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Solar Radiation as Energy Source for Plants Water Pumping System

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Abstract: A solar based water pumping system for watering of plants in garden was established in this study. Daily energy generation for the period of 3 months were assessed and the effectiveness of the solar radiation for powering up the pump was evaluated. A complete solar photovoltaic (PV) system which includes 50W solar panel, solar charge controller, AC-DC converter and 12V DC battery was established in the work where it was used to water *Aloe Vera* plants. Data shows that water flow rate reached its maximum value during sunny days were radiation at its peak and recorded a very low rates during rainy days. An almost 45-50% reduction in the water flow was seen during the bad weather with least solar radiation. Despite the bad weather, water supply was not halted and sufficient energy have been generated to ensure a consistent pump operation for the growth of the *Aloe Vera* plants. In can be concluded that, solar based pump is indeed suitable for watering plants in the garden even though at times solar radiation is not at its peak. This is because it seems that plants did not need to be watered on 24 hours basis. On contrary, minimum volume of water is needed to ensure good plant growth.

Keywords: Solar panel, Pump efficiency, Plants watering, Solar powered pumping system.

1. Introduction

Water is a critical input for plants growth and agricultural production [1]. It is also an essential element in food security. In plant growth, water helps germination of seeds, plays an important role in photosynthesis (where plants processes/prepare their food), transports of nutrients and minerals from the soils to plants, and supports in maintenance of plant structure where it applies appropriate pressure to the plants tissue [2]. Moreover, irrigated agriculture crops and plants contributed nearly 40% of the

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total food produced worldwide. When water is lacking, plants and/or agriculture crops will use long-term storage of starch to build energy through respiration. Nevertheless, if water is not replenished, the conversion of starch into energy exceeds the production of starch and thus, made the plants weak. Consequently, the leaves lose its original structure which indicates early warning that the plant needs watering [3].

In rural area where there is no electricity watering of plants is solely depending of rainfalls. However, during lengthy warm climates water is rarely available for the plants. Alternative solution would be to establish a water reservoir adjacent to the plant area and water the plants with the use of pumps. Pumps run on electricity and without it, rendering them worthless. A viable solution would be to employ a solar-powered pumps (a water pump powered by a solar radiation energy system). No electrical power points are needed and energy for the pump is generated through solar radiation [4]. The rapid advancement of solar energy, particularly photovoltaics, makes this technology very appealing for use. A solar-powered pumping system costs about the same as a new windmill, but it is more dependable and requires less maintenance. A solar-powered pumping system is more expensive up front than a gas, diesel, or propane-powered generator, but it requires significantly less maintenance and labour in the long run [5].

Although electricity generation via solar photovoltaic (PV) is not yet cost-effective when compared to electricity supplied by a conventional national electric grid, it is currently cost-effective when compared to the cost of extending the electric grid in stand-alone installations especially in rural area. The solar pump helps to transport water to the plants and are very effective when the weather is sunny and dry. They can be installed in valley and forest areas or other locations where wind exposure is poor and accessibility to national grid is difficult [6].

In this study, a 50W solar PV water pumping system for plants was established and its performance were evaluated based on the pumping efficiency at various weather conditions. The solar PV system includes 50W solar panel, solar charge controller, AC-DC converter and 12V DC battery. As a proof-of-concept, *Aloe vera* plants were grown on a large pot and watered using the established water pumping system. Arduino data acquisition platform was used for data logging where it records the daily water pumping rate by the solar pump system. Installation cost and pay-back period for energy savings (value for money in installing solar PV electrical system) was also discussed.

2. Materials and Methods

2.1 Solar-powered pumping system

A solar powered pump operated based on the electricity produced by solar photovoltaic (PV) panels where energy is solely depending on the radiated thermal solar energy from the sunlight. The schematic diagram for the solar powered pump system is illustrated in Figure 1. It consisted of 50W solar panel, solar charge controller, 12V 40Ah battery, a DC-AC converter and finally the pump. The solar panel is the main element of the system and it produces electricity based on the solar radiation. A 50W solar panel was used and it is connected to the charge controller. Energy harvested by the solar panel i.e. in a form of direct-current (DC) voltage is channeled to the 12V battery and linked to the DC-AC converter. The battery stored any excess energy from the solar panel where else the DC-AC converter converts DC form energy into alternating-current voltage that is needed for the pump operation. Moreover, the solar charger controller also records the amount of energy produced. Finally, a pump was connected to the power inverter where it transports water from the main water source into the designated planting area. The pump was chosen based on the amount of water discharged and the head of water. Lastly, a sprinkler was used in this setup where water was pumped around a set of pipes. It is then divided by sprinklers, resulting in the formation of small water drops that fall to the ground. At the terminals, spray heads evenly disperse water throughout the whole soil surface.

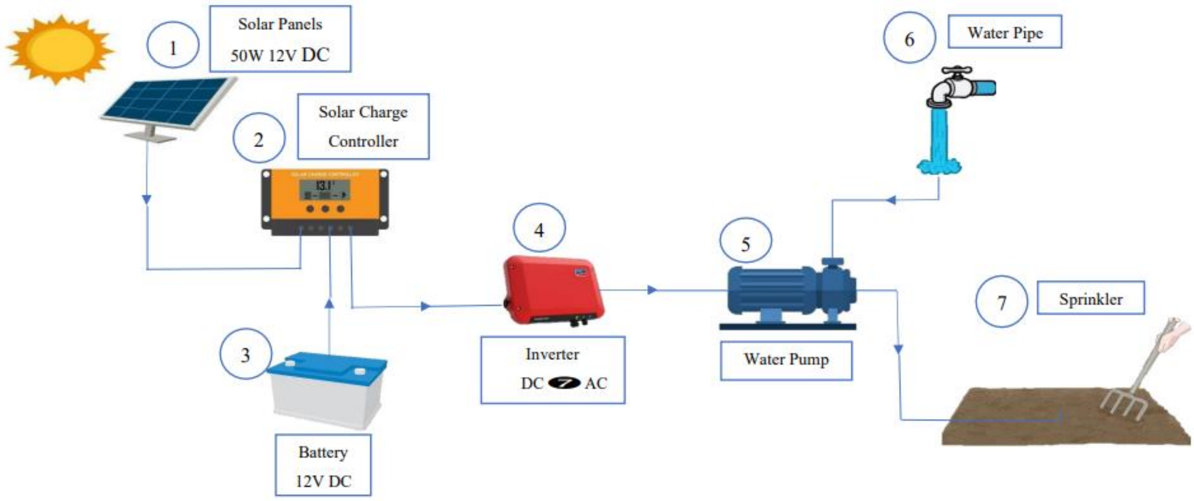

Figure 1. Schematic of the solar-based water pumping system established in the work for watering of *Aloe vera* plants; (1) solar panel (2) solar charge controller (3) 12V battery (4) DC-AC power inverter (5) water pump (6) water source (7) sprinkler piping system.

2.2 *Aloe vera* plant growth

Aloe vera plant is a succulent plant. Similarly, to cactus, succulents (i.e. *aloe vera* plant) would do best in dry conditions [7]. Such characteristic in indeed ideal for the proof-of-concept of the solar based pumping system where continuous water supply is not compulsory for the plant growth. A large pot containing regular potting soil with addition of non-organic perlite additive was prepared for the *Aloe vera* plant growth. The pot use also has reasonable amount of holes in order to allow water drainage. About 4-5 cm of *Aloe vera* tip leave was planted as seed into the pot and watered regularly for the plant growth. The progress of the plant growth was evaluated by measuring the height of the plant from ground up using a ruler. The plant was grown indoor in order to ensure that water supply for the plant growth came only from the water pump.

2.3 Data logging via Arduino platform

Arduino UNO data acquisition device was integrated into the setup for data logging. A small water flow sensor was connected between the pump and the sprinklers system to enable for the measurement of the water flow rates in liter per minute. The sensor sends out analog DC voltage signal ranging between 0 and 5VDC. Calibration was performed by correlating the analog DC signal from the water flow sensor to the actual water flow rates. The water flow rates were measured manually by estimating the time needed (in minute) to achieve 100 ml of water. Monitoring was done using a laptop and data generated from the water flow sensor was stored using a memory card module for Arduino. All system was operated automatically.

2.3 Estimation of power generation by the solar PV

The power generated by the solar PV panels ($P_{MP} - kWh$) used in this work is estimated using the following equation-

$$P_{MP} = e_{PV} \, . H_G \, . A_{PV} \, . n_S \, . n_P$$

Where e_{PV} is the efficiency (%) of PV panels – assuming to be about 20%, H_G is the solar radiation (kWh/m^2) incident on solar panels, A_{PV} is the area of solar panel (52m x 67m), n_S and n_P are the number of serial and parallel panels which in this work only one was used.

3. Results and Discussion

3.1 Solar energy profiles and solar-pump pumping capacity

Solar energy profiles and the workability of the solar based pump established in the work were evaluated for the period of three months i.e. between April and June 2022. Figure 2 shows the average daily incident shortwave of solar energy per square meter of the panel installed. Shortwave radiation is a radiant energy produced by the sun that contains wavelength ranging from infrared through visible light and ultraviolet. Such shortwave radiation contains high amount of energy that can be collected by the solar panel [8]. Amount of energy collected (and/or produced) was calculated and was found to be between 4.4 kWh and 4.8 kWh in April, 3.9 kWh and 4.3 kWh in May, and between 3.8 kWh and 3.9 kWh in June. Local weather conditions in Parit Raja in these months (i.e. between April and June) shows a gradual increase of cloudy weather conditions and not much of sunny days. These explain the drop in the incident shortwave energy from April to June. Despite the bad weather, sunny days hit its peak around the midday and recorded a temperature as high 38-39^{o}C.

Since the experiment was indeed carried out in Parit Raja, Johor, local weather does have a significant impact on the amount of solar energy generated and therefore, influences the water pumping rate as well. Figure 3 illustrates the variation of the pump capacity throughout the month of April until June 2022. In April 2022, although a steady voltage current was recorded from the solar panel, the water pumping capacity did not operate at its maximum rate. The solar-pump merely managed to retain pumping capacity between 3 l/min and 4 l/min. However, at times especially during sunny day the solar pump did manage to supply water about 5 l/min and 6 l/min. A steadier flow conditions was observed in May 2022 where water flow rate remains high around 7-8 l/min. In fact, in the first week of the month, during nearly 6-7 hours of clear and sunny day, the solar pump managed to function stably at approximately 9 l/min. A similar trend can also be seen in June 2022 whereby water flow rates varied slightly between 7 l/min and 9 l/min throughout the month. A large drop in the water supply was also observed in June 2022 where it only managed to operate at 4 l/min. It was suspected that during these times (i.e. beginning of 2nd week of June and the last week of June), heavy rains lasted nearly a day long and perturbed generation of electricity via solar panel.

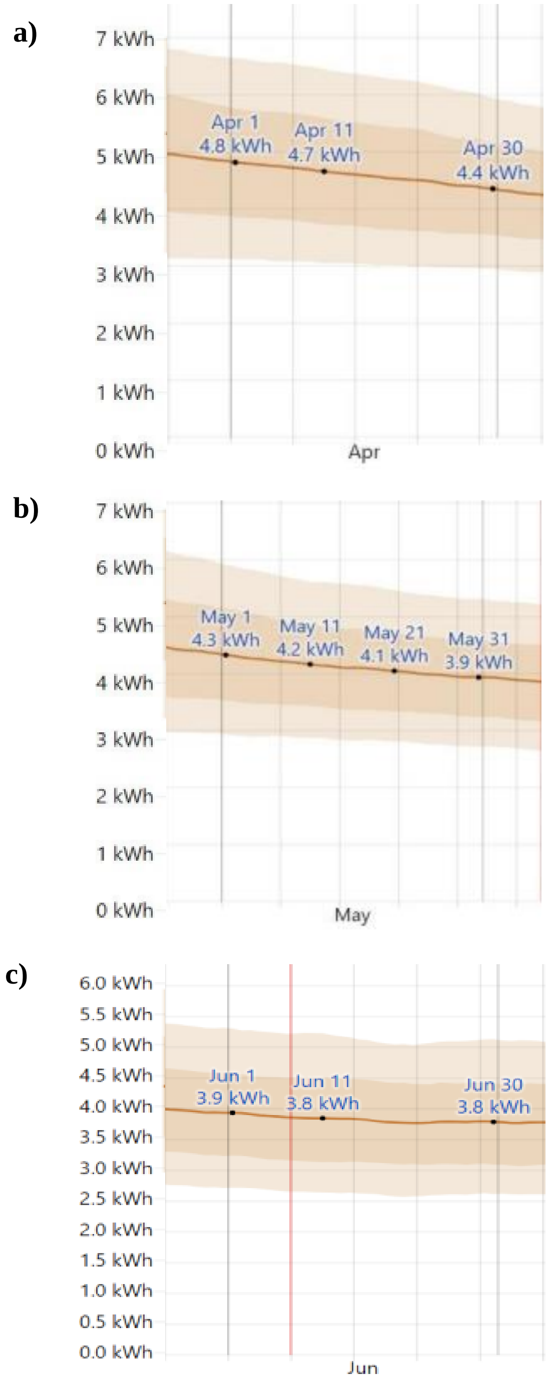

Figure 2. Profiles of average daily incident shortwave of solar energy in a) April b) May c) June.

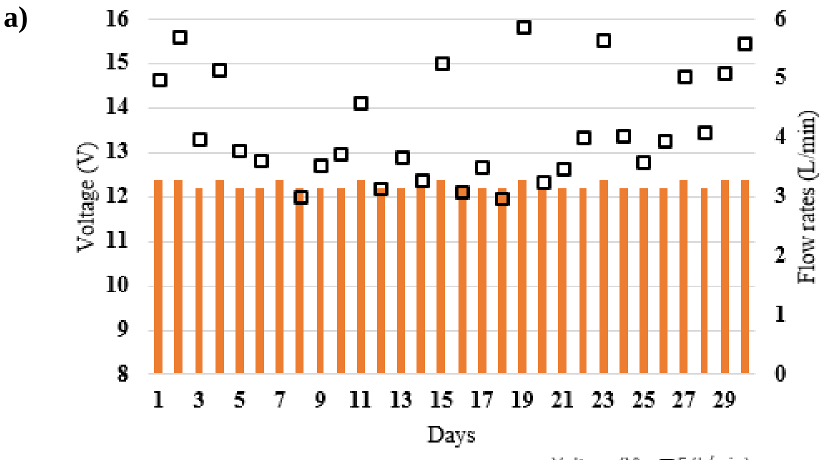

Figure 3. Profiles of average solar energy generation (DC voltage) and pumping capacity in a) April b) May c) June.

3.2 Growth of *Aloe vera* Plant

In order to further demonstrate the functionality of the solar-based pump, *Aloe vera* plant was grown indoor and water for the plant growth was only supplied by the solar-based pump. The progress of the growth for the *Aloe vera* plant is presented in Figure 4. It can be clearly seen from the growth profile, the *Aloe vera* plant had grown steadily for the duration of weeks where it grew 0.375 cm per day. Given the size of the battery used for the solar-based pump, the pump operation only lasted for 3-4 hours before the energy stored in the battery is completely depleted. Despite that, from our observation, there was no growth defect such as dead leaves or yellowish color leave that usually shows nutrient deficiency in plants. It was suspected that sufficient amount of water has been supplied to the plant and there was no sign of water logging. Water logging usually occurs when soil is too wet (results of too much water) and could cause root rot and susceptible to soil borne disease [9]. Such condition is not desirable for the growth of *Aloe vera* plant.

a)

b)

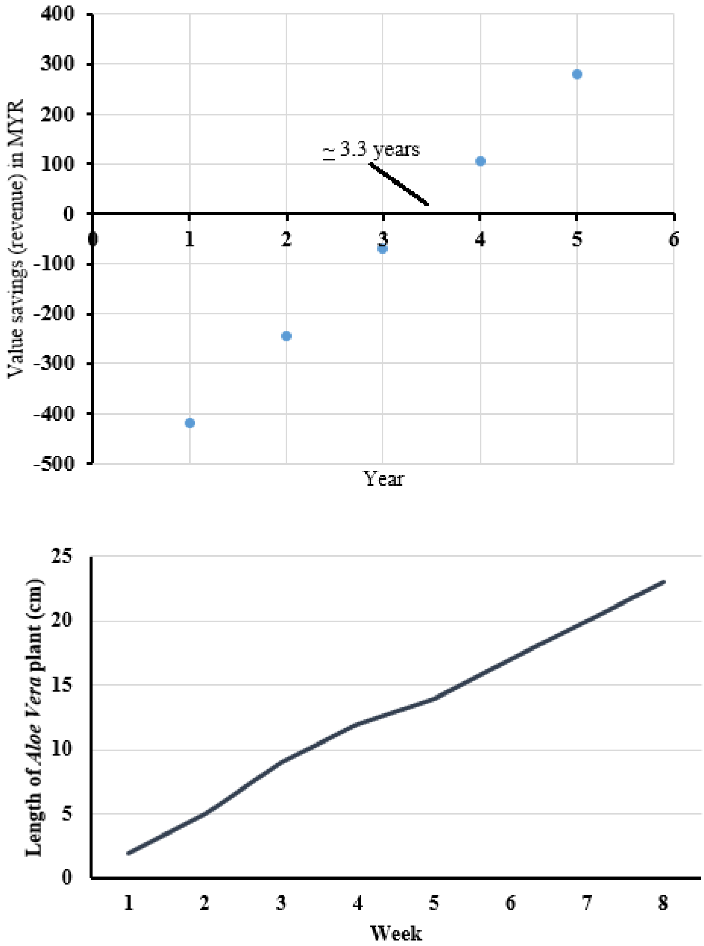

Figure 4. a) Payback period of the 50W solar panel installation cost (~3.3 years). b) The progress of the *Aloe vera* plant growth over the period of weeks.

Although the installation for such solar-based pump can be expensive at times but given the current electricity rates, energy can indeed be saved and break even in few year times. In our work, total cost to set-up the solar pump is approximately RM 507 and for an electricity tariff of RM 0.5 per kWh, it will take about 3.3 years to break even and start to profit from the energy savings (Figure 4a). Moreover, solar pumps are not that difficult to install these days. There are also easy to maintain and use regardless whether it is for supplying water to a garden or to power an irrigation system. Water supply can be achieved without worrying too much on the increase of the electricity bill.

4. Conclusion

A solar-based water pumping system has been successfully established where it included 50W solar panel, solar charge controller, AC-DC converter and 12V DC battery. Stability of energy generation was evaluated for the period of three months where incident shortwave solar was recorded to be within the range of 3.8 kWh and 4.8 kWh. Water flow rates as high as 9 l/min was recorded during clear sunny days and drop significantly to 4 l/min during cloudy and rainy days. Despite the bad weather, water supply for the growth of the *Aloe vera* plant was not halted and was sufficient to support the plant growth. Payback period for the installation cost of the solar-based pump system was found to be about 3.3 years. It can be concluded from this work that solar-based pumping system is indeed a viable solution especially for irrigation system in remote area or for a watering plants in the garden where electrical points are not accessible.

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