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Research Article

Comparative Study Between the Track Solar PV and Fixed Solar PV in Water Pumping System

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Abstract: Solar pumping system is among the renewable energy techniques developed over the decades, and this system is used to solve the problem of water and food scarcity since the amount of rainfall is consistently decreasing especially in the northern part of Nigeria. This research tends to design the solar pumping system with automatic tracking of the solar PV to optimize the amount of solar irradiance extracted by the solar PV under the climatic conditions of Kano State, Nigeria, and it compares the results obtained with the system without tracking technique. It was found that the total average amounts of water pumped by the tracked and fixed systems were 1370 m^3/day and 804 m^3/day for sunny days. And for cloudy days they were 750 m^3/day and 714 m^3/day. It was recommended to develop an energy storage battery with very sensitive material to store the solar energy extracted to cover the gap between sunny and cloudy days.

1. Introduction

Food and water are among the necessities in the life of both animals and plants, but food scarcity is the major challenge of mankind in most developing countries like Nigeria. This food scarcity is due to the low rainfall rate especially in the Northern part of Nigeria and lack of the irrigation channels in the areas. Local farmers are suffering from these issues, and solar pumping systems will solve these problems.

A solar pumping system is a system that pumps water with electricity generated by photovoltaic modules. The operation of this system is simple in operation with its low cost of maintenance and it's friendly to the environmental impact. Solar pumping systems are useful where there is no grid electricity [1].

The solar photovoltaic arrays are connected directly to the controller which tracks the solar beams falling on the arrays in order to optimize the solar irradiances harnessed by the solar photovoltaic arrays, and converts the DC energy extracted by solar PV to AC energy, and the AC motor shaft is connected to the pump [2].

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The quantity of water pumped by a solar pumping system depends on the total amount of solar irradiances harnessed in a specific time. The flow rate of the water pumped is determined by both the amount of solar energy available and the size of the PV array used to convert that solar energy into electricity [3].

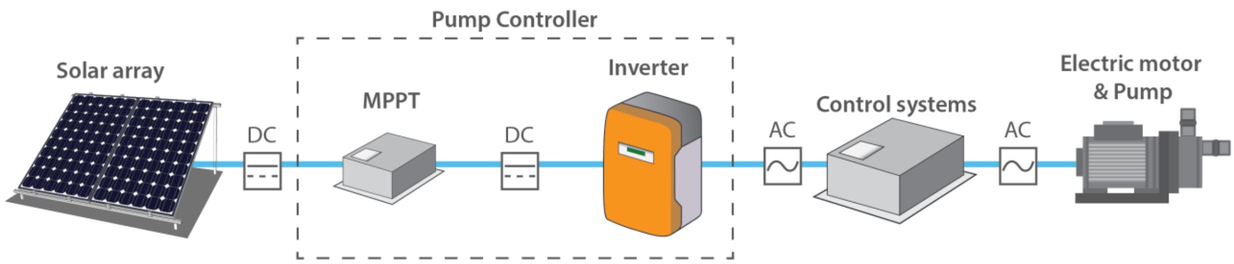
Many works have been done relevant to the solar pumping system among which there are some conducted with hybrid solar PV systems and some others carried out using tracking control systems. According to Ahmad *et al.* [4], the larger pumping systems with a capacity of 150,000 litres/day of water were achieved from an overall head of 10 meters. Manfrida and Secchi [5] designed a solar hybrid system for pumping water and generating electricity. The analysis was performed on two different types of motors: one with variable speed and another with constant speed. It was concluded that at a constant speed of pump with 7000 m^3 of storage capacity and at 42.8% of the energy generated by the PV capacity of 600 KWp can be stored. Whereas the analysis with the variable speed of the pump with 9000 m^3 of storage capacity, at 48.6% of the energy generated by the PV capacity of 600 KWp can be stored. Munir *et al.* [6] designed and constructed a water pump system in a remote area of the Iraqi-Syrian border location for drinking purposes with a capacity of 130 m^3. Alajlan and Smiai [7] designed and constructed two main PV systems, one for the pumping of water and another for the desalination of water by reverse osmosis method and the desalination produces 600 litres/hour.

Solar pumps for irrigation are under-utilized for most of the year because the irrigation farming system is a seasonal farming system, but this system can also be utilized for domestic uses and the rearing of livestock animals.

2. System Description

The study was conducted in Garko Local Government, Kano State. Garko is located in the East of Kano City with coordinates of 11°39'N, 8°54'E and a total population of 162,500 during the 2006 census [8]. The local government occupies a total of 450 square kilometers.

This system consists of solar arrays where the solar irradiance is harnessed as direct current (DC), and these arrays are connected with Maximum Power Point Tracking (MPPT) control which is used to make the solar arrays at an optimum solar trajectory to harness maximum solar irradiances. Solar inverter is used to convert direct current harnessed by solar arrays into alternating current (AC) and it is linked with the MPPT control and finally to the electric motor which is used to run the water pump. Then the water pump actions take water from the well, dam, river or any water source to the overhead tank as shown in Figure 1 below.



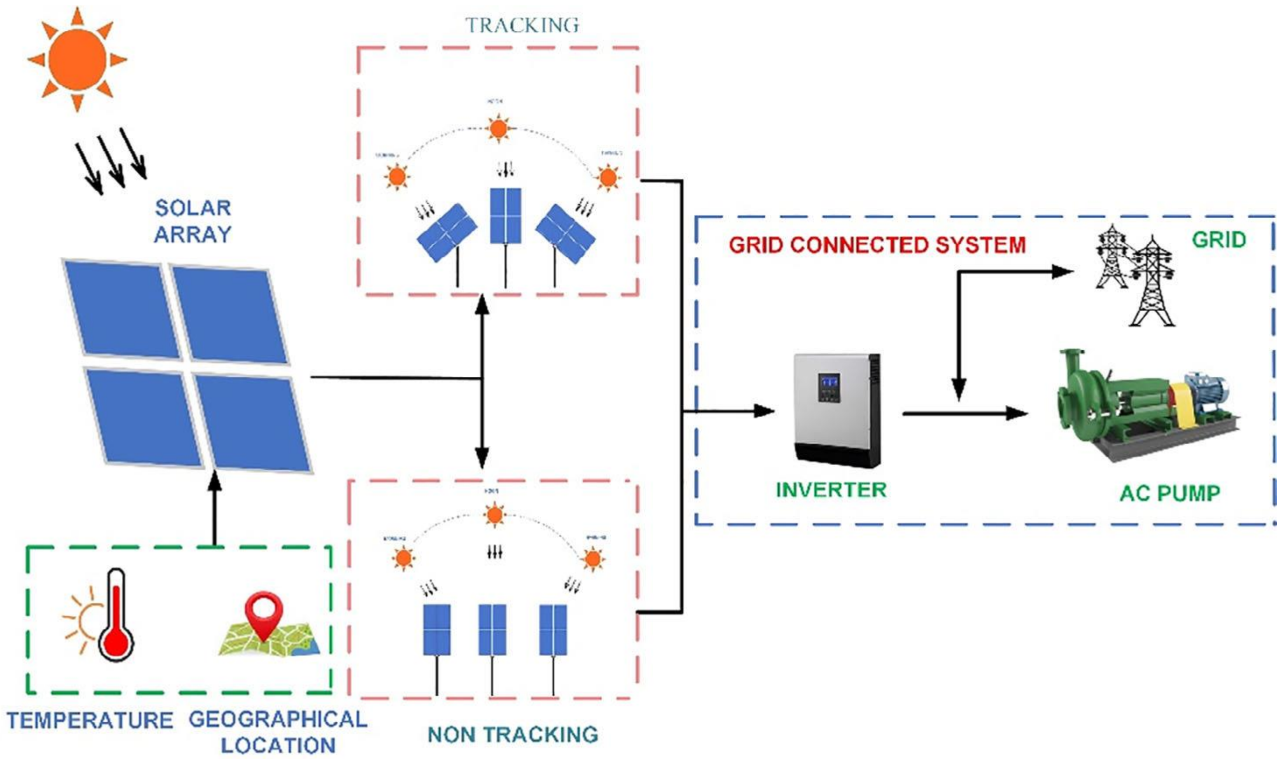


Figure 1: Solar Pumping System Configuration [11]

This system typically uses a surface pump system whereby a shallow well (Tube Well) is used as a source of water. The solar water pump is located above the water level and a suction pipe is used for drawing the water from the water source.

3. Design of the System's Components

To design any pumping system, the quantity of water required per day of the location for the summer and winter seasons must be obtained from the literature.

3.1. Design and Selection of the Water Pump

To select a water pump, the static head, drawdown head, pressure head and losses head were added together to give the total dynamic head as given in equation (1):

$$H_{td} = H_{st} + H_d + H_l + H_p \quad (1)$$

Where:
H_{td} is the total dynamic head (m); H_{st} is the static head (m); H_d is the drawdown head (m); H_p is the pressure head (m) and H_l is the losses head which is the sum of frictional loss head and fitting loss head as in equation (2):

$$H_l = H_f + H_{pf} \quad (2)$$

Where:
H_f is the frictional loss and this can be calculated using the Darcy formula as expressed in the equation (3) as given by [9]:

$$H_f = \frac{32lQ^2K_f}{\pi^2D^4g} \quad (3)$$

And H_{pf} is the fitting loss head and it can also be found using the expression given in equation (4):

$$H_{pf} = \frac{8Q^2K_{fi}}{\pi^2D^4g} \tag{4}$$

Where:
l is the length of the pipe (m); Q is the flow rate (m^2/s); K_f is the empirical factor which depends on Reynolds number; D is the diameter of the pipe (m); g is the acceleration due to gravity (m/s^2); and K_{fi} is the fitting loss factor.

The quantity of water the system can pump could be obtained using the expression given in equation (5):

$$Quantity\ of\ water\ pumped\ V = \frac{P_{pv}I_p\eta_{mp}F}{\rho g H_{td}} \tag{5}$$

Where:
P_{pv} is the power of the solar PV array (W); I_p is the average daily solar irradiance ($kWh/m^2/day$); η_{mp} is the efficiency of the motor-pump system; and F is the mismatch array factor.

The hydraulic power exerted on the water pump could be found using the formula given in equation (6) as:

$$Hydraulic\ Power\ P_h = \frac{\rho g H_{td} Q}{3600} \tag{6}$$

3.2. Design of Control System

When the solar PV array harnesses the solar irradiant, the solar irradiance is in DC form and the controller is used to convert the DC form of solar irradiance into AC form. This solar irradiance can be optimized to extract the peak DC load using the Maximum Power Point Technique (MPPT). The voltage across the AC circuit of the load can be calculated using equation (7) as:

$$V_{AC} = \frac{V_{DC}M_a}{\sqrt{2}} \tag{7}$$

Where:
V_{DC} is the DC voltage of the controller (V)

The power output exerted on the AC circuit of the controller can be found using the equation (8):

$$AC\ Power\ Output\ P_{AC} = I_{AC}V_{AC}\sqrt{3} \tag{8}$$

The efficiency of the controller is the ratio of the power output of the AC circuit to the power given out by the DC circuit as given in equation (9):

$$\eta_c = \frac{P_{AC}}{P_{DC}} \tag{9}$$

3.3. Design of the Electric Motor

The electric motor is used to run the water pump due to its less maintenance cost and it's being cheap in the market [2]. The torque used to rotate the shaft of the pump could be obtained using the equation (10):

$$T = K_L W^2 \tag{10}$$

The power liberated to the shaft of the motor is given in equation (11) as:

$$P_m = TW \tag{11}$$

The efficiency of the motor can be found by dividing the power liberated to the motor shaft with the AC circuit power output as given in equation (12):

$$\eta_m = \frac{P_m}{P_{AC}} \tag{12}$$

3.4. Design and Selection of Solar Photovoltaic Arrays

For the solar PV array to pump water from the tube well, the solar modules must be connected in series and parallel.

The number of Solar PV modules connected in series is given in equation (13):

$$No\ of\ PV\ in\ Series\ Connection\ N_{PV-series} = \frac{Pump's\ Motor\ Voltage\ V_{pm}}{Operational\ Voltage\ of\ PV\ Module\ V_{op-PV}} \tag{13}$$

And equation (14) is given to find the number of PV modules connected in parallel as:

$$No\ of\ PV\ in\ Parallel\ Connection\ N_{PV-parallel} = \frac{Pump's\ Peak\ PV\ Voltage}{V_{op-PV} \times N_{PV-series} \times I_{PV} \times F_{De-rating}} \tag{14}$$

The total power output for the solar PV array can be found using the expression given in equation (15) as:

$$PV\ Power\ P_{PV} = \frac{P_h}{I_p \eta_{mp} F} \tag{15}$$

The efficiency of the solar PV array is given in expression (16) as:

$$\eta_{PV} = \frac{P_{PV}}{A_C I_T} \times 100\% \tag{16}$$

The efficiency of the overall system is the product of the efficiency of the solar PV array and the efficiency of the motor pump as expressed in the equation (17) as:

$$\eta_{total} = \eta_{PV} \times \eta_{mp} \tag{17}$$

4. Performance Assessment of the System

The amount of solar irradiance harnessed by the solar PV, the flow rate of the water pumped by the system per hour and the efficiency of the system are parameters measured to ensure that the solar pumping system is working efficiently. In this study, the above parameters were measured for tracking PV and fixed PV of the system for 30 days on both cloudy and sunny days. The average of each measured parameter was used to plot the charts.

Figure 2 presents the performance of the solar pumping system with tracking PV during a sunny day. The test started when the sun started to rise and ended when the sunset at an interval of 30mins for each day. The average amount of solar irradiance, flow rate and efficiency of the system was at maximum values of 1125 W/m^2, 95 m^3/hr and 81 % respectively within the time frame of 12:30 to 13:00 of the day. At 9:30 and 15:30 there was a rapid increase and decrease in the amount of solar irradiance respectively, and this is due to cloud cover during these hours. This result agreed with the research done by Singh and Kumar [12].

Figure 3 shows the performance of the solar pumping system with fixed PV on a sunny day. The test started when the sun started to rise and ended when the sunset at an interval of 30mins for each day. The average amount of solar irradiance, flow rate and efficiency of the system was at maximum values of 867 W/m^2, 54 m^3/hr and 77 % respectively within the time frame of 12:00 to 13:00 of the day. This concurred with the result obtained by Narayana *et al.,* [13].

Figure 4 presents the performance of the solar pumping system with tracking PV during a cloudy day. The test started when the sun started to rise and ended when the sunset at an interval of 30mins for each day. The average amount of solar irradiance, flow rate and efficiency of the system was at maximum values of 836 W/m^2, 52 m^3/hr and 79 % respectively within the time frame of 12:30 to 13:00 of the day. Bouselham et al., [14] obtained similar results to this one.

Figure 5 presents the performance of the solar pumping system with fixed PV during a cloudy day. The test started when the sun started to rise and ended when the sunset at an interval of 30mins for each day. The average amount of solar irradiance, flow rate and efficiency of the system was at maximum values of 826 W/m², 50 m³/hr and 76 % respectively within the time frame of 12:30 to 13:00 of the day. The result obtained is similar to the one obtained by Katan *et al.,* [15].

Finally, it was observed that as the sun rose the amount of water flow rate for both tracked and fixed solar PV was increasing whereas it was decreasing when the sun got to set. Hence, it was found a high variation of the water flow rate simultaneously with the changes in the amount of solar irradiance harnessed by the solar PV, and this concurred with the result obtained by [10]. The total average amounts of water pumped by the tracked and fixed systems were 1370 m³/day and 804 m³/day for sunny days. And for cloudy days they were 750 m³/day and 714 m³/day. Helmy and Gad [16], Shabaan et al., [17], Jamil [18] and Pande et al., [19] obtained similar results to the results obtained in the present study.

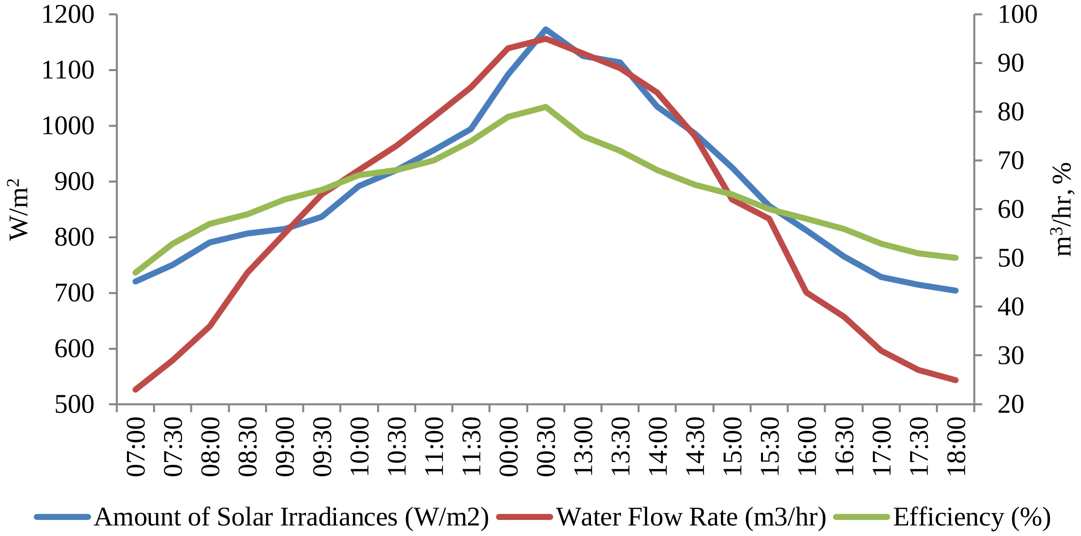


Figure 2: Performance of Tracking Solar Pumping System for Sunny Day

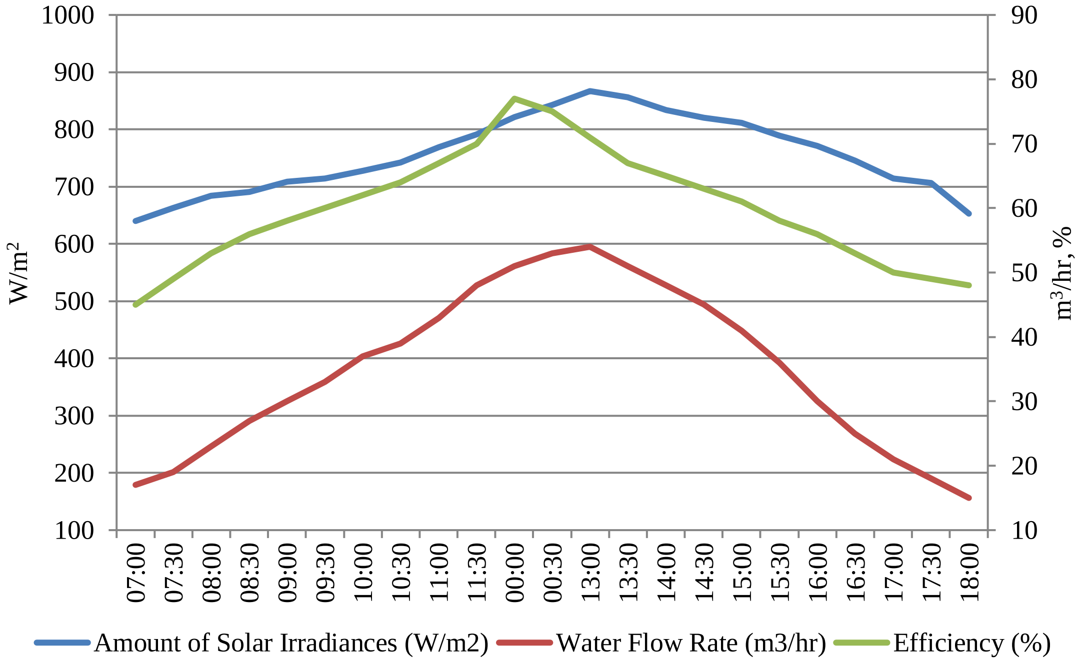


Figure 3: Performance of Fixed Solar Pumping System for Sunny Day

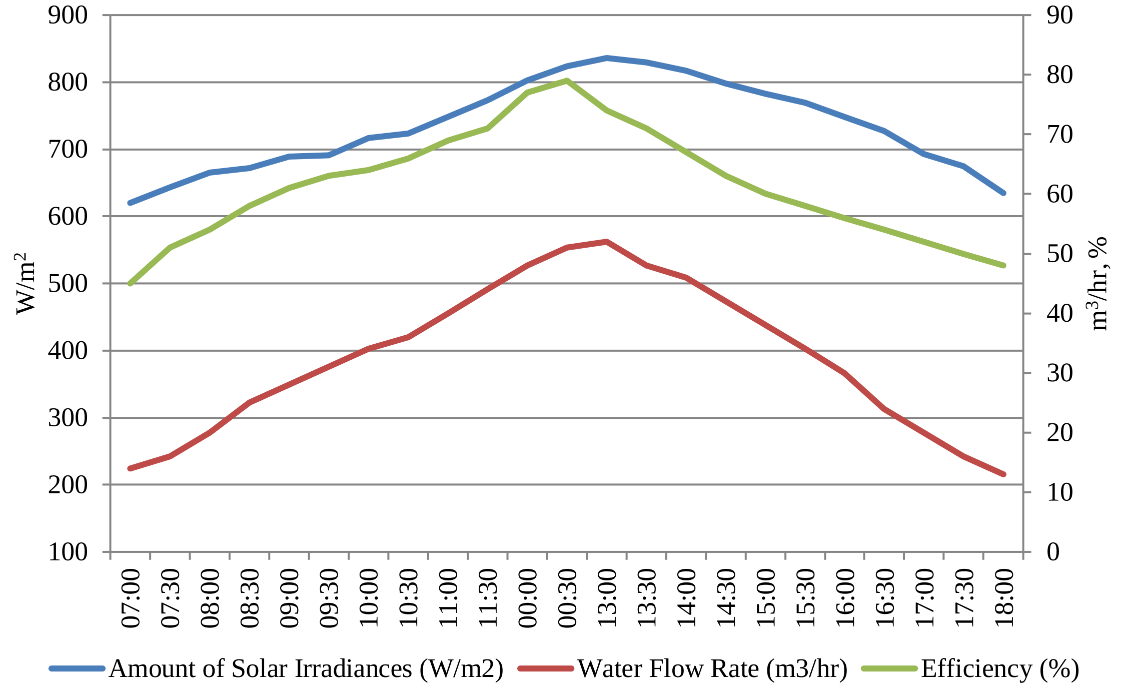


Figure 4: Performance of Tracking Solar Pumping System for Cloudy Day

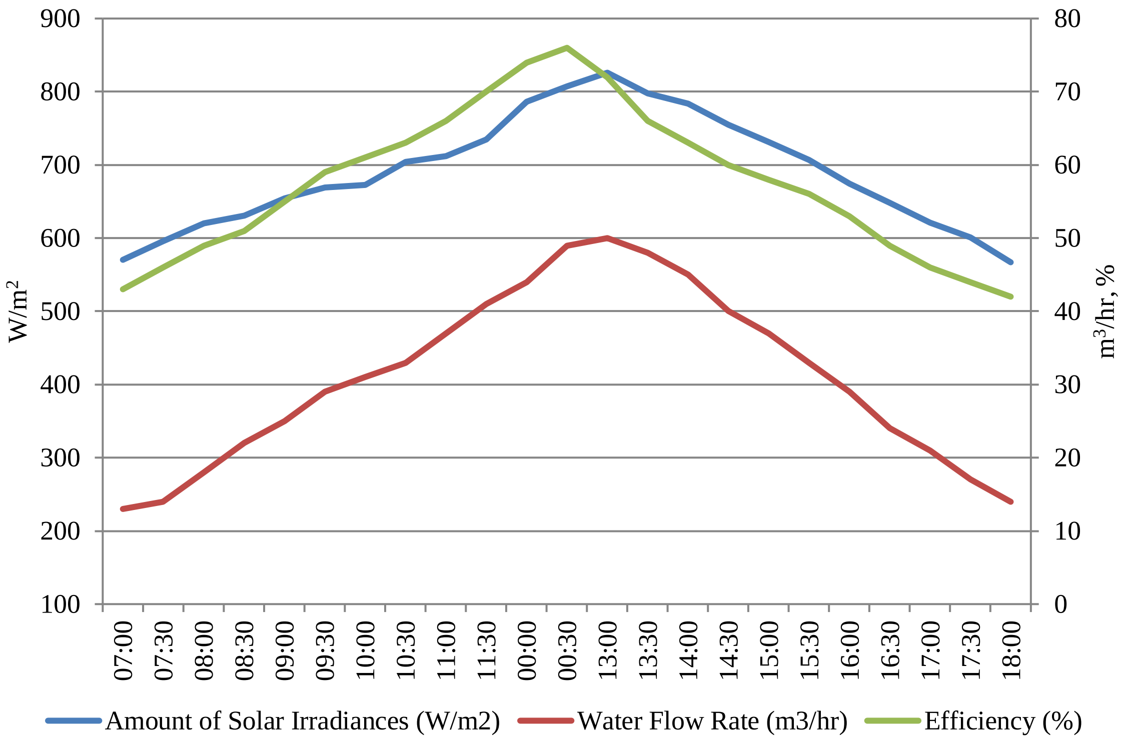


Figure 5: Performance of Fixed Solar Pumping System for Cloudy Day

5. Conclusion and Recommendation

5.1. Conclusion

This study designed the solar pumping system for agricultural use in Kano State Nigeria using maximum power point techniques with a consideration of design factors such as technical, environmental and economic factors. The designed system compared the results obtained by the tracking techniques with the fixed solar PV of the solar pumping system. It was finally observed that the amount of water pumped by the tracking system per day was much higher than that of fixed solar PV systems, and so were their efficiencies. Although there are some fluctuations in the results of both cloudy days, this is due to the fact that there are cloud covers and heavy rainfall during the time readings are taken from the system and there is little effect of cloud cover on tracking PV solar pump.

5.2. Recommendation

It was recommended in future research to have a higher energy storage battery that can store the solar energy extracted so that the system can overcome the wide gap between the amount of water pump on sunny and cloudy days.

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