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Design Procedures for Standalone Photovoltaic Solar Water Pumping System for Rural Communities

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Abstract— *Photovoltaic solar energy conversion has become dependable energy source worldwide for provision of electricity for both domestic and commercial applications. However, one impediment in the use of this energy source is lack of proper system design. The consequence is failed projects especially in the rural areas of developing nations like Nigeria. This work provides a simple approach for designing standalone solar water pumping system in for rural communities. In the absence of accumulated solar data over time in the rural communities in Benue State, model equations that provide good approximations are employed in few steps to design a solar water pumping system for water provision in rural communities.*

Keywords— *Cheap electricity: Design: Model equations: Photovoltaic conversion: Pumping system: Solar radiation.*

I. INTRODUCTION

Solar energy is the most clean and abundant energy resource that has entered into world economy and utilized to provide cheap electricity to the growing population. However, one impediment that hampers the effective use of solar systems in most developing nations like Nigeria is poor system design. Many solar projects like solar water boreholes, streetlights, traffic lights etc, have failed in Makurdi, Benue State and various factors may be deemed responsible. However, this work focuses attention only on system design with solar water pumping system in view. The failure of solar water boreholes may be a function of many factors including; water dries up, the refilling rate of water in well lower than the pumping rate, overheating of pump, sand or foreign particles blocking the pump and increasing flow friction [1]. Others may include, wrong sizes of materials selected including; pump sizes, pipes, solar array area, poor construction and plumbing work, which makes the system a failed one or uneconomical [1], [2]. To provide effective and economical solar water pumping system, the basic requirements must first be articulated based on parts availability before procurement and installation. The basic components that require prior information include; the depth of the borehole and the height of water storage tank collectively called; vertical lift. Secondly, the quantity of water required per day. These are the basic determinants of the size of the pump and photovoltaic array area [1].

The importance of using solar energy for water pumping cannot be overemphasized. Because in Nigeria, electricity from national grid is, poor, costly, and epileptic such that even when supplied, the voltage may be low for any meaningful use and the cost of fuel is high and fluctuates widely [2]. Therefore, many water boreholes abound in Makurdi town, yet owners still find water because of the high cost of using standby electricity generating plants. Thus, solar photovoltaic energy conversion that is cheap lends itself for use in this direction. However, the initial costs of materials like PV panels, pump, water tank, pipes, and construction work may be high that makes the initial installation cost intensive. Yet, there is no running cost and the system requires minimal maintenance. The minimum maintenance, entails cleaning of birds droppings on PV array and dust, tightening of loose bolts and nuts due to flexing in the wind, which anybody can do once shown the way [3].

Photovoltaic solar energy conversion in Makurdi has many advantages, which makes its application attractive; there are long hours of effective sunshine, water demand peaks when the irradiance peaks. In addition, photovoltaic solar energy conversion remains the only energy source that does not contribute thermal pollution to the atmosphere or the environment [4]. However, its few disadvantages will be noted; it is diurnal (available and active during the day only) and seasonal (vary with season and the climatic conditions) [4, 5]. However, these disadvantages are minor because water storage tanks are used to store water for use in the night or on very cloudy days.

Although, photovoltaic solar energy conversion technology is advanced in developed nations of the world and some parts of Nigeria however, Makurdi town, headquarter of Benue State struggles with effective utilization of this technology. Many solar projects are abandoned for none performance. It appears that the designs used for installation were not properly made. Therefore, this study provides basic equations that enable the design of a photovoltaic solar water pumping system, on standalone bases (without the use batteries and not connected to any other power source). Therefore, only water is stored for use during the nighttime or cloudy days.

1.1 Problem Statement

A survey of Makurdi metropolis showed that most solar water boreholes failed to function optimally. This study opined that no proper system designs were carried out before installation. Thus, in absence of solar data collected over time within the locality, this study used model equations to design photovoltaic solar pumping system that will be effective and economical to pump water from boreholes for use by the rural communities.

II. LITERATURE REVIEW

To decide on building a solar water pumping system, the first factors to evaluate are the volume of water required per hour or day, time required, the vertical lift and the photovoltaic materials available [4]. This information enables the selection of the required capacity of the suitable pump. The size of the pump must be such that will overcome the total flow frictions due to effects of gravity, pipe bends etc., that tend to hinder the free flow of water and increases energy consumption thereby weakening the pump [2], [6], [7], [8]. The basic design steps reviewed in this work include:

i. Daily water requirements,
ii. Pump selection,
iii. Area of the PV array,
iv. The power generation from PV solar array
v. Energy balancing factor

2.1 Daily Water Requirements

Water requirement per a day is determined from the population of users and purpose. This is determined with a little surplus to take care of unexpected use that might occur [8]. The quantity of water in metre cube (m^3), time in hours (t) of effective sunshine is evaluated. Then, water flow rate is calculated at maximum solar condition. In addition, the environmental conditions of system location, especially solar irradiance and ambient temperature, wind speeds etc all have effect on the water flow rate. Therefore, to determine the actual amount of daily water requirements, losses due to these factors are considered especially in deciding the area of the PV array [9]. The density of the water, effect of gravity, the pump efficiency, the amount of unused solar energy (kWh) and the hourly variations of pump pressure due to variation in irradiance, all these require compensation from the PV array size. The weather conditions also affect the water-pumping rate because of the cloud cover and season (dry or wet), the diurnal characteristic of the sun, this problem are addressed by installation of water storage tanks to store water and use during nighttime or cloudy days [10].

Therefore, having decided on the volume ($V\ m^3$) of water required per day, the flow rate (Q) to meet this demand is given by [7], [10] as;

$$Q = V/t\ (m^3/s) \qquad (1)$$

Where,

V= volume of water in m^3
t= effective hours of sunshine per day

Similarly, the water flow rate (u) given by [12] as:

$$u= Q/A\ (m/s) \qquad (2)$$

Where, A = cross section area of the flow pipe in meters

2.2 Pump Selection

The size of the solar pump is selected based on the vertical lift and total loss head in the pipe due to flow friction. The vertical lift (H) includes; the depth of the borehole and the total loss head, calculated from Bernoulli equations [13]. The pump has to overcome all the resistances at every point for it to lift enough water to the required height at the correct time. Therefore, different sizes of pumps and the corresponding vertical lifts and sizes of pipes are available from manufacturers to select-based on particular needs [5], [7], [9]. Friction losses, also depend on pump maintenance, the pipe diameter, the length, should be such that it allow water flow with minimum losses [7], [9].

The limitation of the pump for stand-alone PV system may be based on the limitations of the irradiance and array area too. Therefore, it is important to keep friction losses low because the pumping efficiency reduces drastically if large friction losses are present [13], [14]. The other factors likely to affect water flow rates depend on installation. Installing solar pump close to the bottom of the borehole and without sand screen may suck in sand while pumping. Thus, manufacturers of solar pumps address this problem by providing sand screen that protect the pump from sucking sand or other foreign matters in the pump shroud [14]. In some boreholes, water replenishment may be less than the pumping rate, which causes the pump to run dry and overheat. Thus, references [15-18] recommended the use of float valves in storage tanks to switch off the pumping system whenever the water level reaches maximum level in the tank. The stoppage time also allows the pump time to cool down before starting again. The working efficiency of the pump depends on its capacity and the electric power input. However, it is possibly not the best criterion for judging the performance of the pumping system, since the pump power remains constant but the input solar energy varies according to different hours of the day [19], [20].

Thus, the vertical lift (H) is calculated including the various head losses from the Bernoulli equation in the form given by [11], [12] as:

$$H= (P_2-P_1)/\rho g+ (u_2^2 +u_1^2)/2g + Z_2-Z_1 + \sum h_L \qquad (3)$$

Where;

$(P_2-P_1)/\rho g$ = difference in the static heads in meters
$(u_2^2-u_1^2)/2g$ = difference in dynamic heads in meters
Z_2-Z_1 = difference in potential heads in meters
$\sum h_L$ = total head loss in meters

The total losses due to flow in pipe bends, elbows, joints and friction along flow in vertical pipe can be evaluated using equation given by [5], [7], [13] as:

$$\sum h_L = \sum H_L\ u^2/2g + f\ l/d\ u^2/2g$$

Summarized to:

$$\sum h_L = u^2/2g\ (\sum H_L + f\ l/d) \qquad (4)$$

Where,

$\sum H_L$ = sum of losses due to pipe bends, elbows, joints etc (m)
f = friction losses due to flow in vertical pipe per 100m length (f_{100}= 0.227) and for a pipe less than 500m long the ratio l/d is negligible [17].

Further evaluation of (3) and (4), for solar water pumping the pressure head, is negligible because P_2 is atmospheric, initial velocity (u_1) is zero; Z_1 is also zero because it is base point. The ratio of length per diameter is negligible if the length of pipe is less than 100 meters by length [17]. Thus, eliminating the insignificant heads equation (3) reduces to:

$$H= Z_2+ u_2^2/2g + f \qquad (5)$$

The pump selected must lift water through the vertical head equation (5), therefore the hydraulic power (P_h) is needed at the pump shaft to lift water from the borehole to this height [5], [17]. To increase the size of the PV system will increase the daily water output and the working hours, but it will also increase the installation cost. Therefore, the decision for the optimum sizing of the PV depends on two criteria: achieving the required water from the system based on the availability of the solar energy in the location and achieving the lowest price per m^3 of water over the operating period of the station [17]. Therefore, the required hydraulic power (P_h) is calculated as:

$$P_h = \rho g H Q \quad (6)$$

Where,

p_h = hydraulic power rquired at pump shaft (W)
ρ = density of water (kg/m^3)
g = acceleration due to gravity (m/s^2)

Thus, the required pump capacity is decided by dividing the average hydraulic power over the efficiency of the selected pump [19] given as;

$$Pc = P_h/\eta_p \quad (7)$$

2.3 Sizing PV Array Area

Different models enable sizing of the PV solar area to suit the required power, however, the first consideration for each of them is the availability of solar power. Availability of solar radiation on the horizontal surface is called standard irradiance (Gr) and given as $1kW/m^2$ [18], [19], [20]. For effective evaluation of sun's radiation of a site, the total daily irradiance (Sr) is collected from the particular location over years and averaged [20]. However, in absence of such data, approximate model equations are applicable. Solar power (P) is generated from a PV array of a given specific area and efficiency generally represented by [5], [14] as:

$$P = Gr A_{PV} \eta_{PV} \quad (8)$$

Where,

Gr = reference irradiance ($1kW/m^2$)
A_{PV} = area of the PV array m^2
η_{PV} = reference efficiency of the panels

Thus, the daily solar power (P_o) required for a given PV array area is given by [5] as;

$$P_o = A_{PV} Sr \eta_{PV} \quad (9)$$

Where,

Sr = the daily solar irradiance for the site

Since, the daily electric power generated is for the purpose of proving hydraulic power to the pump, the PV array must balance with the hydraulic power requirements. Thus, according to reference [5], [16] the required effective surface area of the PV array may be found by equating equations (9) and (6), thus;

$$A_{PV} = \rho g H Q / Sr \eta_{PV} \eta_s \quad (10)$$

η_s = efficiency of the pumping system

2.4 Power Generation by the PV Array

The solar irradiance received on a horizontal surface, in Makurdi metropolis starts from morning (6 am) and climax in the afternoon (12.00) and decreases steadily to evening (6pm). The altitude of the sun in the sky is represented by the hour angle, called zenith angle (Z^o) [17]. The solar noon is used as reference point because the local clock time is arbitrary divided into 24 time zones, each zone with a speed of degree of longitude while, the sun traverses a degree in every 4 minutes. Therefore, dividing the number of minutes from solar noon converts the minutes to zenith angle [17].

Thus, the daily power required for pumping from the PV array depends on the daily irradiance, hydraulic power, efficiency of the pumping system and the efficiency of the PV array. In the absence of empirical data, reference [17] provided equation that enabled the estimation of power on a horizontal surface, showed that for a tilted surface at L^o, there are direct, and diffuse components of radiation impinging on such surface at any given time. The components are related as;

$$\text{Direct insolation component} = Sr \cos L^o, \quad (11)$$

$$\text{Diffuse insolation component} = Sr \cos^2 (L/2)^o \quad (12)$$

Where,

L^o = geographical location (latitude angle) of the site

Therefore, adding equations (11) and (12) and considering that the conversion depends on the zenith angle, surface area of the PV and its efficiency, and the latitude of the site, combining these parameters, the daily solar power generated (P_o) given by reference [17] becomes :

$$P_o = S_r \cos Z^o A_{PV} \eta_{PV} [\cos L^o + \cos^2 (L/2)^o] \quad (13)$$

Where,

Z^o = Zenith angle or altitude of sun in the sky
L^o= geographical location of site on the earth surface (degree of latitude of the site).

A general rule to is to oversize the solar panel by at least 30 % to make up for the losses due to variations in weather conditions and cloudy days below normal [17].

The photovoltaic cell is a device that converts solar radiation into electricity. Direct current (dc) electricity is produced when sunlight interacts with semiconductor materials and most manufacturers use silicon and its derivatives [17], [18], [20]. The manufacturers design PV cells with average sizes; 12 cm in diameter and 0.25 mm thick and generates up to 4 amp and 0.5 volts (2 watts) of electrical power [8], [10]. These cells are build up into panels of 36, 72 or more depending on the purpose. Generally, PV solar panels as units of arrays are made in different sizes and efficiencies depending on the manufacturer's choice. Thus, Dankoff Solar Products Inc USA, produced theirs with the following dimensions; length, 1188mm, width 530mm and thickness, 43.5mm and area 0.63 m^2 with open circuit current/voltage of 20V/5A and closed circuit voltage/amps of 18V/4.86A [20]. In addition, a panel contained thirty-six cells and each cell having a diameter of 0.1016m. Among many other manufacturers there is; Standard; Vikram Eldora Ultima 250W polycrystalline panel of length 1,640 mm by width of 992 mm by the height of 40 mm and area of 1.63 m^2. Deluxe—Solar World 280Wmono-crystalline panel 1,675 mm × 1,001 mm × 33 mm (or 1.68 m^2 [5], [20].

2.3 Load-Electricity Balancing Factor

The load-electricity balancing factor (φ) is defined as the ratio of energy utilized by the pump to the maximum power generated by the PV array. The manufacturers' matching factor is fixed approximately at 0.9, which is the ratio of closed and open circuit voltages [5], [17]. The power supplied to pump shaft (hydraulics power) is expected to balance closely with the power generated from the PV array for the system to be economical. Therefore, the load balancing factor (φ) is fixed by the local designer and should high enough to make system effective but devoid of waste. Therefore, the PV array area is based on solar irradiance of the site, temperature and wind velocities etc. The balancing factor(φ) is function of the daily hydraulic power (P_h) output and electric power(P_o) input whereas, working efficiency depend on the pump capacity (P_c) and inputs electric power (P_o).The balancing factor is a constant since it depends on two variable factors. However, for the working efficiency one the pump capacity is a constant while input power only is a variable. Therefore, the balancing factor is ideal criterion for measuring solar water pumping performance and not the working efficiency. Therefore, there is need to carry out proper assessment based on the availability and type of materials, in the market and the level of irradiance before parts purchase and installation [20]. The load-electricity balancing factor is a relation between the hydraulic power and input electric power given by references [5], [18], [19], which divide equations (6) by (13) as;

$$\varphi = \frac{P_h}{P_0} \qquad (14)$$

φ = load-electricity balancing factor from system design

III. MATERIALS AND METHODS

3.1 Materials

A survey of Makurdi town for available photovoltaic solar materials showed that a few brands of solar panels are available. However, Dankoff product was assessed for the purpose of this study. The set of Dankoff solar panels appraised had the following specifications: length 1188mm, width 530mm. Power ratings: open circuit voltage/current: 20V/5A and the closed circuit voltage/current was 18V/4.86A, with rated efficiency of 12 %. Similarly, a survey of boreholes within the International Market Area, a sub regional area of Makurdi town revealed that the vertical lifts of most boreholes range between 60m to 80m including the heights overhead tanks. In addition, the average daily water requirement is about 50 m^3. From the State Meteorological Unit Makurdi, the geographical location of Makurdi: 7^o 41’ N and longitude: 8^o 37’ E, and has average of 9 hours of effective sunshine per day. The clouds cover, especially during dry season when water needs peaks is about 10%.

3.2 Methods

Equations (1) to (14) are used to simulate a standalone PV solar water pumping system within Makurdi metropolis.

3.2.1 Water requirements rates

The daily water flow rate (m^3/min) required to meet the need of 50 m^3 within the effective period of nine hours of sunshine is calculated using equation (1). Whereas, the flow velocity is calculated using from equation (2).

3.2.2 Pumping head and Pump

The total vertical lift (H), which the pump is expected to lift water is calculated using equation (5).The vertical lift comprise of the losses in the pipe due to flow characteristics, bends, joints and friction. The hydraulic power (P_h), must be supplied to the pump shaft to move water to the required height and this is calculated by the use of equation (6). The study selected suitable pump capacity (Pc) based on the hydraulic power and the pump’s reference efficiency. Thus, the capacity of the pump selected was based on equation (7).

3.2.3 The required PV array area

Having determined the hydraulic requirements next is to determine the area of PV array (A_{PV}) that will generate the required electric power to match with hydraulic power. Thus, the surface area is calculated using equation (10), considering the average sizes of PV panels in the market. The daily electric power (P_o) generated from the given array, is calculated using equation (13) that depend on the zenith angle. The details of conversion from minutes to zenith angle (Z^o), daily power (P_o), using the latitude of Makurdi as the angle of tilt etc., for details, refer to Appendix, Table A-1.

3.2.4 The load-electricity balancing factor

The hydraulic power (P_h) and daily electricity generation (P_o) are variable factors that depend on the zenith angle (Z^o) and weather conditions. The balancing factor (φ) calculated using equation (14).

IV. RESULTS

The results are presented in Fig. 1 and Fig. 2a and 2b.

V. DISCUSSION

Fig. 1 shows the results of the general performance of the solar water pumping system simulated in this work. Electric and hydraulic powers generated from solar irradiance and the water discharge rates. The blue dotted curve indicates the electric power (P_o) generation by the photovoltaic array as the ‘sun traverses the sky’ from morning (6am) to evening (6pm) and each dot shows the position of sun at the hour. The y-axis indicates the quantity electricity generated at each hour and at the same axis is the hydraulic power (P_h) generated represented by the green dotted curve. The hydraulic power (P_h) curve is the power applied at the pump shaft to lift water through the vertical height at that hour. The gray horizontal line appearing almost constant, above the x-axis, indicates the head (vertical lift) shown in centimeters (cm). The red and dotted line appearing straight on the x-axis shows the water discharge rate at each hour. Each dot shows water discharge rate at that hour.

It will be observed that from 6am to 8am the electric power generated is not enough to provide the necessary torque to the power to turn the pump shaft, therefore no water is pumped at this time. However, at about 9.00 am (at the point where P_h curve crosses line H) on the chart, electricity generated begins to turn the shaft and water is pumped through the vertical lift and reaches maximum at 12 noon and begins to reduce until three o’clock (3.00 pm). After three o’clock, the electric power converted is no longer strong enough to power the pump. Thus, the period between 9 am to 3 pm represent the optimal pumping period whereas, the peak pumping is at 12 noon when insolation is highest. There appears to be no clear distinction in the discharge rates between the hours (9 am – 3 pm), the difference is small (Table A-1) and not captured by the chart. However, the area between points 9.00 am and 3.00 pm, hydraulic line (P_h), and the water discharge line (Q m^3/min) represent the daily amount of water required.

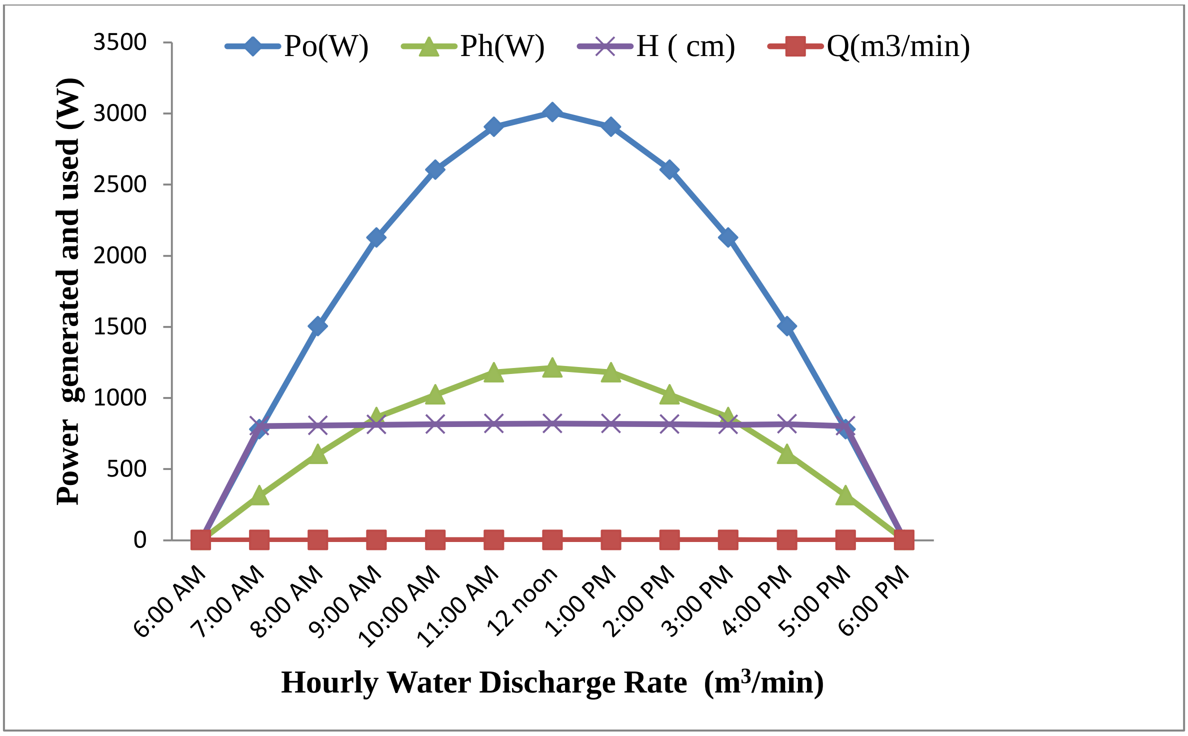

Fig. 1. Electric (P_o), Hydraulic (p_h) Power and Water Discharge Rates (Q) as the Sun traverses theSkyfrom6 am - 6 pm

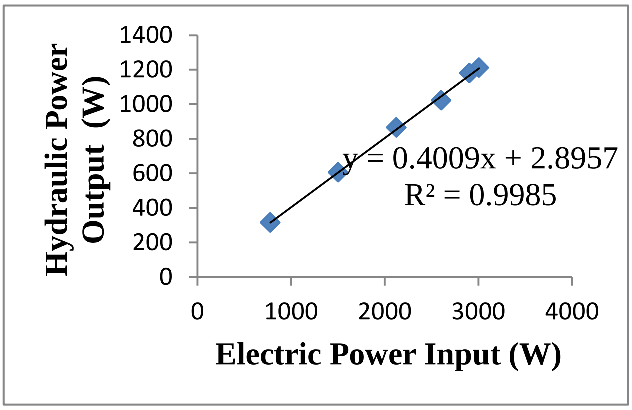

Fig. 2(a): Relationship between Electric and Hydraulic Power

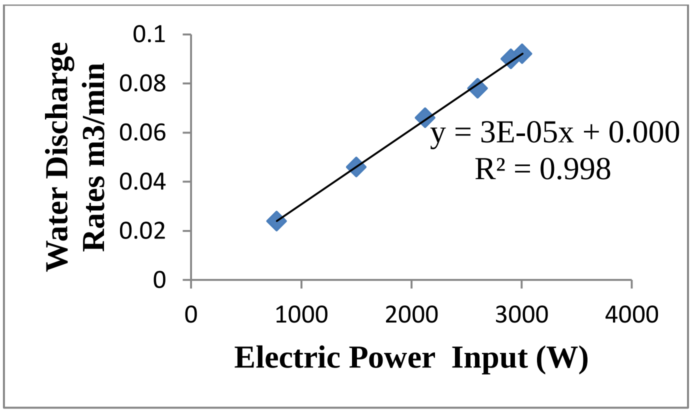

Fig. 2(b): Relationship between Electric Power and Water Discharge Rates

Fig. 2a showed the relationship between the hydraulic power output and solar electric power input. It will be observed that the trend line did not cross either of the axes. This point is compared to the point of ‘no work’ in Fig. 1 from 7am - 8.55am and 3 pm - 6 pm, and demonstrates that the sun’s radiation at these times is not active enough to cause charge separation in cells to generate electricity. At the point where the trend line commenced, the electric power (P_o) input is about 800W and at this time the system starts to function generating hydraulic power (P_h)of about 300W.

Fig. 2b, is the result of the relationship between electric power input and the water discharge rate (m^3/min).The trend line showed that at the point no sufficient electricity is generated (6am-8.55 am) no water output. It further showed that at the point where the P_h curve crosses the head (H) line, water begins to discharge. The water output increases and reaches maximum at 12 noon as indicated in Fig. 2b, where insolation is maximum. The regression equation in Fig. 2b showed that, if all other parameters are constant, water discharge rate depends on the solar irradiance and the converting system.

VI. CONCLUSION AND RECOMMENDATIONS

At the end of this work, model equations suitable for effective design of solar water pumping system are presented and discussed. It is therefore, recommended that intending users interested in using solar water pumping should first carry out proper design base on the methods presented herein to have a functional and economical system devoid of waste.

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APPENDIX A

1.0 Detailed calculations

Equations (1) to (13) simulate an economical PV solar water pumping system within Makurdi metropolis.

1.1 Water requirements rates

The water required to achieve the daily requirements of $50m^3$ is calculated from equation (1). Noting that the effective hours of sunshine per day was given as 9 hours.

The rate of water requirement was given in equation (1) Substituting values:

$Q= 50\ m^3/(9\ h \times 60min \times 60\ s) = 1.54 \times 10^{-3}\ m^3/s$

Similarly, the velocity of water flow (u) was given in equation (2) putting in values gave:

$u = 1.54 \times 10^{-3}/ [\pi(0.0752)^2/4] = 0.35\ m/s$

1.2 Pumping head

The pumping head (H) is calculated using equation (5) as: $H = 80 + (1.54 \times 10^{-3})^2/ (2 \times 9.81) + 0.8\ (0.227) =80.20m$

The hydraulic power (P_h) is calculated from equation (6) as;

$P_h = [10^3 kg/m^3 \times 9.81 m/s^2 \times 80.20m \times 1.54 \times 10^{-3} m^3/s] = 1211.61\ W$

The pump capacity is given from equation (7) as:

$Pc = P_h/\eta_p = 1211.61/0.\ 80 = 1514.51W\ (1.5\ kW)$

1.3 The required PV array surface area

The surface area of array calculated from equation (10) as:

$A_{PV} = [10^3 \times 9.81 \times 80.20 \times 1.54 \times 10^{-3}]/ 1000 \times 0.12 \times 0.80 = 12.60\ m^2$

Number of modules (N_m) = $12.6\ m^2/0.63m^2$ = 20 modules

Thus, length of array = 0.53 x 20 = 10.6m

Width of array = 1.188 m

1.4 Electric Power generation

The daily power generated from the array is calculated using equation (13)

$P_o = S_r\ CosZ^o A_{PV} \eta_{PV} [cosL^o + cos^2\ (L/2)^o]$

The generation of electricity by this model shows that solar radiation depends on the hour angle (Z^o). In the absence of accumulated solar data to determine average daily insolation (Sr), the standard reference insolation (Gr), is assumed to be Sr at 1000 W/m^2. Reference [10] noted that a general rule is to oversize the solar panel by at least 30% to make up for the losses less than ideal weather condition and cloudy days. For a vertical lift of 80.2 m, electricity generation at maximum Z^o and vertical lift of 80.2 m:

$P_o = 1000 \times Cos\ (0^o) \times 12.6m \times 0.12 \times 1.9892 = 3007.67\ W$

Thus:

$P_o = 3007.61(0.3) + 3007.61 = 3909.91W$

1.5 The Load balancing factor

The load-electricity balancing factor, calculated from equation (14):

$\varphi = P_c/P_o = 1211.61/3007.67 = 0.40$

TABLE A-1: Conversion from Minutes to Degrees and to Zenith Angle

Time	**Cycles/ Minutes**	**Min. to Degrees**	**Zenith Angle (Z^o)**	**P_o (W)**	**Q (m^3/min)**	**Ph (W)**	**H (cm)**
6 am	60 x 6 = 360	360/4	90°	0	0	0	8000
7 am	60 x 5 = 300	300/4	75°	778.44	0.024	314.70	8003
8 am	60 x 4 = 240	240/4	60°	1503.84	0.046	605.81	8006
9 am	60 x 3 = 180	180/4	45°	2126.74	0.066	865.44	8012
10 am	60 x 2 = 120	120/4	30°	2604.22	0.078	1022.79	8015
11 am	60 x 1 = 60	60/4	15°	2905.19	0.090	1180.14	8018
12 noon	60 x 0 = 0	0	0°	3007.67	0.092	1211.61	8020
1 pm	60 x 1 = 60	60/4	15°	2905.19	0.090	1180.14	8018
2 pm	60 x 2 = 120	120/4	30°	2604.22	0.078	1022.79	8015
3 pm	60 x 3 = 180	180/4	45°	2126.74	0.066	865.44	8012
4 pm	60 x 4 = 240	240/4	60°	1503.84	0.046	605.81	8016
5 pm	60 x 5 = 300	300/4	75°	778.44	0.024	314.70	8003
6 pm	60 x 6 = 360	360/4	90°	0	0	0	8000