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A Mobile Solar Pv Water Pumping Demonstration System For Public Outreach

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Introduction

Agricultural producers providing drinking water to livestock in rural areas of Arizona have different options when it comes to the technology for getting water their animals. Utility-supplied electricity is a traditional, practical solution, except when the location of the submersible well is located far from existing power lines. The initial cost of installation can be an economic barrier. Fossil-fuel powered pumps, such as gasoline, diesel, or natural gas are a second consideration. Pumps and engines are available, but the cost for fuel and attending to the operation of the pump and engine can be expensive, as well as dealing with the carbon emissions. A traditional method adopted by many rural ranchers was the installation of a windmill. The advantage of a windmill is it is an established technology, is renewable, can be operated without on-site supervision, and parts and materials are available. Unfortunately, for wind technology to be effective, there needs to be enough wind at a given speed to keep the well pumping water and the windmill unit requires continuous maintenance and repair. A renewable alternative is to convert the windmill over to solar photovoltaic (PV)-powered pumping system. Solar powered systems are gaining in popularity due to reasonable cost, availability, few components, low maintenance, no carbon emissions, and taking advantage of available sunshine, especially in Arizona. The challenge of demonstrating the solar PV-powered technology is an operating well pump may be situated hundreds of feet below ground and not accessible for viewing. A solution was to create a system to demonstrate solar PV-pumping technology. The system would need to be mobile, simple to assemble and disassemble, easy to transport in a trailer, and setup for operation at practically any location.

This factsheet focuses on the development and use of a mobile solar-powered water pumping system used to demonstrate and educate farmers, ranchers, and the public about how a PV pumping system operates. Individual system components along with hand tools used to measure system performance will be presented and their use explained.

A solar-powered water pumping system is representative of the simplest type of solar photovoltaic (PV) systems; the PV-Direct type. This system is made up of a solar module (or array) and a direct current (DC) load. The electrical load is a direct current (DC) submersible pump and is matched to the DC-power producing capabilities of the solar PV module (or solar array). There is no energy storage in a PV-Direct system. This is the most economical and simplest of all types of solar PV systems. For more information on types of solar PV systems, see the factsheet *Types of Solar Photovoltaic Systems AZ 1745-2017* (Franklin, 2017). The pump operates when the sun is shining and directs sunlight onto the solar PV module. This fits well with watering livestock. As daylight temperatures increase, animals require more water. As the sun shines, a solar-powered pump is operating. In the absence of sunlight, the pump is not operating. It is cheaper to store water than to store energy, so water pumped during the day can be stored and used later. For livestock producers, pumped water is typically stored in a large cistern or tank. Water is drawn from the cistern or tank to fill smaller water troughs or plumbed to small individual waterers. If the operation of the waterer requires a specific water pressure, the holding cistern or tank can be in placed at a higher elevation such as on a hill or mounted on a stand to create flow pressure. Every 2.31 feet of elevation creates 1.0 psi of flow pressure. So, if your waterer requires 15 psi to operate, the tank will need to be elevated approximately 35-feet above the waterer.

Under cloudy conditions, less sunlight results in less water being pumped. A livestock producer will plan for low-sunlight conditions by storing a larger quantity of water. A rule of thumb is to plan for three days of autonomy (no energy from the sun) to store enough water for livestock. Calculating the total amount of water required in gallons per day by the total number of livestock and multiplying this quantity by three (3) will provide the capacity needed. For example, if the total gallons of water needed per day (gals/day) for all livestock is 1,000 gallons, a tank with a capacity to hold at least 3,000 gallons would provide water for three days if the pump is not operating to capacity due to cloudy conditions. Fortunately, our geographic location provides a higher amount of peak sun hours (PSH) per day which results in higher solar-powered pumping capacity. A peak sun hour is measured in the amount of time sunlight intensity achieves a level of 1,000 watts per square meter (W/m^2). In the southwest, we are accustomed to receiving between five and six peak sun hours (PSH) of $1{,}000 W/m^2$ per day. So, a pump operating for 5 to 6 hours

Figure 1. Mobile Solar-Powered Water Pumping Demonstration System. Source: Author

Figure 2. A solar module mounted in a fixed position on a mobile frame. Source: Author

per day, every day, can continuously pump water to fill the tank. A float valve (like what is found in a toilet tank) can be installed in the water storage tank to regulate the water level and prevent the tank from overfilling. When the desired water level in the tank is reached, the float valve will trigger the pump controller to shut off the pump.

Very little maintenance is required for this type of system. Except for the pump, there are no moving parts in the system. Shading from dust or dirt settling on the surface of the solar module (especially following a monsoon storm) can reduce the effectiveness of the solar module and lower the voltage and current production of the solar module. If vandalism or theft of materials is possible, the construction of a fenced enclosure may be necessary to protect the solar module.

Portable Solar PV Pumping System Components

Three principal components make up a solar-powered submersible well. A solar module, a pump controller, and the submersible pump. The size and type of pump selected is dependent on variables such as how deep is the well, how far down in the well the pump will be set, how many feet (vertically) the water will need to be pumped, and how much water (flow rate measured in gallons per minute (GPM)) is needed. The size of the pump is measured in voltage which is the amount of electricity needed to provide power. The pump controller is sized to the pump, and the solar module (or multiple modules wired together, forming an array) are sized to provide the voltage and current to operate the pump. Typically, the solar module or array is sized to provide more voltage due to system inefficiencies, and low sunlight intensity. There are other components required to connect the three system components together. These will be addressed in this factsheet.

Our mobile solar photovoltaic water pumping demonstration system is made up of a Solarland 85-Watt solar PV module, a Sun Pump (pump) controller, and a Sun Pump submersible diaphragm pump. Other system components include a mock-well cistern, a poly stock water trough, a safety disconnect switch, and poly tubing to convey the water from the well to the trough, and for our demonstration, a return-line for water from the trough to the mock-well cistern.

Solar Module

The Solarland polycrystalline solar photovoltaic (PV) module generates the electricity to provide power to the submersible pump. The module is sized to meet the direct current (DC) voltage needs and direct current (DC) amperage capacity of the submersible pump. Our module is mounted in a fixed position on a mobile frame. The module is mounted at a tilt angle equal to the latitude of Tucson (AZ), 32°. The mobile frame can be rotated in any direction to show the effects of the changing location of the sun over the course of the day.

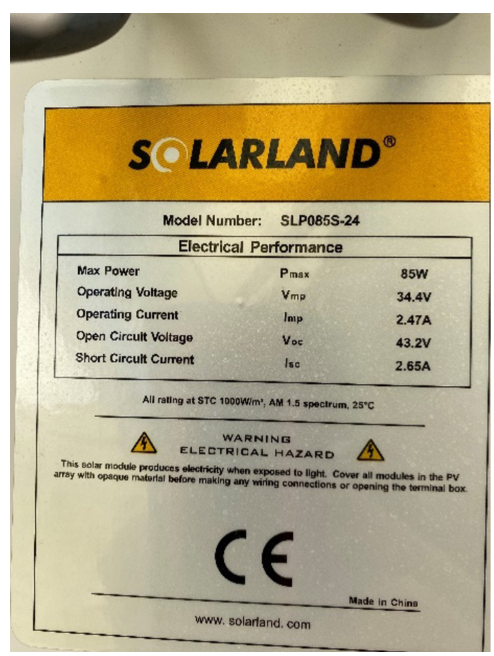

Figure 3. Solar module spec sheet on backside of solar module for a solar pumping system. Source: Author

The polycrystalline solar module powering our system is designed for a 24V system and produces 85 watts of power at maximum power (Pmp) under Standard Test Conditions (STC). The maximum operating voltage (Vmp) is 34.4 volts (DC) and maximum operating current (Imp) is 2.47 amps (DC). This module works will with solar pumping applications. On the backside of the solar module is a spec sheet with information about the power producing capabilities of the solar module. Two electrical leads wired to a junction box mounted on the rear of the module are connected to interconnection leads going to a safety disconnect switch. The safety switch is mounted on the rear of the mobile frame supporting the solar module.

Safety Disconnect Switch

The safety disconnect switch isolates the solar module from the pump controller. The non-fused switch box can be secured with a padlock during system set up and disassembly to prevent accidental energizing of the pump controller.

The positive (+) lead from the solar module is connected to the switch and the negative (-) lead is connected to a bus bar in the switch box. A ground conductor (green) is connected to the module frame and the switch box.

Figure 5. Safety disconnect switch is a recommended feature. Source: Author

Pump Controller

The pump controller is the "brains" of the system. It serves as the interface between the solar module and the submersible pump. The controller includes a power switch to turn on and off the pump. Multiple LED lights indicate power from the module (when sun is shining), a power out over current indicator, a remote switch function indicator, and low water cut off indicator. The controller serves as a liner current booster. Under low sunlight conditions (sun rise and sun set), the controller increases the current to boost the voltage to get the pump operating. To protect the user and the equipment, the pump controller should be grounded. A green-colored insulated wire is connected to the pump controller and in a permanent-mounted location, is connected to a copper rod buried in the ground.

The ends of the positive (+) and negative (-) leads from the disconnect switch are placed under the labeled screws (PV +) and (PV-) and the ends of the positive (+) and negative (-) leads from the submersible pump are placed under the screws labeled (LD+) and (LD-). Typically, the black-colored wire is the negative lead and red-colored wire is the positive lead. The green-colored wire is the ground for the system. The ground wires are landed under the labeled ground bus bar toward the back of the controller. The remote switch option is used when a float switch is added to the system.

Figure 6. Solar pump controller Source: Author

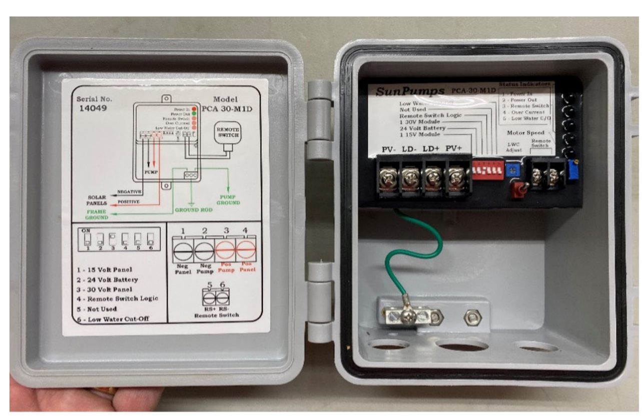

Figure 7. Pump Controller

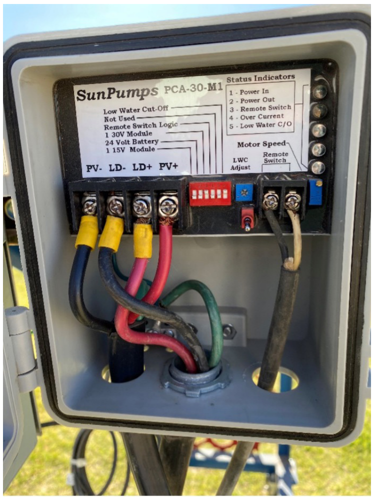

Figure 8. Pump controller with wired connections installed. Source: Author

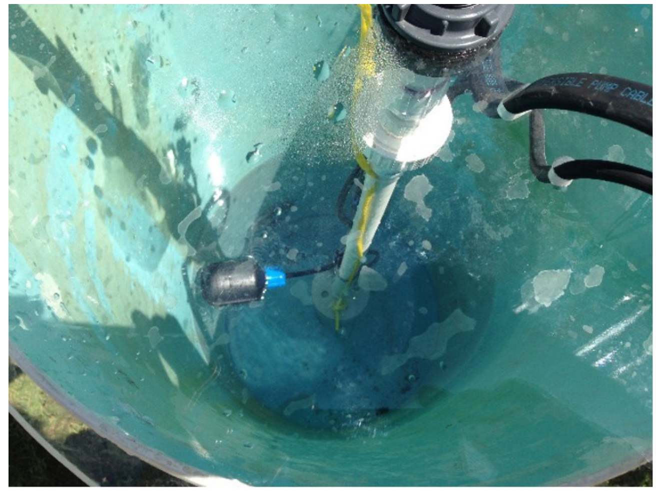

Figure 10. Float switch used in a low water cut off application in the mock well cistern Source: Author

Float Switch

The float switch is an application to monitor water level in the well or in a water storage tank. The float is attached to the drop pipe above the submersible pump in the well. Water level above the pump will keep the float in a horizontal position. When the water level drops (due to active pumping) the float drops down with the water toward a down-hanging near vertical position. This shuts off the pump to allow the well to re-charge with water from the surrounding aquifer. Incoming water raises the float back up to a near horizontal position and turns on the pump.

When used to control the level of water in a storage tank, the float logic is reversed. When the level of water in the storage tank reaches a desired level, the rising float will turn off the pump. When the level of water drops, and the float drops toward the vertical position the pump is energized and begins operating. The actual reaction time can be over a minute.

Mock Well

To simulate a submersible well we selected to use a piece of larger diameter PVC pipe. The pipe had to be large enough to stand vertically on its own and with the weight of water and allow viewers to see the submersible pump hanging from the well cap (clear acrylic lid). To cycle the water, a hole was drilled near the bottom of the cistern and a bulkhead fitting mounted. Banjo clamps were used to connect a 2 ½ - inch diameter reinforced poly tubing to the PVC cistern and a stock water trough. Re-charging the well occurs when water flows from the stock trough to the PVC cistern. Water fills the PVC cistern to the same level as the water level in the stock trough. If we desire a higher water level, we can elevate the stock trough (place on cinder blocks or wood blocks).

A submersible well will have a sanitary well seal on the top. For our demonstration, we elected to use a clear acrylic plate to serve as a lid. This permit viewing down inside

Figure 9. Float switch used in a low water cut off application in the well. Source: Author

Figure 10. Float switch used in a low water cut off application in the mock well cistern Source: Author

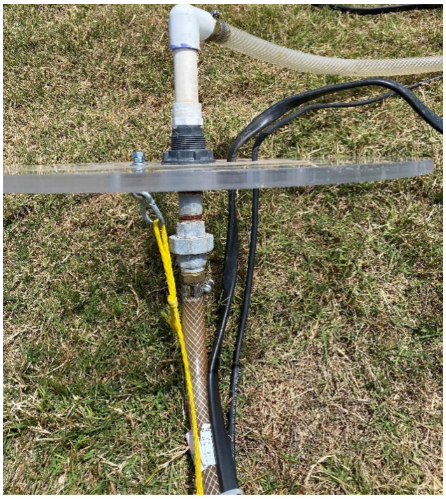

Figure 12. Acrylic lid with pipe fittings attached. Source: Author

Figure 13. Reinforced poly tubing return line. Source: Author

our cistern. A hole is drilled in the center of the acrylic and fitted with a pvc union. A galvanized pipe fitting is used to connect the drop pipe (3/4-inch reinforced poly tubing) and support submersible pump. To secure the pump to the lid, a poly rope is tied to an eyebolt attached to the acrylic lid. The other end of the rope is tied off to an eyebolt fastened to the top of the well pump. Holes were cut into the acrylic lid to allow the waterproof electrical wiring from the well pump to pass through. The pump is suspended to hang at about half the height of the PVC cistern. We wanted to be able to install a float switch above the submersible pump and demonstrate the low water cutoff function of the pump controller.

We can temporarily stop the flow of water returning to the PVC cistern from the stock water trough using a ball valve installed in the 2 ½-in reinforced poly tube. This will cause the water level in the mock well cistern to drop. When the float switch drops, this will signal the low water cutoff. Opening the ball valve on the return line will allow the mock well cistern to "re-charge". When the water level rises and raises the float switch, it will deactivate the low water cut off and the pump is once again energized to resume pumping water.

DC Submersible Pump

Our DC submersible pump is a diaphragm pump. Our pump is designed for operation at a depth of 60 feet and a flow rate of 1.8 to 4.8 gallons per minute (GPM). For our demonstration system, this is more than adequate. For wells with deeper bore holes with greater pumping depths, larger capacity pumps are available. The pump is pollution-free, corrosion-resistant, and designed to be used in remote locations. This model is designed to be operated in a range of 12 to 30 volts DC. Three electrical wires connected to the pump (red, black, and green) are spliced to a waterproof electrical cable.

An eye hook installed on the top the pump is for securing a safety rope. The rope serves as a safety line in case the drop pipe should fail. This pump is sized for a ¾-inch diameter drop pipe.

Figures 14. & 15. DC Submersible diaphragm pump Source: Author

Figure 16. Wires from pump are spliced and sealed with silicon to prevent corrosion.

Figure 17. Eyehook installed in top of pump with safety rope attached.

Poly Livestock Water Trough

Our demonstration system uses a 100-gallon poly livestock water trough equipped with banjo connector fittings. The connector fits the ends of the 2 ½-inch reinforced poly tubing. A ¾-inch poly tubing from the pump conveys water to the stock trough. The trough is light enough to travel and holds enough water to demonstrate the operation of the pumping system.

Figure 18. Poly livestock water trough Source: Author

Figure 19. Stock water trough with a banjo connector fitting. Source: Author

Testing the Operation of the Pumping System

Angle Finder

The solar pumping system can be positioned for optimum solar output. The optimum tilt-angle of the solar module is the latitude of the location. For Tucson, AZ the this is 32°. During the summer months when the sun's path is higher in the sky, we adjust the tilt by lowering the module 15-degrees (32° – 15°) to 17° to stay perpendicular to the sun. During winter months, we adjust the tilt for the lower path the sun takes. We add 15-degrees to the tilt angle from latitude (32°+ 15°) to 47°. The output of the solar module is measured using the leads of a digital multi meter to measure DC voltage.

Figure 20. Angle finder reveals the tilt-angle of the solar module. Source: Author

Solar Irradiance

Another hand tool used in our demonstration system is the pyranometer. This tool measures the level of sunlight intensity (solar irradiance) from the sun in units of watts per square meter (W/m^2). On a clear day, solar irradiance levels reach 1,000 W/m^2. In the solar industry, this value is considered a Standard Test Condition (STC). The measured output rating of all solar modules (measured in watts maximum power) is performed in a laboratory at 1,000 W/m^2. Sunlight intensity will vary though out the day. From sunrise, solar irradiance levels can be measure under 100 W/m^2 and increase as the sun's altitude increases. A reading of less than 1,000 can be divided by 1,000 to arrive a percentage of how much output we can expect from our solar module.

Solar Cell Temperature

Temperature affects solar module output. Every 1°C above 25°C can result in a 0.41% decrease in module voltage. A non-contact thermometer can be used to measure the cell temperature of a solar module. The Standard Test Condition (STC) for temperature for solar modules is 25°C (77°F). The temperature reading is taken on the underside of the solar module and measures solar cell temperature. A reading of 53°C is a difference of (53°C - 25°C) is a 28-degree difference. 28-degrees x -0.41% = -11.5% which means the module loses

Figure 21. Pyranometer measures sunlight intensity in Watts/m2. Source: Author.

Figure 22. A non-contact thermometer is used to measure the surface temperature on a solar module. Source: Author

11.5% in power output when the solar cells are 53°C. So, our 85W module operating at a solar cell temperature of 53°C (127.4°F) is expected to produce approximately 75.2W of power.

Digital Multimeter

The digital clamp on multimeter with the capability to measure both AC and DC electric current and voltage is used to check the operating voltage of the module. Turn the dial to "Voltage" and verify the meter is measuring DC voltage. Placing the metal tips of the leads on the screws for the PV+ and PV- reveals the voltage of the module entering the pump controller. The module is rated at 34V DC. Under ideal conditions (a minimum of solar irradiance of 1,000 W/m^2), the reading obtained can be as high as 40V DC.

The digital multimeter is used to check the voltage of the pump. The bare, pointed leads of the multimeter are placed in contact with the screws on the pump controller labeled LD + and LD - (which stand for "Load Positive" and "Load Negative"). The value obtained is the quantity of direct current (DC) voltage going to the submersible pump.

Figure 23. Checking the voltage on the PV connections of the pump controller with the digital multimeter. Source: Author

Figure 24. Taking a voltage reading of the PV with the digital multimeter Source: Author

Summary

The mobile solar-powered water pumping demonstration system is an effective tool to demonstrate the concepts of using solar energy to provide power for a submersible well pump for applications such as livestock watering and irrigation. Observers can be engaged in the setup, connection, operation, testing, and take down of system components. This can be done when access to an actual operating submersible well pump on a well site is not feasible. The system is portable and fits in the back of a small cargo trailer. The unit is ideal for Cooperative Extension Centers, Resource Conservation Offices, and schools wanting to conduct a demonstration of solar-powered water pumping fundamentals to farmers, ranchers, and off-grid solar enthusiasts.

Resources

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SunPumps. (www.sunpumps.com)

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