Review/Derleme

www.ziraatdergi.akdeniz.edu.tr

AKDENİZ ÜNİVERSİTESİ
ZİRAAT FAKÜLTESİ DERGİSİ
(2011) 24(2): 115-123

Photovoltaic water pumping systems: A study on PV water pumping system installation

Güneş Pili (PV) pompalama sistemleri: PV su pompalama sistem kurulumu üzerine bir çalışma

Nuri CAGLAYAN, Can ERTEKIN

Akdeniz University Faculty of Agriculture Department of Farm Machinery 07070 Antalya, Turkey

Corresponding author (*Sorumlu yazar*): C. Ertekin, e-mail *(e-posta)*: ertekin@akdeniz.edu.tr

ARTICLE INFO

Received 6 December 2010
Received in revised form 6 October 2011
Accepted 10October 2011

Keywords:

Solar cell
Photovoltaic energy
Solar water pumping systems

ABSTRACT

Renewable energy sources have been important for humans since the beginning of civilization. The technologies of this energy offer the promise of clean and abundant energy garnered from self-renewing resources such as the sun and wind. One of these energy sources is photovoltaic energy. There is an increasing demand for solar cells that convert sun light into electricity in both agricultural applications and daily life. Photovoltaic energy can have many applications in agriculture, providing electrical energy in various cases, particularly in areas without an electric grid. With the increased use of solar water pumping systems, more attention has been paid to their design and optimum utilization in order to achieve the most reliable and economical operation. In this study, photovoltaic technology was discussed and various suggestions have been made for the calculations in the design and use of the PV water pumping systems for agricultural irrigation.

MAKALE BİLGİSİ

Alınış tarihi 6 Aralık 2010
Düzeltilme tarihi 6 Ekim 2011
Kabul tarihi 10 Ekim 2011

Anahtar Kelimeler:

Güneş pili
Güneş pili enerjisi
PV enerjili su pompalama sistemleri

ÖZ

Yenilenebilir enerji kaynakları insanlar için medeniyetin başlangıcından beri önemli bir yer tutmuştur. Öte yandan, yenilenebilir enerji teknolojileri güneş, rüzgâr gibi temiz ve bol bulunan kaynaklardan enerji elde etmeyi amaçlamaktadır. Bu enerji kaynaklarından biri de güneş pili enerjisidir. Güneş ışığını kullanarak elektrik enerjisi üreten güneş pillerine talep, hem tarımsal üretimin birçok uygulamasında, hem de günlük yasamda gün geçtikçe artmaktadır. Güneş pili enerjisi özellikle elektrik şebekesinin olmadığı kırsal alanlarda elektrik enerjisi sağlamak amacıyla kendine pek çok uygulama alanı bulabilmektedir. Kullanımı gün geçtikçe artan güneş enerjili su pompalama sistemlerinden en uygun ve ekonomik şekilde yararlanmak için sistem tasarımına dikkat edilmelidir. Bu çalışmada, güneş pili teknolojisi tartışılmış, tarımsal sulama için güneş enerjili su pompalama sistemlerinin kullanım ve tasarım hesaplamalarına yönelik çeşitli öneriler verilmiştir.

1. Introduction

The renewable energy systems have been included in the energy research programs and in the energy policies of the governments. The cleanness of an energy source became an important parameter in energy programs especially in developed countries and the contribution of renewable energy systems such as solar, wind and geothermal relatively increased. The developing countries are also including more of renewable energy systems in their energy programs for a sustainable economic growth. Solar energy presents substantial potentials to provide a significant portion of future energy needs of Turkey. The highest and lowest solar energy potential of Turkey is in the Southeast Anatolian region with an average solar radiation of 14.37 MJ m^{-2} d^{-1} and sunshine duration of 8.2 h d^{-1} and in the Black Sea region with an average solar radiation of 11.02 MJ m^{-2} d^{-1} and sunshine duration of 5.4 h d^{-1}, respectively (Ertekin et al. 2008). Turkey has an average annual sunshine duration of 2640 h and an average solar intensity of 3.6 kWh m^{-2} day^{-1} given in Table 1 (EIE 2010). Residential and commercial sectors, especially in the southern and western regions had an installed flat plate collectors of 750 ha in 2001 for solar heating. Use of solar energy is expected to increase sevenfold from its 1999 value of 0.11 Mtoe by 2020 (Evrendilek and Ertekin 2003).

Turkey is going through a change of policy in the energy sector, adopting a policy of privatisation of some of the state-owned energy companies. On the other hand, Turkey needs adaptations in the energy field for meeting the European standards as Turkey is seeking a full membership to the

Table1. Monthly solar energy potential of Turkey (General Directorate of EIE 2010).

Months	Monthly Total (kcal cm^{-2} $month^{-1}$)	Solar Energy (kWh m^{-2} $month^{-1}$)	Sunshine Duration (hours $month^{-1}$)
January	4.45	51.75	103.0
February	5.44	63.27	115.0
March	8.31	96.65	165.0
April	10.51	122.23	197.0
May	13.23	153.86	273.0
June	14.51	168.75	325.0
July	15.08	175.38	365.0
August	13.62	158.40	343.0
September	10.60	123.28	280.0
October	7.73	89.90	214.0
November	5.23	60.82	157.0
December	4.03	46.87	103.0
Total	112.74	1311.16	2640.0
Average	9.40	109.26	320.0

European Union (EU). Due to the limited primary energy resources, the rate of primary energy production to consumption is noticeably decreasing in Turkey. The current rate of Turkey's primary energy production to consumption of 35% is expected to decrease to 30% in 2010 and 26% in 2020 (Sinton et al. 2002). This requires more energy to be imported in the form of either electricity or primary energy source, such as oil or natural gas in the near future. In order to limit the energy to be imported, the contribution of renewable energy resources in the total electric generating capacity has to be increased. Especially wind and solar may compensate for the declining rate of primary energy resources. The renewable energy contribution to this installed electricity capacity was negligible with a total installed capacity of 0.04 MW. The total installed photovoltaic power capacity in Turkey is estimated around 2 MW, which should be increased in a near future, together with other renewable energy systems (Celik 2006).

Photovoltaic cells produce electricity when sunlight excites electrons in the cells. The most promising photovoltaic cells in terms of cost, mass production and efficiency are those manufactured using silicon. However, the durability of photovoltaic cells should be lengthened, and production costs should be reduced several times to make their use economically competitive before their use can become widespread. Photovoltaic cells with about 18% efficiency can be used to produce 1 billion kWh yr^{-1} of electricity on approximately 2800 ha of land, which is sufficient to supply the electrical energyneeds of 100 000 people. The energy input for making a photovoltaic system capable of delivering 1 billion kWh during a life of 30 years is calculated to be approximately 143 million kWh (Evrendilek and Ertekin 2003). Most commercial PV cells are made from silicon, and come in three general types: monocrystalline, multicrystalline, and amorphous (Figure 1).

Monocrystalline cells are made using silicon wafers cut from a single, cylindrical crystal of silicon. This type of PV cell is the most efficient, with approximately 15% efficiency, but is also one of the most expensive to produce. Multicrystalline cells are less expensive to produce than monocrystalline ones, due to the simpler manufacturing process and lower purity requirements for the starting material. However, they are slightly less efficient, with average efficiencies of around 12%. Amorphous silicon PV cells are made from a thin layer of monocrystalline silicon placed on a rigid or flexible substrate. They are relatively easy to manufacture and are less expensive than monocrystalline and polycrystalline PV, but are less efficient with efficiencies of around 6%. Their low cost makes them the best choice where high efficiency and space are not important. A solar tracker may be used to tilt the PV arrays as the sun moves across the sky. This increases daily energy gain by as much as 35% (Sinton et al. 2002).

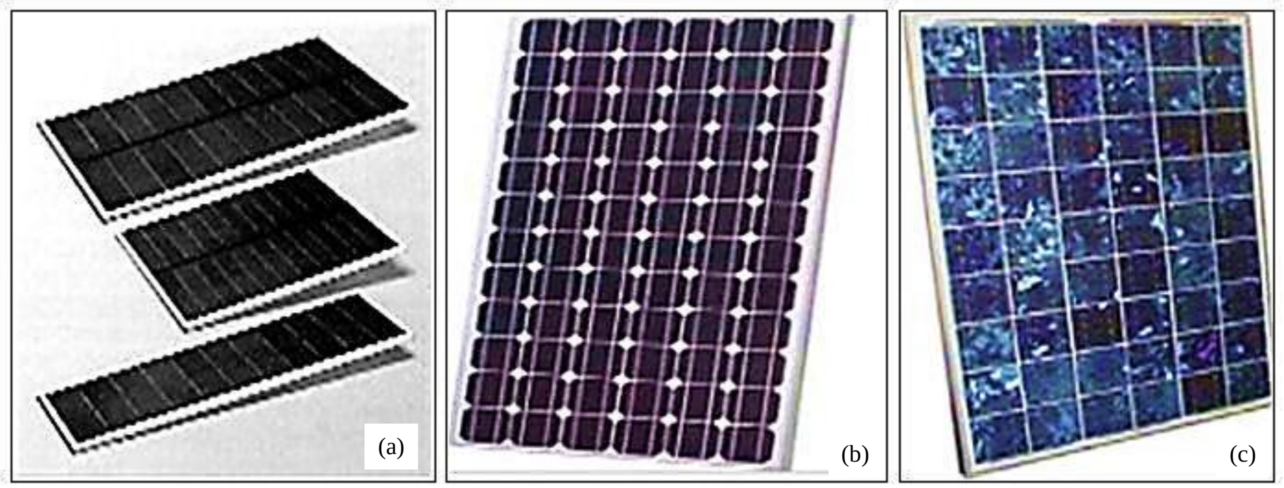

Figure1. Types of PV modules: a) Amorphous, b) Monocrystalline, c) Polycrystalline (Evoenergy 2010).

2. Solar Water Pumps

PV water pumping systems are used principally for four applications:

- Off-grid homes and cabins,
- Livestock watering (pond and stream protection),
- Aquaculture (aeration, circulation, and de-icing),
- Irrigation (best for small scale applications).

Solar water pumps are specially designed to utilize DC electric power from photovoltaic panels. They must work during low light conditions at reduced power, without stalling or overheating. Low volume pumps use positive displacement (volumetric) mechanisms which seal water in cavities and force it upward. Lift capacity is maintained even while pumping slowly. These mechanisms include diaphragm, vane and piston pumps. These differ from a conventional centrifugal pump that needs to spin fast to work efficiently. Many designers of solar water pumps took the approach of using positive displacement pumps, which bring water into a chamber and then force it out using a piston or helical screw. These types generally pump more slowly than other types of pumps, but have good performance under low power conditions and can achieve high lift (Lorentz 2010). A submersible pump remains underwater such as in a well Figure 2a,a surface pump (Figure 2b) is mounted at water level either adjacent to the water source or in the case of a floating pump (Figure 2c) on top of the water.

Surface pumps are less expensive than submersible pumps, but they are not well suited for suction and can only draw water from about 6 vertical meters. Surface pumps are excellent for pushing water long distances. A centrifugal pump has a series of stacked impellers and chambers. When operating at low power, the amount of water pumped by centrifugal pumps drops dramatically. This makes centrifugal pumps somewhat limited in solar applications, though efficient centrifugal pumps are available. Centrifugal pumps are used where higher volumes are required. A pump controller (current booster) is an electronic device used with most PV water pumping systems. It acts like an automatic transmission, helping the pump to start and not to stall in weak sunlight. The smallest PV water pumping systems require less than 150 W and can pump at 0.007 m^3per minute. Over ten sunny hours in August, such a system can pump up to 4.2 m^3. For example, one brand of submersible pump with 300 W of PV, can produce over 5 m^3 per day from a 45 meters deep drilled well. The equivalent 0.75 HP, 240 V_{ac} pump would require 2000 W of PV, an inverter and batteries to do the same amount of work.

There are other options for pumping water in remote applications. These and their advantages and disadvantages are listed in Table 2 (ITDG 2010).

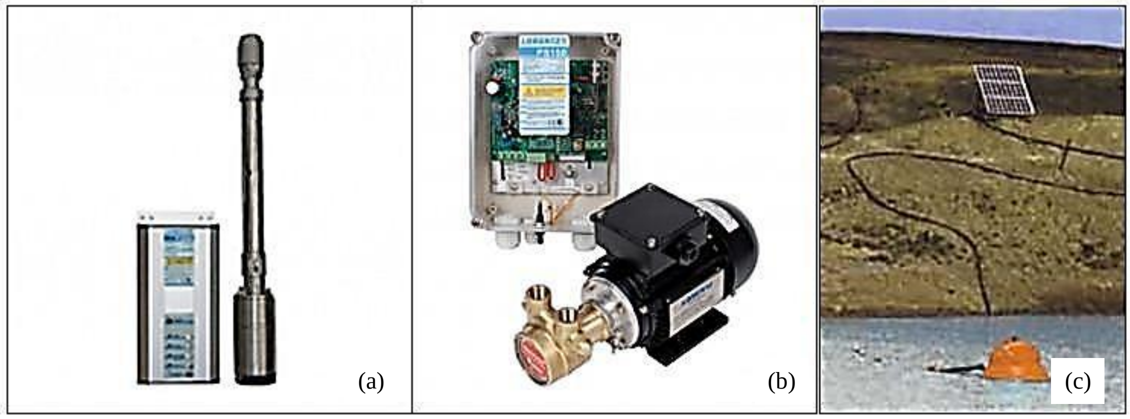

Figure2. Solar water pumps: a) a solar operated submersible pump b) a surface pump c) a floating pump.

Table2. The comparisons between solar and the other remote watering systems.

Pump Type	Advantages	Disadvantages
PV water pumping systems	• Low maintenance • No fuel costs or spills • Easy to install • Simple and reliable • Unattended operation • System can be made to be mobile	• High capital costs • Water storage is required forcloudy periods • Repairs often require skilled technicians
Diesel (or gas) power pump	• Moderate capital costs • Can be portable • Extensive experience available • Easy to install	• Fuel supplies erratic and expensive • High maintenance costs • Short life expectancy • Noise and fume pollution
Windmill pump	• Potentially long-lasting • Works well in windy site	• Water storage is required for low wind periods • High system design and project planning needs • Not easy to install
Hydraulic pump (e.g. rams)	• Unattended operation • Easy to maintain • Low cost • Long life • High reliability	• Require specific site conditions • Low output

2.1. Solar-powered water pumping system configurations

There are two basic types of solar-powered water pumping systems, battery-coupled and direct- coupled. A variety of factors must be considered in determining the optimum system for a particular application.

Battery-coupled water pumping systems consist of PV panels, charge control regulator, batteries, pump controller, pressure switch and tank and DC water pump (Figure 3). The electric current produced by PV panels during daylight hours charges the batteries and the batteries in turn supply power to the pump anytime water is needed. The use of batteries spreads the pumping over a longer period of time by providing a steady operating voltage to the DC motor of the pump. Thus, during the night and low light periods, the system can still deliver a constant source of water for livestock. The most common batteries used in stand-alone PV systems are lead-acid batteries and nickel cadmium (Ni-Cd) plates.

The use of batteries has its drawbacks. First, batteries can reduce the efficiency of the overall system because the operating voltage is dictated by the batteries and not the PV panels. Depending on their temperature and how well the batteries are charged, the voltage supplied by the batteries can be one to four volts lower than the voltage produced by the panels during maximum sunlight conditions. This reduced efficiency can be minimized with the use of an appropriate pump controller that boosts the battery voltage supplied to the pump.

In direct-coupled pumping systems, electricity from the PV modules is sent directly to the pump, which in turn pumps water through a pipe to where it is needed. This system is designed to pump water only during the day.

The amount of water pumped is totally dependent on the amount of sunlight hitting the PV panels and the type of pump. Because the intensity of the sun and the angle at which it strikes the PV panel changes throughout the day, the amount of water pumped by this system also changes throughout the day. For instance, during optimum sunlight periods (late morning to late afternoon on bright sunny days) the pump operates at or near 100% efficiency with maximum water flow. However, during early morning and late afternoon, pump efficiency may drop byas much as 25% or more under these low-light conditions. During cloudy days, pump efficiency will drop off even more. To compensate for these variable flow rates, a good match between the pump and PV module(s) is necessary to achieve efficient operation of the system.

Direct-coupled pumping systems are sized to store extra water on sunny days so it is available on cloudy days and at night. Water can be stored in a larger-than-needed watering tank or in a separate storage tank and then gravity-fed to smaller watering tanks. Water storage capacity is important in these pumping systems. Two to five days’ storage may be required, depending on climate and pattern of water usage. Storing water in tanks has its drawbacks. Considerable evaporation losses can occur if the water is stored in open tanks, while closed tanks big enough to store several days water supply can be expensive.

Also, water in the storage tank may freeze during cold weather (Figure 4).

2.2. Sizing PV water pumping system

Hydraulic energy required (*HER*) (kWh day^{-1}):

$$HER = \frac{VH\gamma g}{3.6 \times 10^{6}} \quad \text{(Equation 1)}$$

where *V* volume required (m^{3} day^{-1}); *H* the head (m); γ the water density (1000 kg m^{-3}) and *g* is the gravity (9.81 m s^{-2}).

$$HER = 0.002725VH \quad \text{(Equation 2)}$$

The solar array power required (*SAPR*) (kWp):

$$SAPR = \frac{HER}{(ASI)FE} \quad \text{(Equation 3)}$$

where *ASI* average daily solar irradiation (kWh m^{-2} day^{-1}); *F* the array mismatch factor (0.85 kWp.m^{-2}) on average (a safety factor for real panel performance in hot sun and after 10-20

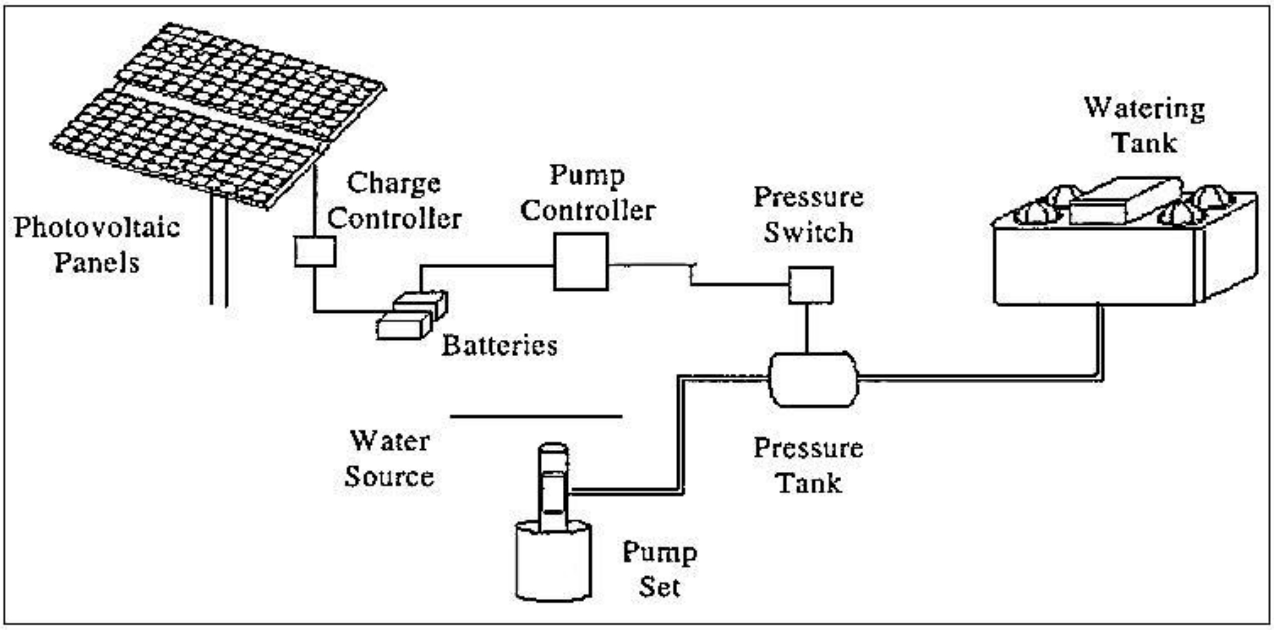

Figure3. Battery-coupled solar water pumping systems (Buschermohle and Burns 1999).

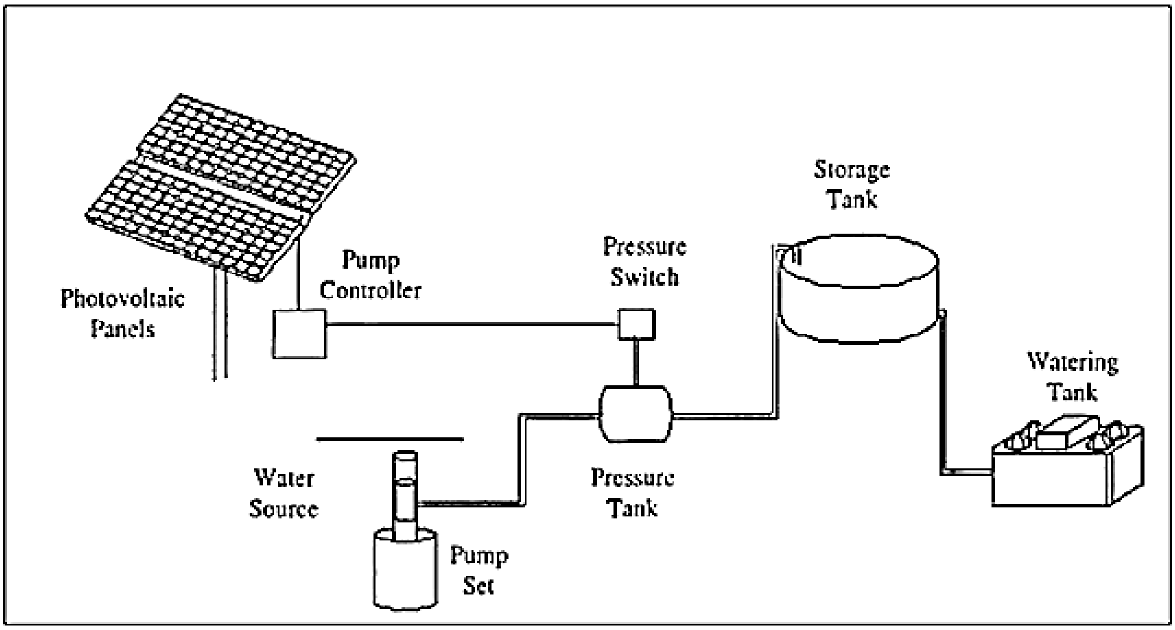

Figure 4. A direct-coupled PV water pumping system (Buschermohle and Burns 1999)

years) and E daily subsystem efficiency 0.20-0.45 typically (ITDG 2010).

3. A Case of study for a PV pumping installation design

The farm consist of two lands pieces, one piece is planted with 550 lemon trees and the daily consumption is 4.5 m^3 in hot seasons. The other piece is ready to be planted with 700 orange trees and the daily consumption is estimated about 5.5 m^3 of water. Daily demand of water is about 8 m^3 for addition usage.

The farm demand in water is estimated about 18 m^3 in summer. The farm has a storage consists of a ground storage tank of 50 m^3 capacity. A simple schematic is shown below (Figure 5) and for the power (P-W) needed to pump water at a volumetric flow ratein m^3 h^{-1} is given by Burkhartzmeyer (2008):

$$P = \vartheta \gamma g H / 3600 \eta_p \qquad \text{(Equation 4)}$$

Where η_p is the pump efficiency (0.45).

The static head H_s is $(A+B)$. In case the water level is drawn down, static head would be $(A+B+C)$. The pump must work against the total head H which includes the dynamic head H_d also,

$$H = H_f + \frac{\vartheta^2}{2g} \qquad \text{(Equation 5)}$$

Where H_f is the frictional head loss in the pipe and υ is the velocity of water at the pipe outlet. The pump efficiency η_p is a function of the load (head and flow rate) and is available as a characteristic curve from the manufacturer. For general design purposes typical values given may be used in Table 3.

The table lists two basic types of pumps, centrifugal and positive displacement (Submersible and Jack pump). Thesepumps can be driven by AC or DC motors. DC motors are preferable for the PV applications, because they can be directly coupled to the PV array output.

Table3. Typical range of pump performance parameters.

Head (m)	Type of Pump	Wire to water efficiency (%)
0-5	Centrifugal	15-25
6-20	Centrifugal with Jet	10-20
21-100	Submersible Submersible	20-30 30-40
>100	Jack pump Jack pump	30-45 35-50

Centrifugal pumps with submersible motors are the optimum for PV applications because of their efficiency, reliability and economy. However, for deep wells Jack pumps are the piston type of positive displacement pumps that move chunks of water with each stroke. They require very large currents therefore they are connected through batteries (Goswami et al. 2000). A PV system is designed to pump water for farm in vicinity of Antalya city. The available information for PV system design is presented in Table 4.

Since required head is very high, a deep well submersible pump with DC motor is needed.Daily required energy (Burkhartzmeyer 2008):

$$P = N \gamma g H / 3600 \eta_p \qquad \text{(Equation 6)}$$

where$P$ is the daily required energy (Wh day^{-1}); N daily needed cumulative water (m^3); H total head (m); η_p the pump efficiency (0.45).

$$P = 18 \text{x} 1000 \text{x} 9.81 \text{x} 35 / 3600 \text{x} 0.45$$

$$P = 3815 \text{ Wh day}^{-1}$$

The system will be used from June to August at a tilt angle of 30°. Values of daily solar radiation at horizontal surface between June and August for Antalya city (EIE 2010);June is 7.17 kWh m^{-2} day^{-1}, July is 7.18 kWh m^{-2} day^{-1} and August is 6.32 kWh m^{-2} day^{-1}.

Table4. The available information for PV system design in Antalya city.

Item	Value
Site	Antalya (36° 07' N 30° 07' E, 57 m)
Ambient Temp	-4°C to 45°C
Average Temp	33.3°C, June to August
Sunshine Duration	8 h day^{-1}
Diameter of the borehole	1.50 m.
Static head	30 m
Maximum Draw-down	5 m
Total head	35 m
Diameter of the water conduction pipe	50 mm (inner diameter)
Capacity of the tank	50 m^3
Daily needed cumulative water	18 m^{3}day^{-1} in August

August has the minimum insulation the panel area will be based on insulation for August. Specifications of PV panels were showed in Table 5. A PV module will be typically rated at 25°C under 1 kW m^{-2}. However, when operating in the field, they typically operate at higher temperatures and at somewhat lower insulation conditions. In order to determine the power output of the solar cell, it is important to determine the expected operating temperature of the PV module. The Nominal Operating Cell Temperature (NOCT) is defined as the temperature reached by open circuited cells in a module under the conditions as irradiance on cell surface (800 W m^{-2}), air temperature (20°C) and wind velocity (1 m s^{-1}).

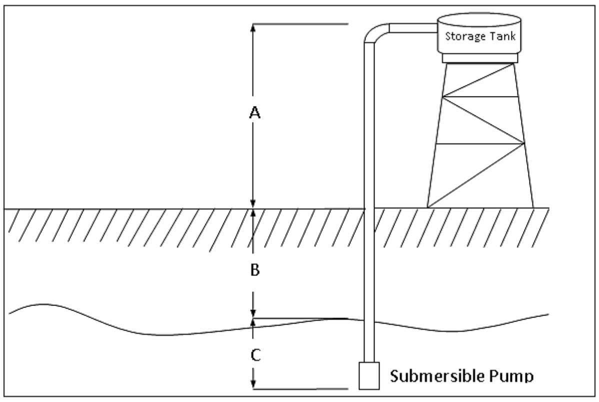

Figure5.A system schematic of a submersible pump.

Table5. Electrical characteristics of PV panels (Lorentz Solar Inc.).

Module	Lorentz LA55-12S
Cell technology	Monocrystalline
Maximum power (P_{max})	55W
Voltage at Pmax (V_{mp})	16.8V
Current at Pmax (I_{mp})	3.3 A
Short-circuit current (I_{sc})	3.7 A
Open-circuit voltage (V_{oc})	20.1 V
Temperature coefficient of V_{oc}	-0.33 %/°C

The equations for solar radiation and temperature difference between the module and air show that both conduction and convective losses are linear with incident solar insulation for a given wind speed, provided that the thermal resistance and heat transfer coefficient do not vary strongly with temperature. The NOCT for best case, worst case and average PV modules are shown in Figure 6. The best case includes aluminium fins at the rear of the module for cooling which reduces the thermal resistance and increases the surface area for convection.

The best module operated at a NOCT of 33°C, the worst at 58°C and the typical module at 48°C respectively (Ross and Smokler 1986) An approximate expression for calculating the cell temperature (*T$_{cell}$*) is;

$$T_{cell} = T_{air} + \left(\frac{NOCT20}{80}\right)S \qquad \text{(Equation 7)}$$

$$T_{cell} = T_{air} + 0.35S \qquad \text{(Equation 8)}$$

whereT_{cell} is cell temperature, (°C), T_{air} as ambient temperature (20°C), Nominal Operating Cell Temperature (NOCT, °C) and *S* is solar irradiance in mW cm^{-2}. Module temperature will be lower than this when wind velocity is high, but higher under still air conditions.

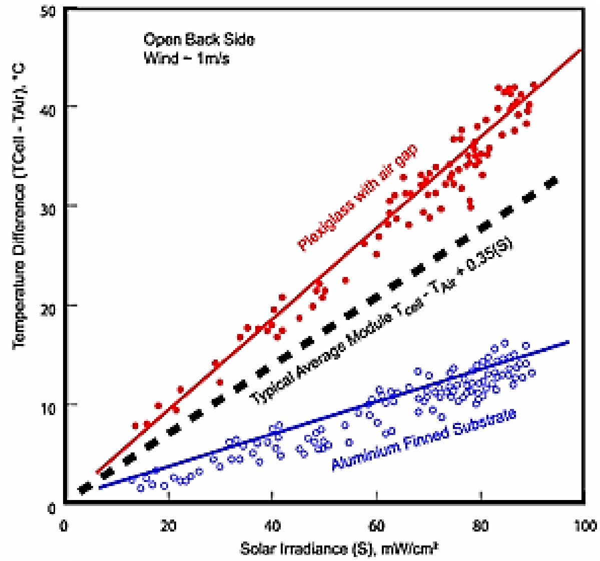

Figure6. Slope of the straight lines represents the NOCT (Ross and Smokler 1986).

The adjusted voltage *V$_{adj}$*for high temperatures can be calculated as;

$$V_{adj} = V_{mp}\left[1 + \left[\left(T_{avg} + T_{cell}T_{ref}\right)T_{coeff}\right]\right] \qquad \text{(Equation 9)}$$

$$V_{adj} = 16.8\left[1 + \left[(33.3 + 4825)(0.0033)\right]\right]$$

$$V_{adj} = 13.68V$$

Where V_{adj} is the adjusted voltage for high temperature (V), V_{mp} the voltage at maximum power, T_{avg} defined as average temperature (°C), T_{cell} defined as the cell temperature (°C), T_{ref} reference temperature (°C, under 1000 W m^{-2}) and T_{coeff} defined as the temperature coefficient of V_{oc}.

In this study, 70 V_{dc} Jack pump with an average efficiency of 0.45 was selected. Hence voltage required is 70 V_{dc}. According to this, PV panels in series for this location: 70/13.68 ≈ 5 panels.

Power output per panel (P_o):

$$P_o = I_{mp}V_{adj} \qquad \text{(Equation 10)}$$

Power output per panel per day (at a standard insulation of 1 kW m^{-2}) (P_d):

P_d=45.14W x 6.32 kWh m^{-2} day^{-1}/1 kW m^{-2}

P_d=285.31 Wh day^{-1}

Assuming an overall efficiency of 90% due to insolation times, wiring etc. Number of panels required (N_P):

N_P =3815 Wh day^{-1}/(0.9 x 285.31 Wh day^{-1})

$N_P \approx 15$ panels. The panels in a PV array are usually first connected in series to obtain the desired voltage; the individual strings are then connected in parallel to allow the system to produce more current. Solar arrays are typically measured under STC (standard test conditions) or PTC (PVUSA test conditions), in watts, kilowatts, or even megawatts (Myers 2009). The array will consist of 5 parallel rows of 3 panels each in series. The daily water pumping rate (DWPR) for August:

$$DWPR = \frac{N_p P_d \eta_r 3600}{g \gamma H} \eta_p \qquad \text{(Equation 11)}$$

$$DWPR = \frac{15 \text{ x } 285.31 \text{ x } 0.9 \text{ x } 3600}{9.81 \text{ x } 1000 \text{ x } 35} \times 0.45$$

DWPR= 18.17 $m^3 day^{-1}$. As a result the system meets the water requirement. A schematic system is shown in Figure 7.

When the PV pumping systems were designed in the different regions, the number of PV panels will be different for each region by reason of daily solar radiation and daily required energy. Table 6 shows the number of PV panels at the same water request in different regions. In the table, it appears that the least number of panels (14 panels) in Van, Tunceli, K. Maras and Gumushane. On the other hand, the most of panels need to be placed in Rize (27 panels), Trabzon (23 panels) and Edirne (21 panels) for the same water request.

4. Conclusion

The photovoltaic water pumping systems offer the appropriate solution to supply water for drinking and irrigation in remote regions. They can provide simple and low labour watering options. Currently, the use of photovoltaic pumps for small-scale irrigation presents a promising option for using solar energy productively and for generating income. The operating principle of the photovoltaic irrigation system is quite simple. A photovoltaic array provides electricity for driving a surface motor pump, which in turn pumps water from a well reservoir collect into a water reservoir.

Solar water pumps are specially designed to utilize DC electric power from photovoltaic panels. They must work during low light and reduced power conditions without stalling or overheating. Low volume pumps use positive displacement mechanisms which seal water in cavities and force it upward with each pump cycle. Lift capacity is maintained even while pumping slowly. PV water pumping system types include diaphragm, helical rotor, piston pumps and rotary vane. Several general points to keep in mind about solar water pumping include:

- An electronic pump controller is used to smooth out the current to the pump. It acts like an automatic transmission in the sense that it helps the pump to start and to operate in low light conditions.
- To reduce the cost of a system, water conservation must be practiced. PV modules are expensive and reducing water use in any manner will save on the installed cost.
- PV water pumping systems are generally most competitive in smaller systems where combustion engines are least economical.

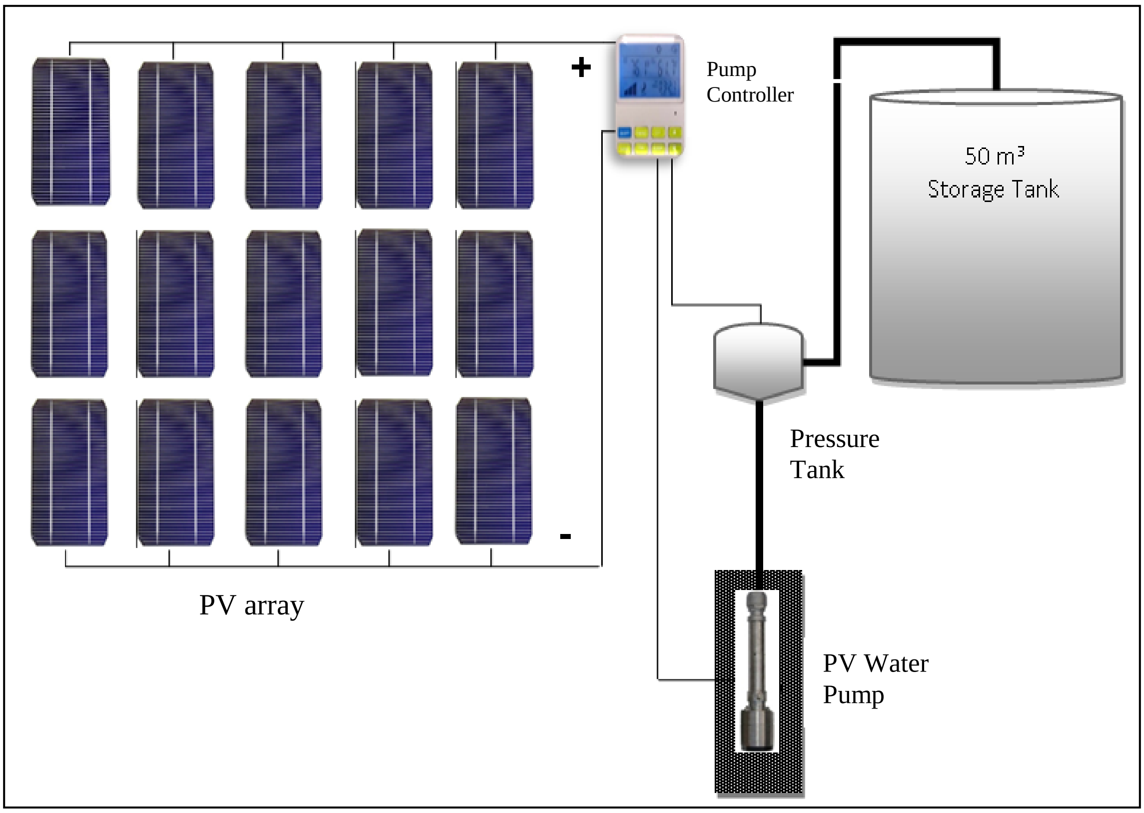

Figure 7.A schematic system for PV pumping system.

Table6. Requirements of PV system for some cities in August (Pump voltage required is 70V).

Site	Average Temperature (°C)	Sunshine Duration (h day^{-1})	Daily Solar Radiation (kWh m^{-2} day^{-1})	Water Required (m^3 day^{-1})	Total Head (m)	Daily Required Energy (Wh day^{-1})	The Adjusted Voltage For High Temperature (V)	Power Output per Panel (W)	Power Output per Panel per Day(W day^{-1})	Number of Panel Required
Antalya	33.30	11.59	6.32	18	35	3815	13.68	45.14	285.31	15
Artvin	20.41	06.80	5.03				14.39	47.50	238.83	18
Isparta	22.77	11.34	5.07				14.26	47.07	238.78	18
Ankara	22.80	10.92	5.57				14.26	47.06	262.09	16
Edirne	23.81	10.03	4.31				14.20	46.88	202.21	21
Sivas	19.90	11.49	5.10				14.42	47.59	242.86	18
Diyarbakir	30.09	11.87	6.26				13.86	45.73	286.35	15
Van	21.74	11.81	6.54				14.32	47.25	309.01	14
Sinop	22.83	08.67	5.09				14.26	47.06	239.29	18
Tunceli	26.73	11.46	6.46				14.04	46.34	299.32	14
Adana	28.27	10.32	5.34				13.96	46.06	245.79	17
Izmir	27.32	11.71	6.19				14.01	46.23	286.42	15
Rize	22.80	04.98	3.35				14.26	47.06	157.72	27
Erzurum	19.19	10.82	5.56				14.46	47.72	265.5	16
Anamur	27.66	11.07	5.70				13.99	46.17	263.14	16
Konya	22.69	11.05	5.90				14.27	47.08	277.79	15
Agrı	21.17	10.37	5.40				14.35	47.36	255.68	17
Tokat	22.02	09.14	5.68				14.30	47.20	268.31	16
Igdır	24.95	09.95	5.01				14.14	46.67	233.87	18
K.Maras	28.05	10.50	6.37				13.97	46.10	293.49	14
Kastamonu	19.62	09.48	4.63				14.44	47.64	220.58	19
Kusadası	25.23	11.51	5.57				14.13	46.62	259.82	16
Kutahya	20.24	09.15	5.88				14.40	47.53	279.71	15
Malatya	26.66	11.88	6.13				14.05	46.35	284.29	15
Mersin	28.07	10.06	6.26				13.97	46.10	288.48	15
Mugla	25.62	10.87	5.40				14.10	46.54	251.35	17
Mus	25.06	12.11	5.92				14.14	46.65	276.29	15
Nigde	21.98	11.53	7.27				14.31	47.21	343.06	12
Ordu	22.87	06.16	4.50				14.26	47.05	211.80	20
Samsun	23.18	07.88	4.90				14.24	46.99	230.14	18
Trabzon	23.07	05.31	3.85				14.25	47.01	181.11	23
Usak	23.11	11.54	5.16				14.24	47.00	242.45	18
Gumushane	19.88	09.91	6.25				14.42	47.60	297.61	14
Afyon	21.64	10.68	6.18				14.33	47.27	292.10	15
Aydın	27.15	10.90	5.84				14.02	46.26	210.17	16
Batman	30.12	11.67	4.87				13.86	45.72	222.75	19
Iskenderun	28.31	09.39	5.16				13.96	46.05	237.44	18
Kars	17.47	10.23	5.31				14.56	48.04	255.28	17
Ayvalik	26.16	11.62	5.26				14.07	46.45	267.39	16
Bartin	21.37	09.08	5.15				14.34	47.32	243.84	17
Bilecik	21.62	09.81	5.40				14.33	47.28	255.36	17
Bingol	26.17	09.65	6.31				17.07	46.44	292.93	15
Bitlis	22.17	09.89	5.80				14.30	47.18	273.74	16
Bodrum	27.64	10.68	5.62				13.99	46.18	259.29	16
Canakkale	24.59	11.34	5.53				14.16	46.73	258.49	16
Istanbul	23.39	09.55	5.23				14.23	46.95	245.45	17

- PV water pumping systems are low maintenance. With automatic shut off from a float valve, they require only occasional inspection.

References

Burkhartzmeyer B (2008) Solar Water Pumping Project Ghana. Joint Project of: World Vision and the Always On Solar™ Project (Rotary and the Northwest Solar Group).

Buschermohle M, Burns RT (1999) Solar-powered livestock watering Systems. http://rapidlibrary.com/files/utesolarstockwateringpb1640-pdf_ulfffxqx9ni89on.html. Accessed 20 October 2010.

Celik AN (2006) Present status of photovoltaic energy in Turkey and life cycle techno-economic analysis of a grid-connected photovoltaic-house. Renewable and Sustainable Energy Reviews 10: 370-387.

EIE (2010) General Directorate of Electrical Power Resources Survey and Development Administration.Solar Energy in Turkey.

http://www.eie.gov.tr. Accessed 15 October 2010.

Ertekin C, Evrendilek F, Kulcu R (2008) Modelling spatio-temporal dynamics of optimum tilt angles for solar collectors in Turkey. Sensors 8: 2913-2931.

Evoenergy(2010) PV Comparison. http://www.evoenergy.co.uk/pv-panels/pv-comparison/. Accessed 11 October 2010.

Evrendilek F, Ertekin C (2003) Assessing the potential of renewable energy sources in Turkey. Renewable Energy 28: 2303-2315.

Goswami DY, Kreith F, Kreider JF (2000) Principles of Solar Engineering. 2nd edition Tylor& Francis Group Publications, New York.

ITDG (2010) Solar (Photovoltaic) Water Pumping, ITDG-Intermediate Technology Development Group. http://practicalaction.org/html/technical_enquiries/docs/solar_pv_waterpumps.pdf. Accessed 15 October 2010.

Lorentz Inc. (2010) Lorentz PV water pumping systems. http://www.lorentz.de/ongrid/en/home. Accessed 11 October 2010.

Myers D (2009) Evaluation of the performance of the PVUSA rating methodology applied to DUAL junction PV technology. American Solar Energy Society Annual Conference.Buffalo, New York 11-16 May 2009, pp.1-4.

Ross RG, Smokler MI (1986) Flat-Plate Solar Array Project Final Report Engineering Sciences and Reliability, Volume VI, Jet Propulsion Laboratory, Publication No.86-31.

Sinton CW, Butler R, Winnett R (2002) Solar-Powered Water Pumping Systems in New York.New York State Energy Research and Development Authority.New York.