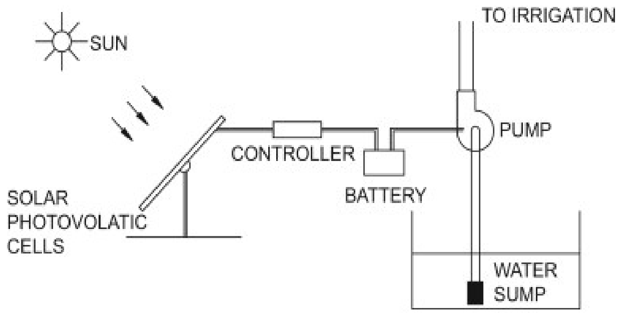
Fig. 2: Schematic layout of photovoltaic irrigation system (Gopal, Mohanraj et al. 2013).

input to water storage tanks using level indicator. The system can also employ sun tracking systems based on single axis tracking or dual axis tracking to increase the power yield and overall efficiency. The tracking system also reduces the size of PV array area and extends the time for peak water pumping.

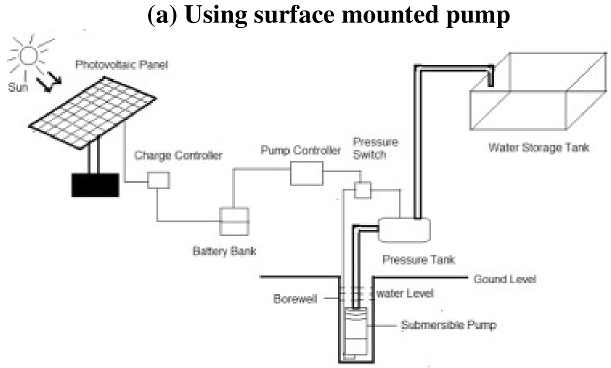
The SPVWPs are used for irrigation purposes are shown in Fig. 2. The number of PV panels is connected in series to form a PV array which supply power to AC motor through inverter. The surface pump is used to lift the water from reservoirs and stored in collecting basin for 24 hours operation. Water supplied from collecting basin to agricultural land for crop irrigation whenever it is required (Gopal, Mohanraj et al. 2013).

Types of Solar PV based water pumps

SPVWPs are of two types; battery-coupled surface-mounted/submersible pump and direct-coupled surface-mounted/submersible pump. The battery-coupled surface mounted and submersible pumps are shown in Fig. 3. The components used in the battery-coupled SPVWPs are PV array, charge controller, batteries, pump controller, pressure switch, storage tank and AC/ DC water pump (For AC water pump, inverter must be incorporated in the components list). The converted electrical energy by PV panel is stored in batteries during day time or clear sunny days and then supplies power to the water pumps whenever it is needed for irrigation. The use of batteries in the solar pumps can enhance operational hours because it can also work in low radiation condition (Sontake and Kalamkar 2016). However, it increase the system complexity, cost and can also decrease overall efficiency of the system as it supplies the lower voltage than PV array at maximum light condition i.e. one to four volts lower.



(a) Using surface mounted pump



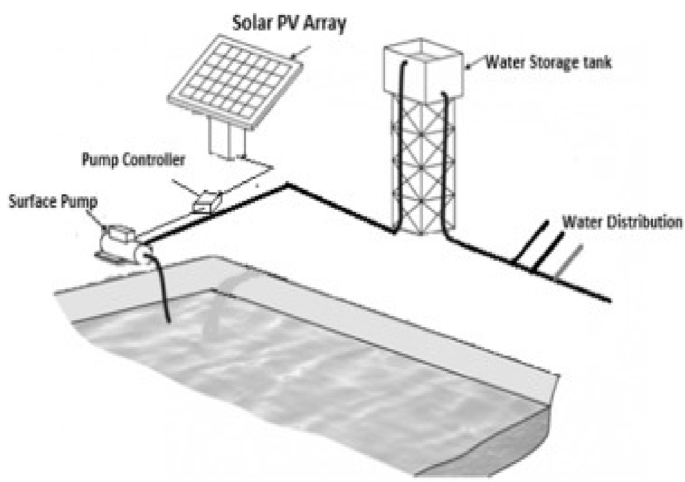
(b) Using submersible pump

Fig. 3: Battery based SPVWP systems (Gopal, Mohanraj et al. 2013, Sontake and Kalamkar 2016)

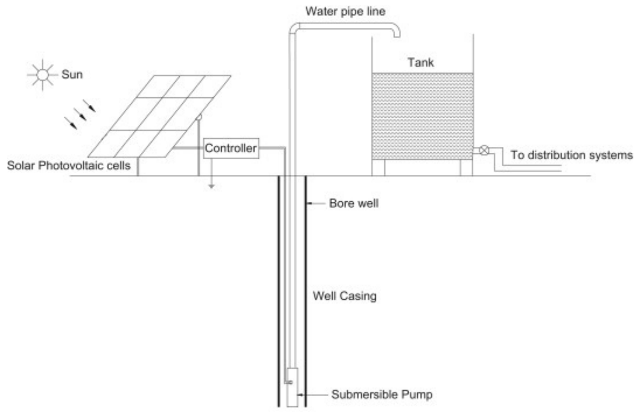
Battery-coupled SPVWPs can work with both surface mounted and submersible water pumps. The DC/AC motor pump are placed near the water surface are the examples of surface mounted water pumps and generally used to lift the moving water such as canals, rivers etc. To lift water to long distances or to high elevations, these pump sets can be developed for high heads. But the main disadvantage of this type of water pump is its suction limitations when used in deep wells. The suction ability of surface mounted water pumps is ranging between 3 and 6 m (Sontake and Kalamkar 2016). The higher cost of installation, mechanical problem due to dynamics of lifting water, burning of motor because of water leakage and cavitation are common drawbacks of surface mounted water pumps.

Submersible pumps are also called as deep well (ground motors) pumps which are designed to operate beneath the earth surface. The submersible pumps do not work in open air condition until these are immersed in water. These pumps are designed to push the water to ground surface unlike the surface mounted pumps which sucks the water out of the ground. The hermetically sealed motor is used which is closely coupled to body of the pump and the typical size of submersible pump is 0.6-1.2 m long and 7-12 mm in diameter. These pump sets are easy to install due to flexible pipe work. As submersible pumps are completely submerged in water so these are less affected by climate and potential damage. At present, submersible pumps based on SPV technology have an overall efficiency of 40-70%.

Direct driven SPV water pumps are simple in design and low in cost because they do not use battery. Therefore, the amount of water pumped is depending on the amount of radiation falling on the PV array during the entire day. As there is no power storage system, the system can work only daytime and unable to operate during cloudy or low light conditions. The direct driven SPV water pumps can work during night and cloudy conditions if large storage tank is constructed to collect water and then can be used when needed. The direct driven SPVWPs can be used for both surface mounted and submersible pumps, as shown in Fig. 4.



(a) Using surface mounted pump



(b) Using submersible pump

Fig. 4: Direct coupled SPVWP systems (Bakelli, Arab et al. 2011, Sontake and Kalamkar 2016)

SOLAR PV BASED GREENHOUSE

Greenhouse systems (also known as poly houses) are built to improve the crop production and quality by maintaining the microclimate inside it. The environment control inside the greenhouse such as temperature, relative humidity, CO_2concentration, ventilation, and growth factor etc. are electricity consuming process which can affect the profit and loss of greenhouse crop production (Chen, Xu et al. 2015). On the other hand, greenhouse requires desired amount of sunlight to produce high crop yield using photosynthesis process. Therefore, to meet the both electricity and sunlight demand of greenhouse systems, semitransparent PV panels can be effectively used.

Organic photovoltaics (OPVs) have drawn great attraction due to its unique properties like transparency, flexibility, light weight and low cost which makes it best possible option for greenhouse systems (Bailey-Salzman, Rand et al. 2006, Cao, Li et al. 2014, Kang, Noh et al. 2014). The OPV has maintained the good compromise between electricity production and light transmissivity in greenhouse systems because they usually block the portion of sunlight and pass the remaining sunlight inside the greenhouse area to maintain the uniformity of light distribution for photosynthesis process (Cossu, Yano et al. 2016). The electricity generated by PV array can be used to maintain the microclimate and irrigation of the plants inside the greenhouse system. The SPV based greenhouse system is shown in Fig. 5 consist of greenhouse system for plants, four pyranometers viz. P_1,P_2,P_3, and P_4 to record global and beam radiations and blue color semitransparent OPV panel to generate electricity.

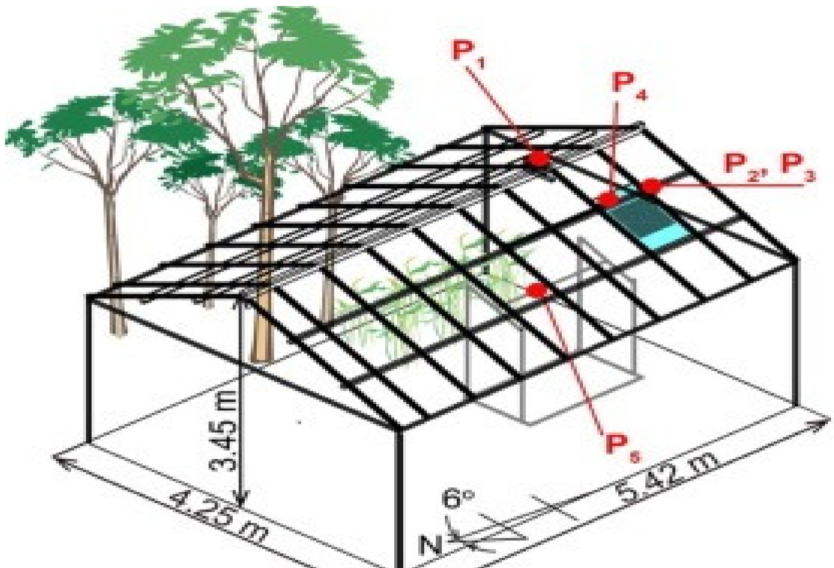


Fig. 5: Semi-transparent PV based greenhouse (Cossu, Yano et al. 2016).

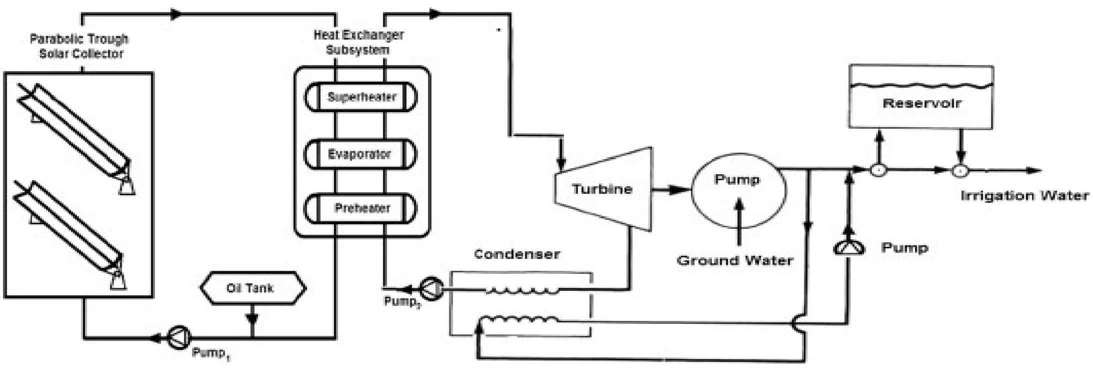


Fig. 6: Parabolic trough collector based STEWP (Batainen 2016).

SOLAR THERMAL ENERGY BASED WATER PUMP

The basic configuration of STEWPs is shown in Fig. 6 works on the principle of thermodynamics which is based on rankine cycle and mainly feasible for large scale irrigation systems. The STEWP system consists of parabolic trough concentrator, heat exchangers, cooling system, power systems and reservoir.

The parabolic collectors are the combination of trough collectors connected in series. The receiver and concentrator are the two components of collectors. The concentrator focuses the collected solar radiation on receiver (made of a stainless steel tube covered by a glass envelope to decrease convection and radiation heat loss to the surroundings) to heat the heat transfer fluid. The heat transfer fluid is circulating in closed loop through the heat exchanger where a transfer fluid transfers its heat to another fluid which is called as working fluid. The working fluid is contained in another closed loop to drive the turbine and power systems which further runs the irrigation pumps. The heat exchanger used in the system comprises of a preheater, an evaporator and an over heater, through which superheated steam under pressure is generated. The expanding gas drives a turbine which can be coupled directly to a water pump or to an electric generator for powering the pump. The gas is then condensed and returned to the heat exchanger to complete the cycle (Bataineh 2016).

Solar powered stirling engine based water pumps

The parabolic dish type concentrator is used to drive the stirling engine which converts the heat energy of sun into mechanical energy. The hot end of stirling engine is completely sealed by glass covering so that heat trapped inside the medium and won't be able to escape out. When the dish type concentrator focuses the sun energy on the hot end of engine, the temperature will rise inside the medium which further give the initial momentum to the flywheel of stirling engine. The power piston of engine transferred its force to flywheel for the rotation of flywheel. The shaft of flywheel is connected to vane of centrifugal pump due to which flywheel transferred its rotary motion to centrifugal pumps. The schematic of solar powered stirling engine based water pump is shown Fig. 7 (Saini, Kohli et al.).

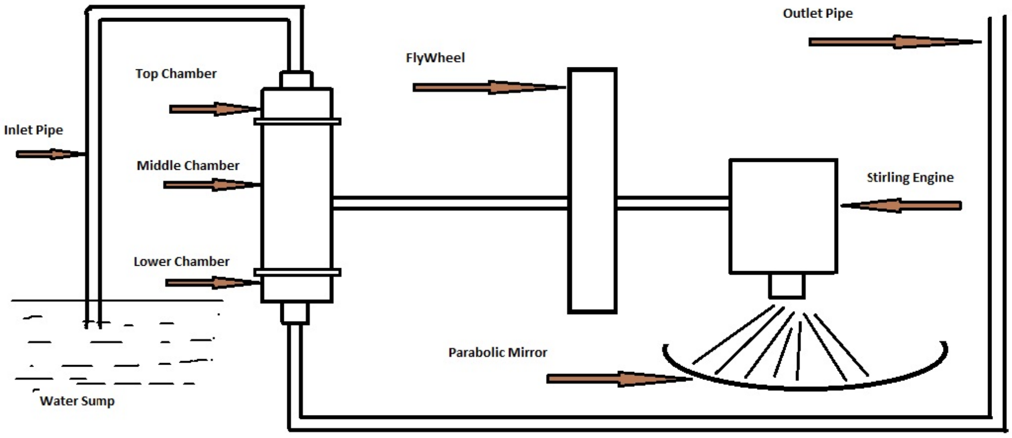


Fig. 7: Solar powered stirling engine based water pumps (Saini, Kohli et al.)

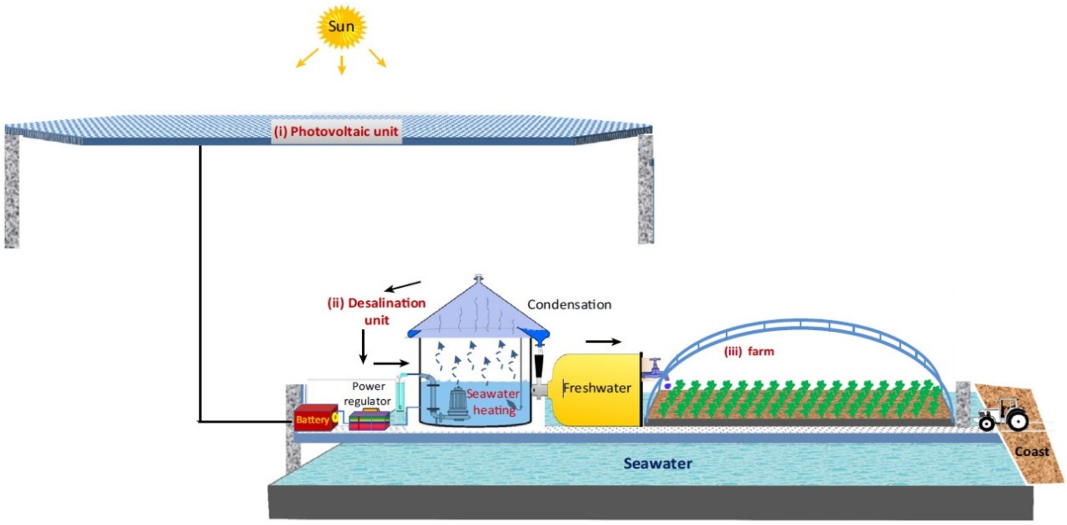


Fig. 8: Schematic of solar powered desalination system for irrigation (Moustafa 2016).

SPV BASED DESALINATION

Nowadays, the shortage of freshwater is a major concern due to rapid growing of world population. Globally, the freshwater is being used for agriculture holds the 70% share of total consumption and about 80% in India (Jones, Odeh et al. 2016). Therefore, the availability of freshwater can be increased by desalination of brackish water in water scarce areas such as south Indian states. The desalination of brackish water for agriculture use has drawn significant attention after the integration of solar energy with desalination techniques. The basic schematic of solar powered desalination technique for irrigation is shown in Fig. 8 (Moustafa 2016).

Apart from brackish seawater, plenty of salty groundwater exists around the world. In India, the existence of brackish ground water is around 60 % of its area and much of that area does not have access to grid electricity (Wright, Van de Zande et al. 2015). Consequently, it is very difficult to run the conventional reverse osmosis (RO) desalination plants due to lack of electricity. A number of desalination techniques are available such as multi-stage flash, multiple-effect distillation, reverse osmosis (RO), vapor compression, electrodialysis (ED) etc. (Ettouney, El-Dessouky et al. 2002). As of now, solar powered RO is the most widely used desalination technology in agriculture, but the problem associated with this technology is the smooth integration of PV array. RO generally operated at constant flow rate and pressure, hence, it require constant power supply. The intermittent nature of solar cannot meet this demand, consequently, large battery banks required for smooth operation of solar powered RO desalination technology (Mohamed, Papadakis et al. 2008, Jones, Odeh et al. 2016).

Recently the study conducted by Massachusetts Institute of Technology (MIT) researchers for the feasibility analysis of desalination technology in rural areas of India. The study was funded by of Jain irrigation system (Indian Company) and sponsored by Tata Center for Technology and Design at MIT. They found that solar powered ED desalination technology could be a best possible option in rural area of India (Wright, Van de Zande et al. 2015).

In electro dialysis, when steam of brackish water is passed through the center of two opposite charge electrodes, then the salt dissolved in brackish water which contains the positive and negative ions are pulled out of the water by these two electrodes and leave the freshwater at the output. The diagram of ED is shown in Fig. 9 and it is capable to recover the higher percentage of freshwater i.e. more than 90% compared to RO technique which is able to recover only 40 to 60%.

SIZING OF SOLAR PANELS FOR WATER PUMPS

In order to design and size a solar based water pumping system, following should be known;

- The amount of water requirement.
- Timing of water supply.
- Knowledge about water source, it may be pond, lake, rivers canals etc.
- The distance of water to be pumped.
- The availability of water in gallon per minute (gpm).
- Depth of well/ground water table.
- The elevation of water to be pumped.
- The quality of water (high silt and minerals contents in water can damage pumps).
- The volume of storage tank, if applicable.

The sizing of solar pumps can be calculated as follows (Practical Action; Technology challenging poverty)

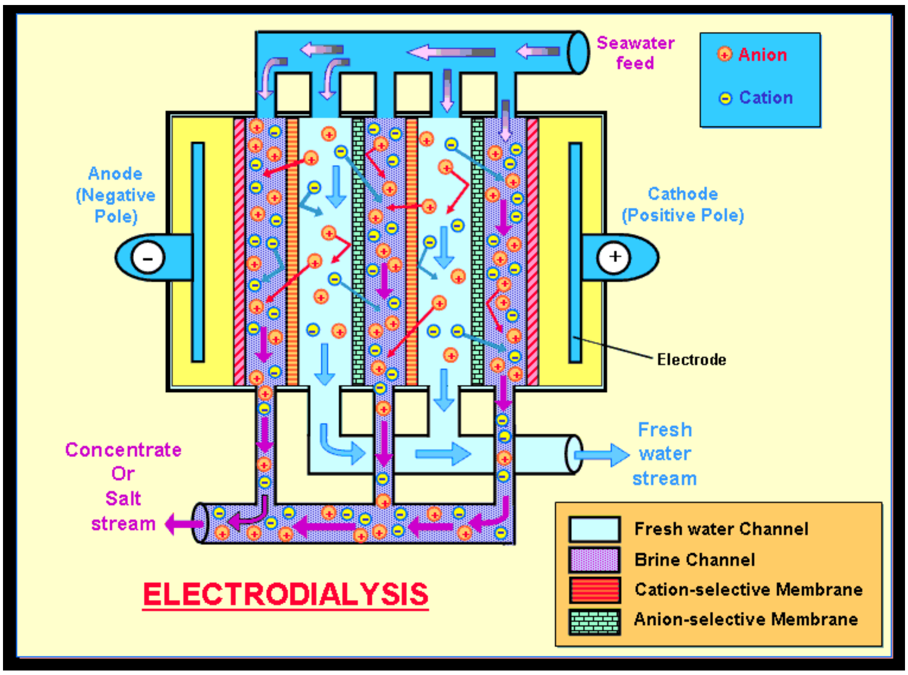


Fig. 9: The electrodialysis desalination technology (Tautai Foundation 2015).

$$\text{The required hydraulic energy } \left(\frac{\text{kWh}}{\text{day}}\right)$$
$$= \text{ volume required } \left(\frac{\text{m}^3}{\text{day}}\right) * \text{ head (m)} * \text{ water density } * \frac{\text{gravity}}{3.6 \text{ x } 106}$$
$$= 0.002725 \ * \text{volume } \left(\frac{\text{m}^3}{\text{day}}\right) * \text{head (m)}$$

$$\text{The required size of PV array (kWp)} = \frac{\text{The required hydraulic energy (kWh/day)}}{\text{Average daily solar irradiation } \left(\frac{\text{kWh}}{\text{m}^2 * \text{day}} * \text{F} * \text{ E}\right)}$$

Where F is array mismatch factor = 0.85 on average;

E is daily subsystem efficiency = ranging from 0.25 to 0.40 typically.

PROMOTIONAL SCHEME FOR SPV BASED WATER PUMPING SYSTEMS

The Ministry of New and Renewable energy (MNRE), Government of India (GoI) offers a capital support to promote the SPV based water pumping systems for irrigation. Subsidy is provided for setting a new solar based pumping unit. National Bank for Agriculture and Rural Development (NABARD), a nodal financial institution of Reserve Bank of India, channelizes the financial process to provide subsidy. The MNRE capital subsidy for solar photovoltaic water pumping systems is available as given in Table 1.

The target of this scheme is to setup a 30000 SPV based pumping units per year in whole country (NABARD 2014). The SPV based water pumps of capacity up to 10 HP are only eligible to receive subsidy under this scheme. MNRE also recommended qualification standards for SPV based pumping units that must be qualified by solar pumping units, are given in Table 2 and Table 3.

CONCLUSIONS

As the human activities, urbanization and economic development continue to grow, the food and freshwater requirement are also required in same pace. Consequently, energy requirement for agriculture activities will also grow. To meet this energy demand with fossil fuel sources in near future become difficult because fossil sources are rapidly depleting and also polluting the environment. Therefore, use of renewable energy technology like solar energy which abundantly available on the earth, can meet this demand. In this article, various methods are described to harness the solar energy for irrigation. SPVWPs are most widely used method for irrigation in rural areas as compared to STEWPs. The reason for widespread use of SPVWPs having easy installation, low cost and simple in operation is recommended. Further new concepts are also evolving like SPV based greenhouses and desalination techniques for sustainable agriculture activities in near future.

Table 1: MNRE Capital subsidy for solar photovoltaic water pumping systems for irrigation

Sr	SPV System	Capacity	Maximum subsidy (Per HP)
1	DC Pumps	Upto 2 HP	57600
		>2 HP to 5 HP	54000
2	AC Pumps	Upto 2 HP	50400
		>2 HP to 5 HP	43200
3.	For pumps >5HP-10 HP, subsidy amount is fixed at Rs.194,400/-per pump		

Table 2: Indicative Technical Specifications of Shallow Well (Surface) Solar Pumping Systems

Description	Model-I	Model-II	Model-III
PV array	900 Wp	1800 Wp	2700 Wp
Motor capacity	1 HP	2 HP	3 HP
Shut Off Dynamic Head	12 m	15 m	25 m
Water Output*	90,000 litres per day from a total head of 10 m	180,000 litres per day from a total head of 10 m	148,000 litres per day from a total head of 20 m

"Average Daily Solar Radiation" condition of 7.15 KWh/ sq.m. on the surface of PV array.

Table 3: Indicative Technical Specifications of Solar Deep well (submersible) Pumping Systems

Description	Model I	Model II	Model III	Model IV
PV array	1200 Wp	1800 Wp	3000 Wp	4800 Wp
Motor pump set type	Submersible with electronic controller	Submersible with electronic controller	Submersible with electronic controller	Submersible with electronic controller
Max. total dynamic head	45 m	45 m	70 m	70 m
Water Output*	42,000 Litres per day from a total head of 30 mtrs	63,000 litres per day from a total head of 30 mtrs	63,000 litres per day from a total head of 50 mtrs	1,00,000 litres per day from a total head of 50 mtrs

"Average Daily Solar Radiation" condition of 7.15 KWh/ sq.m. on the surface of PV array .

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