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Design of Photovoltaic Water Pumping System and Compare it with Diesel Powered Pump

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Abstract

In locations where electricity is unavailable, other means are necessary to pump water for consumption. One option is a photovoltaic (PV) pumping system. Advantages of PV pumping systems include low operating cost, unattended operation, low maintenance, easy installation, and long life. These are all important in remote locations where electricity may be unavailable.

So far, in the development of this research, the focus has been to estimate the available radiation at a particular location on the earth's surface and then analyzed the characteristics of a photovoltaic generator and a photovoltaic network. The purpose of this research is to examine all the necessary steps and key components needed to design and build a pump using photovoltaic system.

Keyword: Design load; Site condition; Annual radiation; Life Cycle Costs; Break-even point; Battery capacity

1. Introduction

Most of the increase in the area of irrigated land in the world has been through the increasing use of engine-driven pumps. However, the increasing price of oil-based fuel has reduced the margin to be gained by farmers from irrigation, since food prices have generally been prevented from rising in line with energy costs. Despite present short-term fluctuations in oil prices, conventional oil-based engine-driven power sources and mains electricity are expected to continue to increase in the longer term. If we are to decrease our dependence on imported oil, we have to find methods for energizing irrigation pumps that are independent of imported oil or centralized electricity.

Solar radiation as a source of energy is. Of course, the epitome of the clean. sustainable energy technology. except for residues possibly arising out of the manufacture of solar component (e.g. semiconductors), solar technology have very low environmental impacts. The environmental impacts of solar system in operation are very low and the source is, for us inexhaustible.

The designer should specify components in the following order:

- Choose place and mounting method for modules, select modules.
- Estimate of the electricity Demand.
- Estimate the overall system losses.
- Prepare full list of parts and tools to order.

Small Comparison between Solar PV & Diesel and gasoline pumps:

Table 1: Comparison between Solar PV & Diesel and gasoline pumps.

Type	Advantages	Disadvantages
Solar PV	Unattended operation	High capital costs
	Low maintenance	Water storage is require for cloudy periods
	Easy installation	Repair often require skilled technicians
	Long life	
Diesel and Gasoline Pumps	Quick and easy to install	Fuel supplies erratic and expensive
	Low capital costs	High maintenance costs
	Widely used	Short life expectancy
	Can be portable	Noise and fume pollution

2. Components of the System

2.1. Photovoltaic panels:

A solar-powered water pumping system is made up of two basic components. The first component is the power supply consisting of photovoltaic (PV) panels (Figure.1). The smallest element of a PV panel is the solar cell.

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Figure 1: Photovoltaic (PV) panels.

Each solar cell has two or more specially prepared layers of semiconductor material that produce direct current (DC) electricity when exposed to light. This DC current is collected by the wiring in the panel. It is then supplied either to a DC pump, which in turn pumps water whenever the sun shines, or stored in batteries for later use by the pump.

Manufacturers normally rate voltage (volts) and current (amps) output from PV panels under peak power conditions. Peak power (watts=volts x amps) is the maximum power available from the PV panel at 1000 W/m² solar irradiance (amount of sunshine) and a specified temperature, usually 25 C (77 F). Typical output from a 60-watt PV panel is shown in Table 2. The amount of DC current produced by a PV panel is much more sensitive to light intensity striking the panel than is voltage generated. Roughly speaking, if you halve the light intensity, you halve the DC current output, but the voltage output is reduced only slightly.

Table 2: Typical output from a 60-watt, 12-volt photovoltaic panel.

Maximum power	60 watts
Maximum power voltage	16.9 volts
Maximum power current	3.55 amps

Individual PV panels can be wired in series or parallel to obtain the required voltage or current needed to run the pump. The voltage output from panels wired in series is the sum of all the voltages from the panels.

For example, the maximum voltage output from two of the 12-volt PV panels wired in series is 33.8 volts. Thus, a 24-volt DC pump requires a minimum of two, 12-volt panels wired in series. The current (amps) output from these same panels wired in series is equal to the current (amps) output from an individual panel, 3.55 amps.

The voltage and current output from panels wired in parallel is the exact opposite of series-wired panels.

For panels wired in parallel, the current (amps) output is the sum of all the currents (amps) from the panels and the voltage is equal to the voltage output from an individual panel.

2.2. Solar (DC) water pumps:

The other major component of these systems is the pump. Solar water pumps are specially designed to use solar power efficiently. Conventional pumps require steady AC current that utility lines or generators supply. Solar pumps use DC current from batteries and/or PV panels. In addition, they are designed to work effectively during low-light conditions, at reduced voltage, without stalling or overheating.

Although wide ranges of sizes are available, most pumps used in livestock-watering applications are low volume, yielding 7-15 liters of water per minute. Low-volume pumping keeps the cost of the system down by using a minimum number of solar panels and using the entire daylight period to pump water or charge batteries. Some solar pumps are fully submersible, while others are not. The use of submersible pumps eliminates potential priming and freezing problems. Most solar water pumps are designed to use solar power most efficiently and operate on 12 to 36 volts DC.

Many solar pumping systems use positive displacement pumps that seal water in cavities inside the pump and force it upward. Their design enables them to maintain their lift capacity all through the solar day at the slow, varying speeds that result from varying light conditions. Positive displacement pumps include piston and jack pumps, diaphragm, vane and screw pumps.

Centrifugal-type pumps that impart energy to the water using a rotating impeller are typically used for low-lift or high-volume systems. Centrifugal pumps start gradually and their flow output increases with the amount of current. For this reason, they can be tied directly to the PV array without including a battery or controls. However, because their output drops off at reduced speeds, a good match between the pump and PV array is necessary to achieve efficient operation.

Pumps, because of their mechanical nature, have certain well-defined operating properties. These properties vary between types of pumps, manufacturers and models. The amount of water that a solar pumping system will deliver over a given period of time (usually measured in liters per minute (LPM) or liters per hour (LPH)) depends upon the pressure against which the pump has to work. The system pressure is largely determined by the total vertical pumping distance (the vertical distance between the water source and the watering tank) referred to simply as elevation head. It is roughly equal to an increase of one bar for every 10.28 meters of elevation head. Simply put, as the vertical pumping distance increases, the amount of water pumped over a given period of time decreases. When system friction losses and discharge pressure requirements (if any) are added to elevation head, the total system head can be determined. Pump manufacturers publish information that describes how each pump will perform under varying operating conditions. The expected flow rates and minimum recommended solar panel sizes for a typical 24-volt, positive-displacement, diaphragm-type submersible pump are shown in Table 3. The choice of pump depends on water volume needed, efficiency, price and reliability.

Table 3: Estimated flow rates in liters per minute for a typical positive-displacement, 24-volt diaphragm type pump.

Total head (meter)	Flow Rate (liter/min)	Current in ampere
0	14.00	1.6
3.048	13.20	1.7
6.096	12.80	2.0
9.144	12.50	2.2
12.192	12.10	2.4
15.24	11.70	2.6
18.288	11.35	2.9
21.336	10.98	3.1
None Shaded areas- Two 53-watt panels in series. Shaded areas – Two 70-watt panels in series.		

2.3. Pump controller:

The primary function of a pump controller in a battery-coupled pumping system is to boost the voltage of the battery bank to match the desired input voltage of the pump. Without a pump controller, the PV panels' operating voltage is dictated by the battery bank and is reduced from levels, which are achieved by operating the pump directly off the solar panels. For example, under load, two PV panels wired in series produce between 30 to 34 volts, while two fully charged batteries wired in series produce just over 26 volts. A pump with an optimum operating voltage of 30 volts would pump more water tied directly to the PV panels than if connected to the batteries. In the case of this particular pump, a pump controller with a 24-volt input would step the voltage up to 30 volts, which would increase the amount of water pumped by the system.

3. 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.

3.1. Battery-coupled solar pumping systems:

Battery-coupled water pumping systems consist of photovoltaic (PV) panels, charge control regulator, batteries, pump controller, pressure switch, tank, and DC water pump (Figure.2). 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.

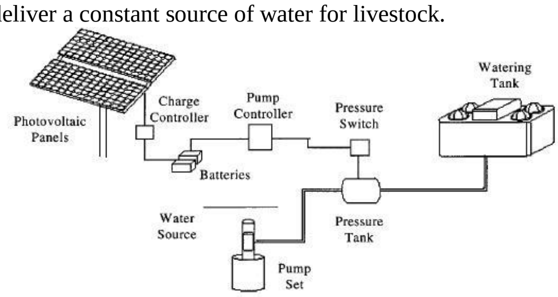

Figure 2: Battery-coupled water-pumping systems.

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.

3.2. Direct-coupled solar pumping system:

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 (Figure.3). 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 percent efficiency with maximum water flow. However, during early morning and late afternoon, pump efficiency may drop by as much as 25 percent 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.

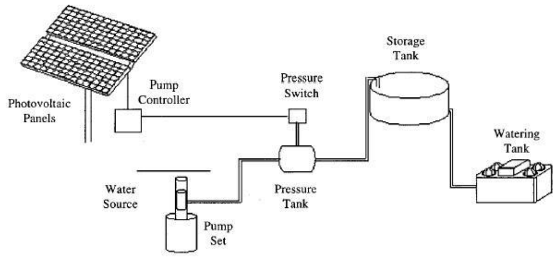

Figure 3: Direct-coupled pumping systems.

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 this pumping system. 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. In addition, water in the storage tank may freeze during cold weather.

4. System Sizing

Before choosing the final components, the system should be roughly sized to allow viewing of approximate component sizes. Later, the components must be sized again by a detailed electrical and mechanical design. The purpose of this chapter is to provide simple tools to roughly estimate the needed system size before contacting a PV specialist.

The approach is to estimate the required component size by making assumptions about the efficiency of all key components and by using monthly average weather data. To make the procedure easier, a set of worksheets (#1--#5) has been prepared for the different steps.

4.1. Specification of site conditions (worksheet #1):

Define the site and weather station location (latitude, longitude) and the monthly average values of the global irradiance on the horizontal surface (kWh/m2) and the annual average as well as the minimum and maximum monthly average ambient temperatures.

Main factors affecting the solar availability are the orientation (tilt and azimuth angel) and the possible shading caused by the surrounding. By multiplying the horizontal radiation values with monthly tilt azimuth angle factor, the monthly radiation values on the module surface can be estimated. This monthly factor is presented for different location for horizon shadowing levels of 0, 20 and 45 degrees.

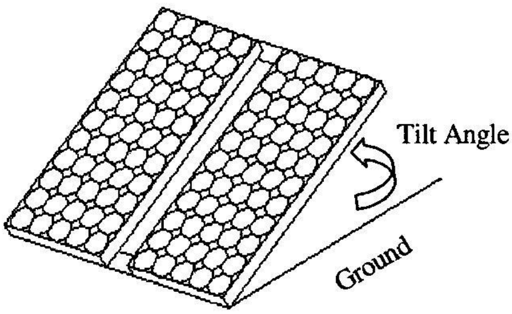

Figure 4: Solar panel tilt angle (Summer Use: tilt angle = 25 degrees, Winter Use: tilt angle = 45 degrees).

Worksheet #1: Define site condition and solar availability.

Shadow: 0, 20° horizon shading, Tilted: 45° angle due south.

4.2. Estimation of the electricity demand (worksheet #2):

The very first step in designing a PV system must be careful examination of the electrical loads. The reasons are twofold:

- Obviously, the sizing of the system components is dependent on the electricity and power demand. For stand-lone systems, his is crucial.
- Oversized systems resulting from a poor load analysis and the idea of staying on the 'safe side' increase the system costs. This is particularly demanding in a field where poor economics are major drawback, which still is the case for PV.

The second reason also leads to the important issue of minimizing loads without decreasing the user's comfort.

4.2.1. Solar pump sizing:

$$HE = V \times H \times \rho w \times g / (3.6 \times 106) \qquad (1)$$

Where:

HE : hydraulic energy (kWh/day)
V : volume (m^3/day)
ρw : water density ≈ 1000 (Kg/ m^3)
g : gravity ≈ 9.82 m/s2

$$Ppv = HE / ((S / \text{days of operation}) \times F \times E) \qquad (2)$$

Where:

Ppv : is the nominal power of PV at standard test condition (STC) in (kW)
S : is the annual solar radiation of the PV array (kWh/m^2)
F : array mismatch factor = 0.85 on average.
E : daily subsystem efficiency = 0.25 - 0.40 typically

Table 4: Define site condition and solar availability (Worksheet #1).

System: "Amman" PV		
System Location:	Latitude:31.57 N°	Longitude:35.57 E°
Insulation Location:	Latitude: 31.57 N°	Longitude: 35.57 E°

Month	Location		Array Plane							
	Ambient Temperature	Horizontal Radiation	*	Tilt, azimuth Shadow factor	=	Radiation				
	(C°)	kWh/m²day	*	fraction	=	kWh/m²day	*	=		kWh/m²
January	10	3	*	1.4	=	4.2	31	=		130.2
February	12	3.8	*	1.3	=	4.94	28	=		138.32
March	18	4.6	*	1.2	=	5.52	31	=		171.12
April	22	5.8	*	1	=	5.8	30	=		174
May	27	7	*	0.9	=	6.3	31	=		195.3
June	31	7.5	*	0.9	=	6.75	30	=		202.5
July	34	7.7	*	0.9	=	6.93	31	=		214.83
August	36	7.3	*	1	=	7.3	31	=		226.3
September	28	5.8	*	1.1	=	6.38	30	=		191.4
October	19	4.3	*	1.3	=	5.59	31	=		173.29
November	17	3.4	*	1.3	=	4.42	30	=		132.6
December	11	2.8	*	1.5	=	4.2	31	=		130.2

Table 5: Estimation of the electricity Demand (Worksheet #2)

Load Description	AC Or DC	AC Load	Inverter Efficiency	DC Load W	Duty Cycle h/day	Duty Cycle Day/Week	Daily Load Wh/day	Nominal Volt	Ah-load Ah/day
-------	---	----	---------	-----	-----	------	----------	------	-----
Water pump	DC	----	-------	250	5	4	(250*4*5)/(7) = 714.28	24	29.761
------	---	---	-------	----	-----	-------	---------	------	-----
------	---	---	-------	----	----	------	---------	------	------
				Maximum DC load =∑ 250 W			Total Daily load =∑ 714.28 Wh/day		Total load =∑ 29.761 Ah/day

Design load (Total load)	≈ 30	Ah/Day
Design peak Current Draw (Maximum DC load / Nominal voltage)	≈ 11	A
Annual load Energy (Total daily load*week in operation (≈38 weeks per year) *7/1000)	≈ 192.9	kWh

4.3. Sizing of grid-connect system (worksheet #3):

The optimum size of grid-connect system also depends on a number of external factors such as : the investment cost of the system, the available budget, governmental subsidies, the energy payback policy of the local utility, and the amount of PV energy directly used by the building. It must be remembered that because of the variable nature of PV power it is seldom used to decrease the peak load demand of the building.

In practice, the nominal size of the PV array should be chosen based on the load size and the budget. The require PV module area APV (m²) can be calculated from the chosen nominal PV power using the formula:

$$APV = Ppv / \eta pv \quad (3)$$

Where:

ηpv : is the efficiency of the modules at STC

The annual energy production of the system can be calculated using the formula below:

$$Epv = \eta Bos * Kpv * Ppv * S \quad (4)$$

Where:

Kpv : is a decreasing factor (~0.9), which takes into account phenomena such as modules temperature, dust, array imbalance, circuit losses etc.

ηBos : is the balance of system efficiency, depend on inverter efficiency or wiring losses.

Table 6: Sizing of grid-connect system (Worksheet #3).

Chosen PV array Power Ppv (kW)	/	PV efficiency ηpv	=	PV array area APV (m²)
2	/	0.15	=	13.33

Chosen PV array Power Ppv (kW)	×	Annual radiation on PV array Worksheet #1 S (kWh/m²)	×	BOS efficiency ηBos	×	Kpv	=	Annual produced energy PV energy Epv (kWh)
2	×	2080.06	×	0.8	×	0.9	=	2995.2864

Annual produced PV energy Epv (kWh)	/	Annual load Energy Worksheet #2 (kWh)	=	PV Load ratio	Directly used PV Energy
2995.2864	/	192.9	=	15.52	0.3 --- 0.5

Chosen PV array Power Ppv (kW)	×	Optimum inverter efficiency	=	Inverter nominal power (kW)
2	×	0.75 --- 0.9	=	1.5 - -- 1.8

Average inverter efficiency	×	Wiring losses	=	BOS efficiency ηBos
0.85	×	1-0.1 = 0.9	=	0.765

4.4. Sizing of battery (worksheet #4):

Battery sizing is the capability of a battery system to meet the load demand with no contribution from the photovoltaic system. For a stand-alone photovoltaic system, the principal goal of battery storage is to ensure that the annual minimum photovoltaic system energy output equals the annual maximum load energy input. The photovoltaic system must also maintain a continuous energy supply at night and on cloudy days when there is little or no solar energy available. The amount of battery storage needed will depend on the load energy demand and on weather patterns at the site. Having too much energy and storage capacity will increase cost, therefore there must be a trade-off between keeping the cost low and meeting the energy demand during low-solar-energy periods.

Table 7: Sizing battery (Worksheet #4).

Design load Worksheet #2 Ah/Day	×	Day of autonomy (Day)	/	Max depth of discharge	=	Usable battery Capacity Ah
30	×	2	/	0.3	=	200

Operating Temp = 25 Discharge rate = 24× Day of autonomy (number of days a battery system will provide a given load without being recharged by the photovoltaic array) = 48 h

Usable battery Capacity Ah	/	Usable Friction of Capacity available	=	Design battery Capacity Ah
200	/	0.95	=	211

4.5. Sizing of array an components (Worksheet #5):

The next step is to size the PV array and the other system components. This is done with the help of worksheet #5. For PV array sizing, the month with lowest radiation on the array plane is chosen as the design month (from worksheet #1).

Dividing the average daily load of the design month by the average daily solar radiation & the system component efficiencies. Yield the necessary PV array size (kW). The efficiencies to be taking into account are the wiring efficiencies, charge regulator efficiency and battery efficiency.

Table 8: Sizing of array components (Worksheet #5).

Operating season (months)	February ------- October

Design month daily load kW/day	/	Lowest radiation on PV array Worksheet #1 kWh/m²day	/	Wiring losses	/	Charge regulator efficiency	/	Battery efficiency	=	Design PV array power kWp
0.98	/	4.94	/	0.9	/	0.85	/	0.9	=	0.289

Design PV array power Wp	×	PV array sizing safety factor	=	PV array power Wp
289	×	1.3	=	376

Design PV array power Wp	/	Nominal voltage V	=	Design array current A
376	/	24	=	15

The design array current is greater than the peak load current.

PV array power Ppv kWp	/	PV efficiency ηpv	=	PV array area Apv m²
0.376	/	0.15	=	2.51

5. A Cost and reliability comparisons between solar and diesel powered pumps

There are very distinct differences between the two power sources in terms ofcost and reliability. Diesel pumps are typically characterized by a lower first costbut a very high operation and maintenance cost.

Solar is the opposite, with ahigher first cost but very low ongoing operation and maintenance costs.

In terms of reliability, it is much easier (and cheaper) to keep a solar-powered System going than it is a diesel engine. This is evident in field where dieselengines lie rusting and unused by the thousands and solar pumps sometimes runfor years without anyone touching them.

The first cost of solar is often daunting to donors and project implementers who are tempted to stretch their budgets as far as possible to reach the greatestnumber of beneficiaries by using a low first-cost option.

But most would probably agree that "quantity over quality" is not a good value if the higher quantity option is not likely to be giving good service five years down the road and if beneficiaries are going to be stuck with interventions they cannot afford to sustain over time.

Solar pumping has had clear advantages for a number of years but the differences are becoming more striking in a world of rapidly escalating fuel costs.

Not only will some of the world's poorest people not be able to afford fuel for their pumps, but living at the end of remote supply chains, they may not even be able to get it in the first place as world demand overtakes supply.

In this example, model choices for a Pumping system that is designed to pump 790 liters per hour from a total Depth (head) of around 30 meters. It compares a solar array of 1900 watts against a 4 kW diesel generator. Both power an equivalent pump of approximately 1 Horsepower = 746 watts, several simulations were performed to gauge the effect of the price of fuel and the fuel efficiency of the diesel generators. These and other parameters are listed below:

Key program inputs:

1) Fuel cost:
   - Case 1: $1.20 per liter.
   - Case 2: $1.70 per liter.
2) Fuel efficiency (consumption) of diesel generator:
   - Case 1: 0.3 liters per kilowatt generated.
   - Case 2: 0.7 liters per kilowatt generated.
3) Solar resource: Annual average of 4.6 peak sun hours per day.
4) Real annual interest rate: 5%.
5) System life: 20 years.

Key program outputs:

1) Initial capital cost: "first cost" for each option – assumes same pump costs
2) Operation cost/year: Average operation and maintenance costs per year. Does not include pump Replacement costs, which would be same for both.
3) Net Present Cost: The present value of the cost of installing and operating the system over the lifetime of the project (also referred to as lifecycle cost).
4) $ Per kilowatt: The cost per kilowatt of electricity per each option.

Simulation 1: "Worst case" for solar: Fuel cost: $1.20 per liter. Consumption rate: 0.3 liters per kilowatt.

Table 9: Simulation 1 Cost comparison for solar and diesel water pumps.

	Initial Capital	Operating cost/year	Total NPC(Net Present Cost)	$ per kWh
PVP (Photo-Voltaic Pumping) Option	$12,300	$335	$16,472	$0.66
DP (Diesel Pumping) Option	$2,000	$4,854	$62,494	$2.48

Simulation 2: "Best case" for solar: Fuel cost: $1.70 per liter. Consumption rate: 0.7 liters per kilowatt.

Table 10: Simulation 2 Cost comparison for solar and diesel water pumps.

	Initial Capital	Operating cost/year	Total NPC	$ per kWh
PVP Option	$12,300	$335	$16,472	$0.66
DP Option	$2,000	$12,525	$158,094	$6.27

We can see from these simulations that solar ranges from one tenth to one fourth (1/10-----1/4) the Net Present Cost of the diesel option.

5.1. Life cycle costs:

Figure.5 shows a comparison for solar and diesel water pumps that includes a range of pumping heads (10m to 200m) and a range of daily flow rates (3,000 – 50,000 liters). The life cycle costs (LCC) were calculated over a 20-years period taking into account upfront cost, operating costs, maintenance costs, and replacement costs.

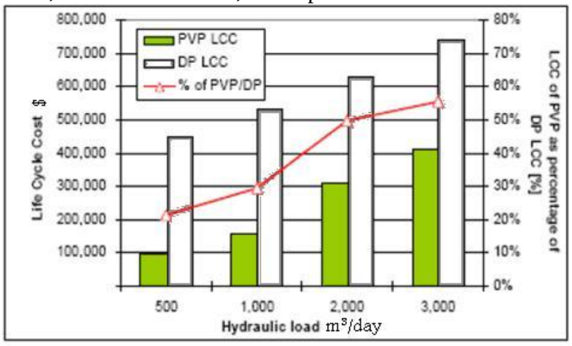

Figure 5: life cycle cost as function of the hydraulic load.

5.2. The break-even point:

Figure.6 shows the break-even point for a single case – a pumping system with an output of 10,000 liters per day from a head of 80 meters. The study also states that for pumping systems having a hydraulic load of 1,000 or less, the break-even point is less than 2.5 years.

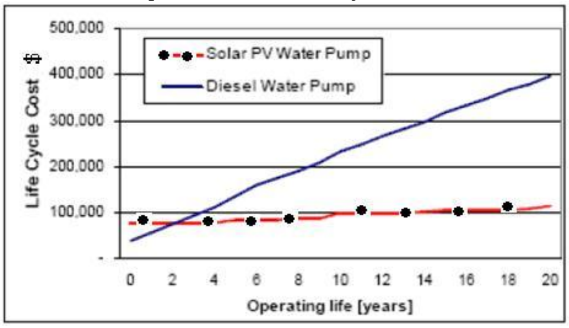

Figure 6: Typical years to break-even graph for PV pump vs. a diesel pump.

6. Conclusion

The output of a solar pumping system is very dependent on good system design derived from accurate site and demand data. It is therefore essential that accurate assumptions are made regarding water demand/pattern of use and water availability including well yield and expected drawdown.

With a solar pump, energy is not available on demand, and the daily variation in solar power generation necessitates the storage of a surplus of water pumped on sunny days for use on cloudy days, solar energy needs to be reserved in the form of either electricity in batteries of lifted water in a storage tank. The suitability of solar power for lifting water to irrigate plants is undeniable because of the complementary between solar irradiance and water requirements of crops. The more intensively the sun is shining the higher is the power to supply irrigation water while on the other hand on rainy days irrigation is neither possible nor needed.

Water pumping has long been the most reliable and economic application of solar-electric (photovoltaic, or PV) systems. Most PV systems rely on battery storage for powering lights and other appliances at night or when the sun is not shining. Most PV pumping systems do not use batteries – the PV modules power the pump directly.

Instead of storing energy in batteries, water is pumpedinto storage reservoirs for use when the sun is not shining. Eliminating batteries from the system eliminates about 1/3 of the system cost and most of the maintenance.

Without batteries, the PV pumping system is very simple. It consists of just three components: the solar array, a pump controller and the pump. The only moving part is the pump. The solar modules are warranted to produce for 20-25 years. The expected life of most controllers is 5-10 years. Pump life can vary from 5 - 10+ years (and many are designed to be repaired in the field). Unless the pump or controller fails, the only maintenance normally required is cleaning the solar modules every 2- 4 weeks! This task obviously can be done cheaply by non-skilled local labor.

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Appendix

1. PV modules Characteristics

Table 11: Characteristics of two type (12, 24 V) 1000 W/m²-PV module.

ELECTRICAL (1000 W/m², 25 °C cell, AM 1.5)		
Nominal Voltage (V_o)	12 V	24 V
Maximum Power (P_{max})	150 W_p ± 5 %	
Short-circuit current (I_{sc})	8,9 A	4,45 A
Open circuit voltage(V_{oc})	21,6 V	43,2V
Maximum power current (I_{max})	8,7 A	4,35 A
Maximum power voltage (V_{max})	17,3 V	34,6 V

Figure.7 schematically shows a characteristic I-V curve of a photovoltaic module together with the generated power curve and two different working points, A and B.

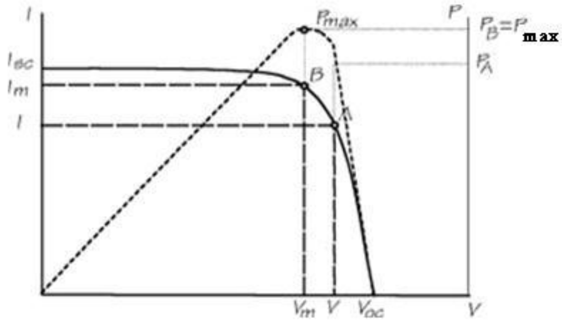

Figure 7: Characteristic I-V curve and generated power curve.

It can be seen that the closer to the maximum power voltage we can make the photovoltaic module work, the greater will be the power we shall obtain from it.

To summarize, depending on solar radiation, the temperature of the cells and of the equipment to which connected, a photovoltaic module will generate a certain current at a certain working voltage, the product of which will set the power generated by the module. Under normal conditions, a photovoltaic module with mono-crystalline silicon cells is likely to produce more current and/or voltage than that specified under standard conditions. In these cases, the values of Isc and Voc may be multiplied by a factor of 1.25, and components such as fuses, conductors and controllers must be adapted to the photovoltaic generator's output.

2. Battery Specifications

A photovoltaic system designer must consider the following when specifying a properly sized and installed battery storage system for a stand-alone photovoltaic system:

- Days of autonomy
- Battery capacity
- Rate and depth of discharge
- Life expectancy
- Environmental conditions
- Price and warranty

The percentage of a battery's rated amp-hour capacity that has been used is called the depth of discharge. Battery life (number of daily cycles) versus depth of discharge (in percent of battery capacity) is shown for a lower cost sealed battery in Figure 8.

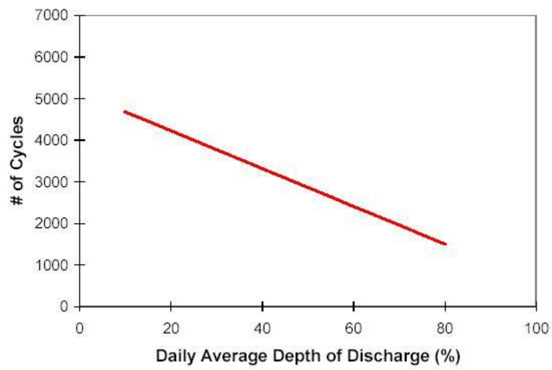

Figure 8: Cycle Life vs. Depth of Discharge.