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Case Report

Sustainable Energy System: Case study of Solar Water Pumps

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A B S T R A C T

In rural areas of countries, agricultural lands require reliable and cost-effective water supply systems. This study evaluates the viability of replacing diesel pumps with solar-powered water pumps (PVPs) in rural Ohio, focusing on borehole depths <100m. The analysis shows that PVPs are a cost-effective alternative to diesel pumps, with a discounted payback period of 7 years for 3 HP solar water pumps. Using life cycle costing and financial modeling in Microsoft Excel, the costs and benefits of PVPs and diesel pumps are compared, demonstrating the economic and environmental benefits of solar water pumping systems.

Keywords: Solar water pumping systems, Agricultural irrigation, Rural development, Renewable energy, Sustainability, Cost-benefit analysis, Life cycle costing, Diesel pumps, Photovoltaic (PV) systems, Energy efficiency, Environmental benefits

1. Introduction

Solar power is a natural and efficient choice for water pumping, offering decades of reliable service with direct drive PV systems. Water pumping (PVWP) systems are simple, reliable, cost-competitive, and low maintenance, meeting a wide range of needs. Dramatic price reductions in PV modules (over 80% in a decade) make PVWP most cost-effective for steady pumping needs like community water supply and irrigation, reducing CO2 emissions from diesel pumps. PV pumping systems consist of a PV array, motor, controller, inverter, pump, and water storage tank, with passive tracking for increased pumping time and water volume. Solar water pumps are economical and environmentally friendly, ideal for farmers, horticulture, and rural areas, even without grid electricity. In a solar water pumping system, sunlight converts into electricity to pump water, depending on pressure, flow, and power. Northwest Ohio's rural areas require individual domestic water wells for crops, making solar water pumps an attractive option. Access to reliable and cost-effective water pumping solutions is a major challenge for millions of small-scale farmers worldwide. Solar water pumps (SWPs) offer a promising solution, with the potential to reduce costs and increase agricultural productivity. The proposed solar pump system utilizes a 3HP submersible pump, 3kW solar panel, and advanced electronics to deliver up to 60,000 liters of water per day. With a focus on simplicity, reliability, and environmental sustainability, the proposed system offers numerous benefits, including long-term cost savings, low maintenance, and minimal environmental impact. By leveraging the power of solar energy, the aim is to make modern irrigation accessible and cost-effective for farmers worldwide.

2. Technological Sustainability

Direct coupled DC solar pumping was first introduced in the field in the late 1970s. Earlier PV water pumping systems have limitations of overall performance of the system due to lack of proper design. Since then, manufacturers have refined their products to improve the performance and reliability. The steady fall in prices of solar photovoltaic (PV) panels have resulted in making solar pumping economically viable for an increasingly wide range of applications. Direct coupled DC solar pumps are simple and reliable but cannot operate at maximum power point of PV generator as the solar radiation varies during the day from morning till evening. However, adding a maximum power point tracker (MPPT) and controls/protections improve the performance of a PV pump. PV water pumping systems have shown significant advancements in the last decade. The first-generation PV pumping systems used centrifugal pumps usually driven by DC motors and variable frequency alternating current (AC) motors, with proven long-term reliability and hydraulic efficiency varying from 25% to 35%. The second-generation PV pumping systems use positive displacement pumps, by low PV input power requirements, low capital cost and high hydraulic efficiencies of even 70% . The current solar pumping technology uses electronic systems which have further increased the output power, performance of the system and overall efficiency of the system. The controller provides inputs for monitoring storage tank levels, controlling the pump speed and uses maximum power point tracking technology to optimize the water. Advancement has taken place in the tracking mechanism of PV arrays from manual tracking to dual axis automatic tracking systems by microcontroller programming.

Remote monitoring systems (RMS) allow manufacturers and service providers to remotely manage, service, and analyze solar water pumping systems, thus addressing one of the challenges associated with systems installed in isolated and remote locations. These systems can perform predictive maintenance, track system failures, and communicate directly with end-users to schedule maintenance.

Pumps are also classified as submersible and surface pumps. A submersible pump remains underwater, such as in a well or any other water body, while a surface pump is mounted above the waterline or adjacent to the water source. Most submersible pumps have high lift capability, but they are sensitive to dirt and sand in the water and should not be run if the water level drops below the pump. Surface pumps are more accessible for maintenance and less expensive than submersible pumps, but not well suited for suction and can only draw water from about 6 vertical meters.

The solar pumps available in the market can lift water from 5 m to more than 200 m with outputs of up to 250 m^3/day. For the past 15 years significant improvement has been done in helical motor pumps (positive displacement pumps) which are submersible and last for many years and are powered by similar motors as used for centrifugal pumps. Advancement has been in the field of controllers for large size PV arrays in the order of 25 kW with 100 kW controllers expected to be developed in near future [1]. PV module costs have significantly declined and are available at a rate of US$ 0.59/Wp in 2014.

A. Diesel pumping technologies

A diesel pump typically consists of four main components:

1. Diesel engine: For this study single or dual cylinder, air-cooled, hand-started diesel engines with a maximum continuous output power of 15kW are considered.

2. Pump element: The most common pump type is the helical rotor pump also referred to as the progressive cavity pump and the piston pump.

3. Discharge/Pump head: The discharge head is fitted above the center of the borehole. The rising main is fitted to the bottom of the discharge head and the engine is coupled to the pulley through belts.

4. Rising main: The rising main consists of 3m galvanized steel pipes (40- or 50-mm diameter) which are coupled together. The conventional diesel pump allows pumping off-grid and only requires fuel transportation to the area where the pump is being employed. The risks a diesel pump entails include environmental pollution and food contamination due to spillage. In order to overcome diesel price fluctuations, battery-based hybrid solutions that combine renewable sources are being developed. As batteries are still quite expensive, alternative hybrid models consist of fuel saving solar systems, which still need the diesel generator, but allow regular irrigation schedules. The most cost-efficient diesel-solar hybrid pumping system is the variable speed drive, where the diesel generator can be turned off completely.

B. Comparison between Diesel and Solar system Pumps

Variable water demand: Diesel pumps can pump water on demand. PVPs do not have that flexibility. A hybrid system such as solar diesel would present an attractive solution, however at a higher cost.

• Supply security: PVP is considered to have less redundancy, is more difficult to repair and is susceptible to lightning strike. Diesel pumping has a more solid service infrastructure and is considered more reliable.

• The diesel system is considered more flexible (flexible in moving a diesel engine to another borehole).

• Diesel fuel is part of an existing infrastructure and the owner can do the minor service on the engine himself. PVP technology requires knowledge of mechanics, electrical and electronics thus making the user/operator dependent on specialized service which is often only available in Windhoek.

• Corrosion is a problem for both diesel and solar pumps

• Diesel pump: Due to the poor quality of the steel riser pipes the installation does not last as long as in the past and the pipes have to be extracted and partially replaced every five to seven years.

• PVPs require no attention and start automatically and are ideal for weak boreholes.

• The environmental impact of diesel pumps includes carbon emissions, possible borehole contamination, and threat to borehole sustainability. PVPs be a resource protection if it is designed for the maximum sustainable yield of the borehole.

• The operation of PVPs is quiet.

PV modules represent 60–80% of the total cost of a PV system. The steady increase in cost of diesel and gasoline prices over the years and decrease in PV system costs make PV pumping attractive from financial perspective also. Furthermore, crystalline PV modules with high efficiencies of 16.84–21.5% are available in the International market in 2014.

C. Evaluation of solar energy system

Moving water using solar pumping systems offers a clean and simple alternative to electric and diesel-driven pump sets. SWPs are often used for agricultural operations in remote areas or where the use of an alternative energy source is desired. If properly designed, solar pumping systems can result in significant long-term cost savings and increased agricultural productivity to farmers.

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D. Suggestions

Most solar pumps are designed to be used in off-grid situations and are designed to be extremely efficient. The most efficient way to use a solar pump is PV-direct, powering the pump directly off the solar panel, without using batteries. Rather than experiencing losses through storing power in batteries, the water itself is stored in a tank to be used when needed. It's much easier to store water than power.

Pumps generally require a high surge in current when starting up, but not a lot of voltage. As a result, when solar pumps are starting in the dim, morning light, it can sometimes have trouble getting started. A Linear Current Booster (LCB) is a device that can be installed between the solar panel array and the pump to increase the current output to get the pump going in lower light. It does so by dropping the voltage output, which doesn't affect the water flow as much as current does. This will allow pumping to begin earlier in the day and continue later in the afternoon as the sun is heading down – giving you more water pumped overall during the day.

A float switch can be connected to control when to turn the pump on or off based on the water level. A pump-up switch or full tank shut off switch will turn the pump on when the tank is low and off when it is full. A pump down float will turn on the pump when the tank is full, and off when it is empty.

If a high storage tank isn't possible, a smaller booster pump can be added to the system to pressurize the pipes. This pump would have to be connected to the battery bank to allow pressurizing at any time of day or night. The booster pump will show the PSI capability and how many amps are needed to create the pressure. A booster pump increases low water pressure and flow. It provides the extra boost needed to bring your water pressure to the desired level. A water booster pump provides pressure to move water from a storage tank or throughout a whole house or commercial facility.

3. Environment Sustainability

The global warming potential and GHG emission potential from photovoltaic systems, during manufacturing, is far greater, up to 10 times than the conventional manufacturing. There can be 5 kinds of photovoltaic modules which are: multi-crystalline, monocrystalline, cadmium telluride thin film, amorphous silicon and copper indium selenide thin film. Amongst the 5 of these types of photovoltaic modules, cadmium telluride thin film has the best environmental benefits, on the other hand, silicon based are the worst to resort to [2]. The environmental strikes of these photovoltaic systems can be developed using better techniques for manufacturing, disposing, reducing thickness of the panel and recycling of the materials used in the module. Solar water pumps contribute to social development in several ways. Since other remote water supply systems are less reliable than solar water pumps. The use of solar water pumps therefore provides a reliable, safe and adequate water supply which improves the community's health. Other benefits to social development are the improvement of social cohesion within the community, reduced migration out of the community, and increased community interaction in social events due to increased time availability In addition, in many rural and poor communities there is a strong link between gender and water. women are responsible for the water supply, spending a large portion of their time to gather the water. The use of solar water pumps can have considerable positive effects for women in these communities. The scope of these benefits is very broad. For instance, the adequate water supply allows them to allocate more of their time to the other activities After installation of solar water pumps women in these communities might allocate more time to activities such as education Construction of the solar water pumps in the agricultural field will generate employment opportunities for both skilled and unskilled local labor. There will also be an induced migration to project areas for people from nearby communities looking for employment. Sourcing of materials locally and demand for local goods and services will increase the earning capacity of local businesses.

E. Evaluation

From an environmental point of view, grid driven water pumps can only be sustainable, if the electricity is produced with as little as possible emissions because the emissions of various gasses emitted by combustion of fossil energy sources like coal is related to climate change as well as health hazards [3].

Solar energy systems do not produce air pollution, water pollution, or greenhouse gases. Using solar energy can have a positive, indirect effect on the environment when solar energy replaces or reduces the use of other energy sources that have larger effects on the environment.

Generating electricity with solar power instead of fossil fuels can dramatically reduce greenhouse gas emissions, particularly carbon dioxide ($CO2$) [4]. Greenhouse gases, which are produced when fossil fuels are burned, lead to rising global temperatures and climate change. Climate change already contributes to serious environmental and public health issues in the Northeast, including extreme weather events, rising sea levels, and ecosystem changes.

By going solar, you can reduce demand for fossil fuels, limit greenhouse gas emissions, and shrink your carbon footprint. Switching from fossil fuels to solar power in the state has the same emissions reduction effect as planting around 150 trees every year [5]. According to National Renewable Energy Laboratory (NREL) among other health benefits, solar power results in fewer cases of chronic bronchitis, respiratory and cardiovascular problems, and lost workdays related to health issues.

However, some toxic materials and chemicals are used to make the photovoltaic (PV) cells that convert sunlight into electricity. Some solar thermal systems use potentially hazardous fluids to transfer heat. Leaks of these materials could be harmful to the environment. U.S. environmental laws regulate the use and disposal of these types of materials.

F. Comparison

When comparing the environmental impact of a PV and a diesel-powered pumping system, one has to take into account a product's whole life cycle – from production to recycling. PV pumping systems have a way smaller negative impact on natural resources depletion, human health, climate change and ecosystem quality than diesel powered ones. Indeed, electric pumping systems are more harmful than Solar pumps when electricity is generated from natural gas. However, the diesel pumping system becomes the better option when electricity is derived from coal and diesel-powered pump efficiency exceeds

12%.

G. Suggestions

Groundwater pumping, energy has the highest environmental impacts on human health, the ecosystem and resource depletion. The potential of increasing the ecological advantage of solar pumping systems compared to diesel powered pumping systems even further lies in increasing the efficiency and lifetime of OPVs (organic solar photovoltaic) and in the implementing of full-scale silicon recycling processes,

The Property Assessed Clean Energy Program (PACE) allows local and state governments to loan money to business owners for energy improvements, which they repay over time through property taxes Partnering with local solar installers to allow customers to lease panels over time can also help reduce up-front costs.

Community solar programs and Non- government organizations seeking for environment protection can allow customers to support and benefit from solar power projects in their communities. Customers can either own a share of a community solar project, or they can subscribe through a Power Purchase Agreement (PPA). Cities can work with their utilities to offer both alternative.

4. Conclusion

A review of current status of solar photovoltaic water pumping system technology research and applications is presented and investigated an agricultural area of 1 acre for irrigation purposes, but the system also can be implemented to the residential sector.

There will be potential work if industry leaders and stakeholders discuss the challenges facing the solar water pump market, setting priorities and policies for the coalition, and identifying interesting areas for this technology roadmap [6]. These topics included the pump energy system design, the environment achievements and the economics.

The study focuses on update on solar water pumping technology, performance analysis studies carried out, optimum sizing techniques, economic evaluation, environmental aspects, policies and regulations of using solar PV pumps worldwide. Based on the study main conclusions are as follows:

PV water pumping technology is reliable and economically viable alternative to electric and diesel water pumps for irrigation of agriculture crops.

PV water pumping for urban, rural and community water supplies and institutions, is another potential feasible sector but is not still widely utilized. The remote inaccessible locations with no grid electricity also need special attention. These sectors still depend on conventional electricity or diesel-based pumping system resulting in increased recurring costs to the users.

Keeping in view the high installation costs of solar water pumps especially for large irrigation and water supplies, more incentives are required to be provided by governments to make the technology further attractive alternative to diesel and electrical water pumping.

Factors affecting the performance and efficiency improving techniques, use of highly efficient PV modules including bifacial modules and degradation of PV generator are areas for further research for lowering the cost, improving the performance and enhancing pumping system lifetime.

Solar pumping is an attractive alternative for irrigation and rural, urban drinking water pumping applications in developing countries especially India, China, other Asian and African countries, keeping in view huge solar potential and the fact that significant rural population lives in the remote areas which requires water for drinking and irrigation of crops.

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