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Solar Driven Irrigation Systems for Remote Rural Farms

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Abstract

Solar powered irrigation technologies have developed significantly in the past decade assisted by the development of higher efficiency, low cost solar Photovoltaic (PV) panels. The technology has come so far as to be able to elapse diesel powered irrigation systems in terms of the payback period and reduction in greenhouse gasses. However, PV technologies are still not being used extensively due to their high initial investment costs and compared to other renewable energy technologies the carbon footprint is still comparatively large. On the other hand, solar thermal technologies are seen to be much cheaper, and have a much smaller carbon footprint, but are marred by low efficiencies. This paper investigates solar powered irrigation technologies (PV and solar thermal technologies) that can be utilised by independent farmers in small-scale remote rural farms in Sub-Saharan Africa. The focus is to be able to identify affordable solar powered irrigation systems that will make use of local resources effectively for drip irrigation.

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Keywords: Solar Energy; Solar Water Pumping, Photovoltaics, Concentrated Solar Thermal, Stirling Engine, Irrigation

1. Introduction

The world population is increasing exponentially and with this there is growing food insecurity that necessitates more farming, and hence, irrigation all over the world. As global temperatures continue to rise, the effort must not only be to boost production but to also do so in consideration of the environment. Furthermore, there is a social

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responsibility that must be addressed in the arid and semi-arid regions of the world where the conditions are getting worse and independent small-scale farmers are getting poorer still as they deal with long dry spells, unreliable safe water supply and polluted ground water reserves. This dictates the development of sustainable irrigation technology that not only serves the purpose of irrigation, but is environmentally friendly and can be afforded in rural areas.

The Sub Saharan Region of Africa has been dealing with inconsistent water supply issues for a long time. Their most reliable source is the abundant ground water supply. However, due to lack of economic incentives only 10% of the reserves are being used [1]. Small scale farms in this region are an average size of 1 hectare [2] and are often in remote rural areas. The farmers there can't cope with the high initial investments required for the purchase of generators and pumps. In addition to this, with the rising fuel costs and regular maintenance, the operation costs are also extremely high for local farmers using conventional technology [3]. The technology needs to improve, and emphasis must be put on renewable energy technologies to move forward in this regard. Solar power, in particular, has great potential in Africa receiving over 2000 kWh of global solar radiation annually, much greater than that received by the top countries implementing solar energy in the world [4].

With high potential in both photovoltaics and solar thermal energy [5], this study tracks the major technological developments made in PV and solar thermal power irrigation technologies and compared on the basis of cost, power output and flow generated. One of defining factors for the suitable technology also discussed, is the ability to make use of the local resources sustainably, this will help reduce the initial costs, maintenance costs as well as reduce the carbon footprint.

2. PV Irrigation Systems

PV irrigation systems use PV panels to produce electricity from solar energy which is then used in conjunction with an electric motor to drive a pump. This system can be further enhanced with the use of batteries for electricity storage, or incorporating a storage tank for water. The type of Pump (whether AC/DC) may also be considered which in turn dictates the type of motor to be used. For instance, in the case for AC powered pumps an AC motor will be required thus an inverter needs to be added to the system to convert the DC power from the solar panel to AC for the motor to utilize. With decreasing cost of PV panel technology, easy integration with available technology, reduction in price of Lithium Ion batteries and rapid commercialisation in recent times, PV irrigation systems have become more accessible for rural farms and a large amount of research has been undertaken on their performance, feasibility and economic viability. Fig. 3 shows performance data of various solar PV systems as per review by Saeed et al [6].

Multi-Junction PV panels are the most efficient form of PV panels but the environmental impact of these panels are higher than that of other renewable energy sources [7,8]. Cadmium telluride cells are a better option with a module efficiency of 19.1%, with the least greenhouse gas emissions and quickest payback period [7,9]. In terms of cost, PV systems fare better in the lifetime cost analysis when compared to diesel [8–10]. The initial investment cost for PV panels are however too high in comparison to Diesel and other renewable energy systems such as solar thermal and wind [8]. However, a PV system can have a payback period of under 6 years [9], which is unmatched by other types of irrigation solutions in remote rural areas.

Based on research by R. López-Luque et al. [11], to irrigate 1 hectare of land less than 1kW power is required and in such cases where the power system required is less than 5kW, the DC motor system is preferred over AC motors. The study further indicates that permanent magnet DC motors provide the highest efficiency, torque and fastest response in comparison to other DC systems. The Positive displacement pump is shown to be beneficial for higher heads while for lower heads the diaphragm pump is better suited both providing efficiencies of 70% [9,12–14].

The use of battery is subject to the location and type of irrigation requirement, the costs of the systems also vary likewise. While an overhead tank may suffice in certain scenarios, others demand the use of battery for on demand use of electricity and a more consistent electricity supply [12,13]. Research by D. H. Muhsen et al. [15], on the other hand, proposed an aluminium foil reflector to boost the solar radiation.

The Power output and costs associated with PV systems vary depending on the irrigation scenarios [14,16–21]. To optimise the design of the PV system and the associated costs, it is important to understand the requirements of the crop by performing site surveys and analysing the working conditions. Considering the high solar potential in sub Saharan Africa and a case for drip irrigation, Fig. 1 shows the proposed solution for retrieving underground water for irrigation. The system provides 13.65% over all thermal efficiency.

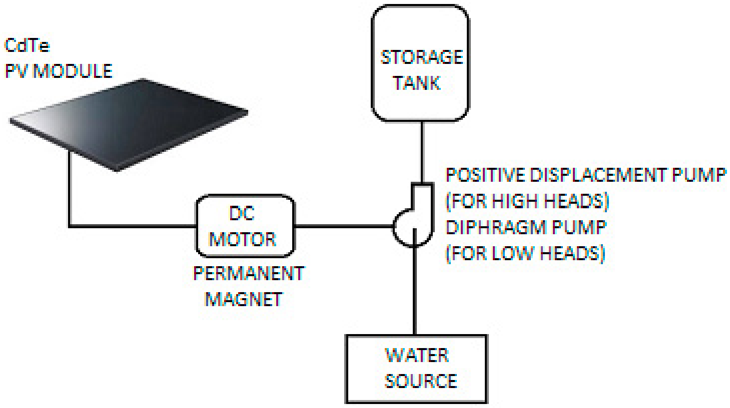

Fig. 1: Schematic of proposed PV water pumping system for remote rural areas of Sub Saharan Africa [6]

Drawback of PV technologies include, the degradation of power of PV cells due to long term exposure is 0.8% per year [22]. At the elevated temperatures and humidity expected in sub-Saharan Africa the issue may be more prevalent. To compensate for this, more intelligent systems may have to be incorporated which will further increase the cost. Another issue with PV technology is that it's manufacture process poses a higher threat to the environment in comparison to other Renewable Energy Technologies and about 4 times more harmful than Nuclear technology [8]. Using batteries and the transportation further elevate the carbon footprint of the technology. Finally, accumulation of dust is another issue associated with PV technology.

3. Solar Thermal Irrigation systems

Solar thermal systems utilize the energy from the sun using a solar collector or a solar concentrated surface to generate mechanical work via a Rankine, Brayton or Stirling Cycle engine. The work generated can be used directly or converted to electricity to power pumps for irrigation. While direct utilization of mechanical energy is desirable, storage of thermal energy is much more complicated when compared to storage of electricity. Location factors and irrigation scenario dictates the selection of direct mechanical drive or conversion to electrical power. There is a shortage of real life testing of solar thermal technologies for irrigation. Fig. 4 shows performance data of various solar thermal systems as per review by Saeed et al [6].

There are two types of solar thermal irrigation systems conventional technologies that use the Rankine Cycle and unconventional systems that use vapour cycle liquid pistons or metal hydride systems [23]. Conventional systems are much larger and more complex in comparison to unconventional systems but is the most widely tested solar thermal systems [8]. Conventional systems require high investment costs, maintenance costs and have very low efficiencies (around 1%) and hence aren't considered for wide scale use for irrigation[14]. Instead conventional solar thermal irrigation may be undertaken in conjunction with desalination, or power generation [15,23]. Standalone, conventional systems are large, expensive and immobile in comparison to PV.

Unconventional technologies include Stirling Engine systems, Two stroke piston systems which are similar to Stirling systems [24,25] and metal hydride systems. Unconventional solar thermal technologies, generally have low pumping potential except for metal hydride systems that have flow of up to 2000 litres with a flat plate collector of just 1m^2 area. However, metal hydrides are expensive and not easily accessible in remote locations [8,23,26].

Stirling engines, are low cost systems, compact and easy to manufacture. Stirling engine irrigation systems are studied for low temperature operations 60 °C – 95 °C [23,27,28]. Due to the flexibility of Stirling systems in accommodating various heat sources and with the possibility of using better solar concentration techniques, higher temperature differences may be obtained which in turn will ensure a larger output from the system[23,25].

The dish type solar concentrator is relatively cheap and the most commonly used solar concentration system used capable of providing concentration up to 500 °C with a single axis tracker. Based on this system, cheaper and easier to manufacture concentration technologies have been designed such as the Linear Fresnel Reflector (400 °C concentration) [29]. Hence, the dish system is a good baseline for concentration technology that can be implemented with solar thermal irrigation systems. Local construction will further reduce the cost as well as carbon footprint of the system. Fig. 2 shows the proposed solution for retrieving underground water for irrigation in Sub Saharan Africa. A hybrid system comprising of Stirling pump with mechanical assist from an external system may be proposed to assist the displacer similar to work conducted by Jokar and Tavakolpour-Saleh [28].

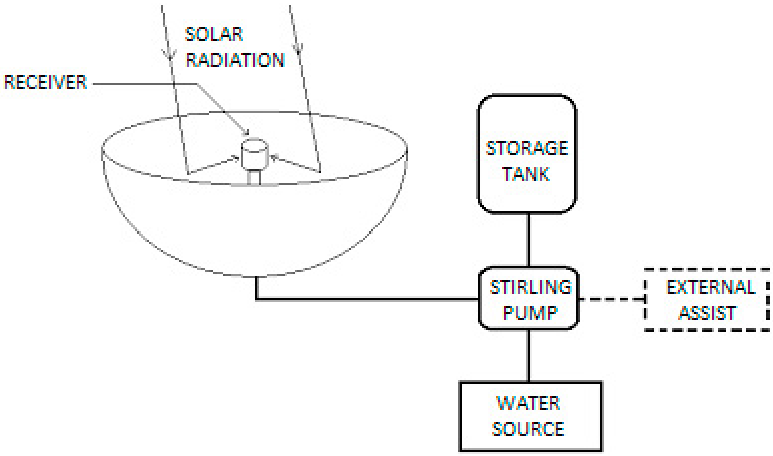

Fig. 2: Schematic of proposed solar thermal water pumping system for remote rural areas of Sub Saharan Africa [6]

4. Comparing Solar PV and Thermal Technologies

Solar photovoltaic systems are far more developed in comparison to solar thermal systems. PV systems have been studied extensively (see fig. 3) and can provide wide range of capabilities ranging from small scale to large scale systems. One of the major issues of solar panels is the investment costs associated with the systems. Even though solar PV technology has seen a decline in costs, it is still very expensive for small scale, independent farmers. Based on the review, solar thermal technologies are not as flexible as PV technologies. Positive results have only been obtained in large scale Rankine systems. However, using the Stirling pump system, solar thermal technology could be utilised for small scale irrigation purposes. There is already a commercially available Stirling pump technology, SunPulse. However, the SunPulse system costs between US$1250 – US$2500 [30] which is still expensive for the Sub-Saharan Africa region. The research aims to develop a system that would be cheaper in comparison to the SunPulse system and this will be done by using locally available resources. Doing so will generate a source of income for the Sub-Saharan Africa region, reduce the cost of the technology, lower the carbon footprint and GHG emissions, and provide local, small-scale, independent farmers with a more affordable irrigation technology.

Data obtained from review [6] have been graphically reproduced for PV technologies as shown below:

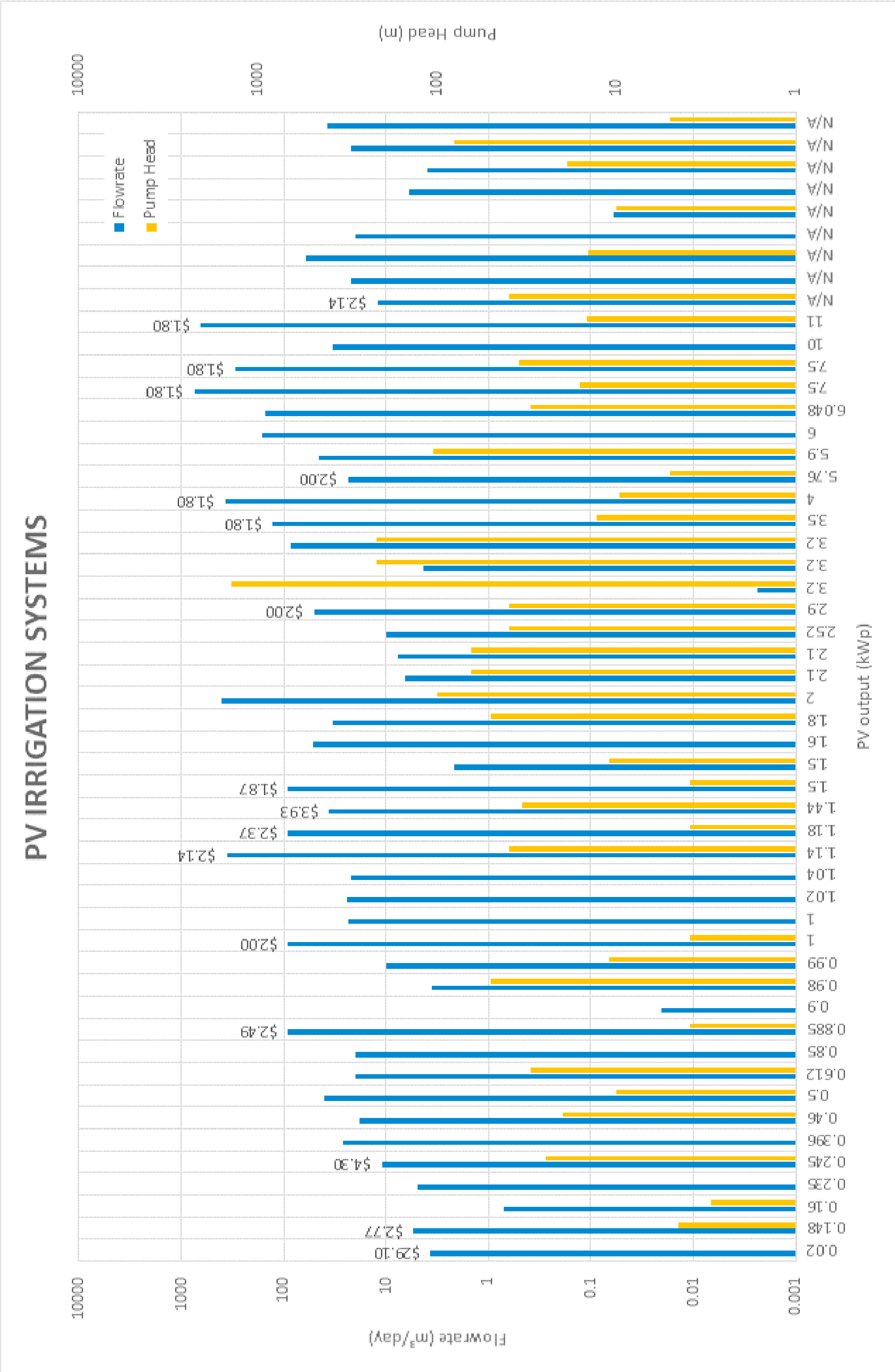

Fig. 3: Shows PV Irrigation data mapping flowrate and pump head to PV output and cost per Watt of system shown where available

Data obtained from review [6] have been graphically reproduced for solar thermal technologies as shown below:

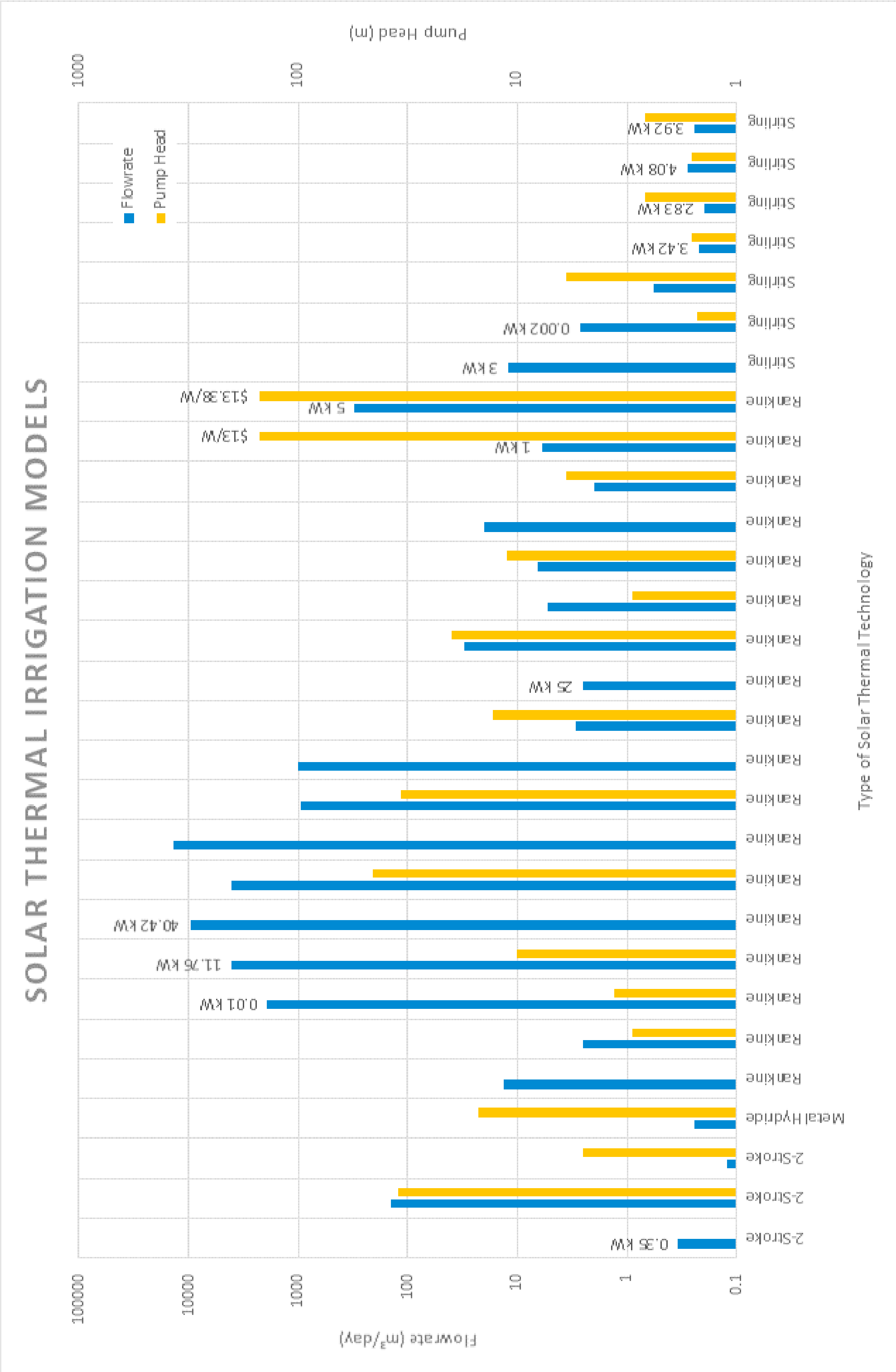

Fig. 4: Shows data of different types of solar thermal systems and the flowrates, head, power generated and cost per Watt as available.

5. Conclusions

Various PV and solar thermal technologies have been discussed. Based on the literature review. The most effective PV system includes and CdTe PV module running a permanent magnet DC motor that drives a pump. The system only functions during ample sun hours and stores water in a storage tank instead of utilising a battery. The most effective solar thermal system utilises a solar concentrator powering a Stirling pump. Similar to the PV system there is no energy storage but instead the system functions at optimal sun hours and stores water.

There is a lot of research and real-life data for PV technology. PV systems require low maintenance and has almost no operational cost which has seen the system implemented abundantly in recent times. However, considering the Sub-Saharan African region, PV systems are still very expensive. Due to its simplicity, Stirling engines provide the opportunity of a solar thermal integrated irrigation system that can be locally produced. Furthermore, Stirling engines can be directly used as a pump thus reducing the number of components in the system. Local production also makes Stirling pumps more environmentally friendly with lower carbon footprint and greenhouse gas emissions when compared to PV systems.

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