Solar PV pumping systems

Solar pumping can help offset the cost of traditional irrigation fuels. The more often a pump is run, the greater the opportunity for savings from solar. Solar pumps are reliant exclusively on the sun to provide power and therefore operate only during daylight hours unless coupled with a battery/storage system. Solar pumps may be a good option for lower water volume and daytime irrigation systems. As yet, affordable solar technology is unable to supply sufficient power to pump enough water for large-scale flood irrigation.

Introduction

Typically, diesel-powered pumps are used in areas where connecting to the electricity grid is difficult. Solar photovoltaic (PV) systems can be an attractive complementary energy source deployed alongside diesel pumps in areas with plenty of sunshine and where the cost to run power lines is high.

Photovoltaic systems have the benefit of being scalable, with capacity ranging from a few watts for applications such as automated farm gates or timers, to hundreds of kilowatts for the homestead and farm sheds. Rather than having one large centralised system, a number of distributed PV systems can be deployed at pump sites.

Solar pumping systems are best suited for transfer operations (to pump water out of bore, for instance, or transfer it from dam to storage tank) in which pumps run continuously for most of the day.

Applications that require water to be pumped at night are not as well suited to solar-powered pumps, as storage solutions such as batteries and storage tanks can add significantly to the cost of the system. Although these energy storage solutions can be expensive, they allow for greater utilisation of the PV system. Depending on the application, stocked water can be fed by gravity when there is insufficient sunlight to power the solar pumps, thus reducing diesel consumption further.

Due to the high capital costs that are still associated with solar systems, simple paybacks of seven to eight years are generally achievable only where pumping currently occurs for more than half the year. These costs are expected to reduce over the coming years as price reductions occur within the solar PV and commercial battery storage industries.

How does it work?

A typical solar-powered pumping system consists of solar panels connected to an electric motor that runs a bore or surface electric pump. A solar pumping solution available from your irrigation supplier will typically supply a DC (mains-powered) pump that is connected directly to the solar panel and does not require a DC/AC inverter. DC brushless motors also offer very high efficiency levels (over 90 percent). In cases where an AC (battery-powered) pump is already in place, an inverter is required between the PV panel and the motor to convert from the direct current generated by the solar panel to the alternate current required by the electric pump motor.

In the case of a solar-diesel hybrid system, a solar pumping system (PV panel plus pump) is installed to complement the existing diesel pump operation. The solar pump can either pump directly into the system to offset diesel pump operation during daytime, or pump water to a storage tank or reservoir (which is part of the solar pumping solution) so that water is also available on cloudy days and at night. This is illustrated in the figure below.
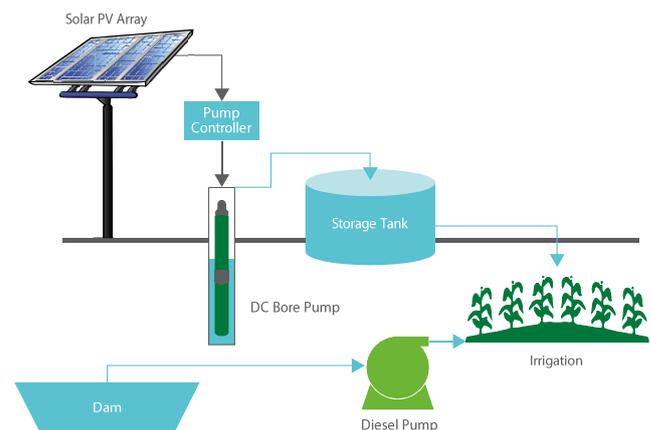

Figure 1: Solar-diesel hybrid system with water storage.

Solar pumping configurations

Three-phase solar pump

This system consists of PV panels connected to a three-phase variable speed drive (VSD) and an AC three-phase pump. Panels are connected directly into the DC bus inside the VSD. These systems are best suited to large pumping applications and will allow the pump to run at low sunlight levels, albeit at a lower speed (i.e. low flow, or no flow if static head).

Solar-diesel integration

This type of set-up includes a very high upfront cost and is not generally applicable for small to medium-sized farms. In a solar-diesel integration set-up, PV is synchronised with diesel engines, with a governor that regulates the diesel load so as to maximise the power drawn from solar. The ideal application would be for deep bores with day and night pumping requirements that justify the initial cost of two systems. This type of system would require running the pumps for the

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majority of the day, six or more months a year, to be a sound financial investment. PV synchronised diesel motor systems are used in mining and industrial-scale operations.[1] With improvements in technology, the costs of such systems may come down, and NSW Farmers is keeping a watching brief on the feasibility of agricultural applications.

Pre-packaged solar pumps

Package solar pump solutions, which include the installation of both PV systems and pumps specifically designed to work with solar PV systems, are becoming more common in drip-feed and spray systems in which daytime pumping is required (e.g. for livestock, vineyards, fruit and vegetables, lucerne, turf etc.). Otherwise, a storage tank (additional cost) could be utilised for night-time irrigation, with gravity feeds to paddocks via open or covered channels and/or pipes. These pumps (submersible or surface) are generally connected directly to the solar PV system (they run on DC power) and don't require inverters. They are very efficient (>90 percent efficiency) and are available in sizes ranging from a few hundred watts to 21 kW (delivering flows up to 2,500 L/min and 350 m lift). They are significantly more expensive than conventional electric pumps, with budget prices normally between $1,000 and $6,000 per kilowatt.

Water storage options

Since initial investment in solar is expensive but the fuel source (light from the sun) is free, it makes sense to install systems that are as small as possible, but run as often as possible. This means that typical solar pumping systems will not be able to draw large amounts of water rapidly but will be relatively inexpensive to operate for many continuous hours. Therefore, water storage will often be a vital component of a solar pumping set-up.

The capacity requirements for a storage tank or reservoir can be determined from the flow rate requirement and the amount of storage time needed (capacity = storage time * flow rate). Depending on water supply conditions, climate and the pattern of water demand, two to five days' storage may be required. Large tanks can be very expensive, so a cost-benefit analysis needs to be conducted to determine the best payback (trade-off between large capital cost and diesel savings).

Similarly, storing water in dams and/or reservoirs carries its own costs in terms of accounting for water losses from leakage through dam walls and evaporation losses during daylight hours. This is of primary concern in situations where the farm is subject to water pumping restrictions. The ideal scenario is being able to use the pumped water immediately, eliminating the need for water storage.

Solar tracking

A solar array can be fixed or can have a tracking system that follows the sun and increases energy yield. The key measure of effectiveness of a solar PV system is the capacity factor, i.e. the ratio between the average power actually provided by the solar panels and the power output specified on the nameplate.

The capacity factor of a fixed-tilt panel typically ranges from 11 to 23 percent, with most commercial modules achieving 13 to 15 percent. This varies depending on location, panel orientation and specific application. A panel with a tracking system further increases the capacity factor by approximately 10 percent; however, tracking arrays are more expensive, and are more suitable for large-scale installations and in areas with long sunlight hours. Alternative scenarios include fixed panels but with a portion of the panels facing a mix of north-easterly and north-westerly directions so as to prolong the number of hours the panels are exposed to sunlight. This, however, requires greater quantities of panels to be installed.

The current upfront cost for PV systems smaller than 10 kW is typically $2.5 to $3/W for ground-mounted systems. Solar panel systems may be able to claim Small-scale Technology Certificates (STCs), which helps reduce the capital cost. The number of certificates created (depending on the capacity of the PV system and its location) can be traded at a market price that typically fluctuated between $30 and $40 per certificate in 2013. Usually, this STC benefit is bundled into the installer's price so that the owner pays only the net amount, and all certificate creation and trading is undertaken by the installer. The Australian Government's clean energy regulator webpage has more information on STCs and a tool to help calculate the total value of STCs in a given system.[2]

Key steps in sizing a solar pumping system

- Determine the total dynamic head (TDH) of the system using flow-rate requirements (L/min), pipe length and diameter, and height between suction and discharge points. TDH = static head + dynamic head (line friction).
- Determine the daily flow (m^3/day) requirement and the expected number of weeks per year of pumping.
- Depending on the water source, choose a surface or submersible (bore) pump.
- Using manufacturer pump curves, select a pump of adequate size to meet head and flow requirements.
- Knowing the power requirement and running time for the selected pump, determine the electrical load profile of the pumping operation to then size the solar PV system. Refer to supplementary paper, *Solar photovoltaics.*
- The capacity of the storage dam or tank is determined by the flow rate the process requires and the storage time, which can be equal to amount of time outside daylight hours for which the pump normally runs.
- Consider using battery storage or combinations.

[1] An industrial-scale system is the SMA-diesel hybrid solution shown here: sma.de/en/solutions/off-grid-solutions/fuel-save-solution.html

[2] ret.cleanenergyregulator.gov.au/Certificates/Small-scale-Technology-Certificates/what-is-stc

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Worked example

A 5kW diesel pump runs 12 hours per day (10 hours during daytime + two hours at night-time) for 30 weeks per year and pumps water at a flow rate of 8 L/second and a 30m head. The solar PV capacity factor for the area is 15 percent. Evaluate the economic feasibility of installing a solar pumping system (comprising solar PV, DC pump and storage tank) to complement the existing pumping operation.

Estimate the diesel pump running cost

The 5kW diesel engine generates 5kW * 12 h/day * 30 weeks * 7 days = 12,600 kWh/yr of electricity. Using a specific diesel consumption of 0.3 L/kWh (33 percent efficiency), the annual diesel consumption is 12,600 kWh/yr * 0.3 L/kWh = 3,780 L/yr.

At a diesel price of $1.5 per litre, the annual running cost is 3,780 L/yr * $1.5/L = $5,670 p.a. The maintenance cost is estimated to be $100/MWh; therefore the annual maintenance cost is 12.6 MWh * $100/MWh = $1,260 p.a.

Estimate savings from solar pump system

If replaced with a solar pumping system of the same size (i.e. by a 5kW solar pump), and using a capacity factor of 15 percent, the size of the PV system required to power the pump for 12 hours a day (100% offset) is: 5 kW * 12 h/day divided by 0.15 * 8,760 h/yr divided by 365 days/yr = 16.7 kW.

Thus, the energy use that is offset by the PV system is 12.6 MWh p.a. (or 3,780 L/yr of diesel), as previously calculated, which equates to $5,670 in annual savings.

Estimate the size of the storage tank

The storage tank capacity is determined by the volume of water that is pumped outside daytime hours, i.e. when the solar PV pump is not available. This volume is: V = Q (L/h) * 2 h = 8 (L/s) * 3,600 (s/h).

Therefore, should you require* 2 hours of = 57,600 L…

Estimate capital costs

Assuming the PV system's installed cost is $2.5/W, the cost of a 16.7 kW PV system is $41,750. The installed cost of the 5 kW DC pump plus controller is estimated at $8,320 and the cost of piping is assumed to be $2,000.

The specific cost of the storage tanks is assumed to be 0.2$/L (installed); therefore the total cost of a 57,600 L capacity storage tank is approximately $11,500.

Thus, the total installed cost of the system is approximately $41,750 + $8,320 + $2,000 + $11,500 = $63,570.

Small Technology Certificates

It is assumed that for this specific location 346 STCs are created from a 16.7 kW system. Assuming a STC price of $30, the total STC capex discount is $10,380.

Total project cost and payback

The total installed cost of the system including the STC discount is: $63,570 - $10,380 = $53,190.

The operating cost of the PV system is estimated at $25/kW p.a., i.e. $25 * 16.7 kW = $418 p.a., giving a net saving of $5,670 – $418 = $5,252 p.a.

When including maintenance savings of the diesel pump, total savings are: $5,252 + $1,260 = $6,512 p.a.

The simple payback for the project is $53,190 divided by $6,512 p.a. = 8.2 years.

Considerations in evaluating quotes

The running cost of the pump is a key factor to consider in your economic evaluation. Diesel price and operating hours need to be assessed before you can determine energy savings.

The pumping efficiency of the solar pump for the particular operating requirements (flow rate and head) is a key parameter when comparing different pumping solutions.

The efficiency of the solar PV system and the capacity factor of the specific location of the project are other key parameters used in sizing the system and determining its output (and thus, its energy savings). The system's efficiency will depend on the type of PV module (e.g. multicrystalline, thin film), while its capacity factor depends on the module tilt angle and whether or not a tracking system is included. The specific cost of the solar pumping system ($/kW) is another benchmark parameter to note when comparing different options.

Compare the cost of a solar PV system with that of running an electrical line to the pumping location and installing a mains-connected AC motor. Cost considerations for this option are:

- the length of line you'll need to run, and the number of poles that will be required from the nearest electrical connection point to the pump location,
- whether the nearest access point for the extension to the pump location is single or three-phase power,
- if the farm only has a single-phase connection, the distance to the nearest three-phase connection point and the cost of running a new line to that point (note that if running a line proves too costly, it is still possible to use a variable speed drive to operate an AC motor),
- determining whether there is sufficient capacity in the existing line and transformers to accommodate the load from new motors, and
- determining the cost of an appropriately sized AC motor/ submersible pump.

When pumping water from bores into water reservoirs, key considerations should include:

- an understanding of water seepage and evaporation rates, especially in the context of farms that may be subject to water restrictions,
- possible lining/covering or reinforcement of embankments of water reservoirs, and
- consideration of alternate pumping arrangements or schedules that allow for the immediate use of water and bypass the need for storage.

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Further information

Information on solar pumps from Grundfos
Grundfos is a solar pumping company that offers several solar pumping solutions.
www.grundfos.com/content/dam/Global%20Site/Industries%20%26%20solutions/waterutility/pdf/Grundfos_Water-Utility_Solar-SP-Pumps_Brochure.pdf

Solar pumping solutions
A list of a number of Australian solar pumping case studies.
www.solarpumping.com.au/pumps_projects.htm

SMA fuel save solution
The website of a company that designs and installs large-scale solar-diesel integration systems.
www.sma.de/en/solutions/off-grid-solutions/fuel-save-solution.html

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New York State Energy Research and Development Authority (NYSERDA), "An Introduction to Solar Energy Applications for Agriculture"
www.matchinggrants.org/global/pdf/doc122-87.pdf

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