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Development and Performance Evaluation of a Trailed Solar Photovoltaic Stand-Alone System for Rice Threshing Machine

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***Abstract*:- A solar PV system was designed and used to power a votex rice threshing machine. The threshing machine was mounted on a two wheel trailer that was designed and fabricated. The performance of the PV system and the threshing machine were evaluated and analyzed. The solar PV system was designed by first determining the power rating of the electric motor to be used on the thresher, from which the array sizing of the PV modules was determined. This also enabled the determination of the battery capacity, appropriate size of charge controller and inverter. The performance of the solar PV system was evaluation by measuring the insolation, current and voltage of the system from 0900H – 1200H daily from a sun meter, ammeter and voltmeter respectively and power output determined. The performance evaluation of the thresher was undertaken by determining its threshing efficiency, the seed breakage and rate of operation (Kg/h). The tractive coefficient, tractive force, tractive efficiency, and drawbar power of the trailer were 0.0294, 17.71kg, 4.797, 70.84kw respectively. The total weight of the machine was measured to be 602 kg. The threshing efficiency of the machine was estimated to be 73% the machine threshed 2.2kg/min and no seed breakage was observed. The Correlation analysis of measured insolation and output current, power output from PVC system in table 2, and 4, were significant at P ≤ 0.01. While correlation analysis of insolation and voltage as in table 4 shows no significantly effect. Simple linear regression analysis of measured insolation and output current, and power output from the PVC system indicates significant relationship, while regression analysis of measured insolation and output voltage shows no significant relationship at P ≤ 0.05. This study developed a novel solar PVC powered rice thresher that harnessed the abundant solar energy of this location for enhanced threshing of rice that would not have been possible because of lack of on-farm power.**

Keywords: Solar; Photovoltaic; Trailed; Rice; Threshing;

1. INTRODUCTION

Energy is an important input for the sustainable development and economic growth of any country. Electrical energy is proven to be the most convenient form of energy source in rural and urban areas and its availability promotes rapid economic industrial growth. Rural inhabitants represent about 70% of the total population in developing countries or almost 50% of the world's total population (Usman, 1985). That means, in Nigeria, several percent of the population in urban areas have no electrical service and about 60% of the rural population in Nigeria whose occupation are predominantly farmers also have no access to grid electrical services (www.iceednigeria.org/policy.Guidel...). According to Galiana (2015), 45% of Nigeria has access to electricity, 10% of rural dwellers have access to electricity. In the same vein, Usman (2013), opined that Nigeria is the most populous black nation on earth, and despite its huge abundant natural resources, it is still one of the poorest in the world with an estimated Gross Domestic Product (GDP) per capita of $2,162 with 50 to 90% of its current population of 170 million people living in rural areas lack access to electricity. This limited access to electrical grid and other services in rural areas has hampered economic activities. Grid extension is not a feasible alternative for many rural areas for processing of most agricultural produce such as milling, threshing, pumping of water, cooling since there is lack or inadequate supply of grid electricity. Threshing operation an arduous and back – breaking tasks are undertaken by families especially women and children in most areas. Rising labour cost and non-availability of labour in rural areas due to continuous drift from rural to urban areas has necessitated the adoption of mechanization of rice production.

Photovoltaic system offers the best alternative solution to providing basic electricity need for so many post-harvest operations in rural locations where there is no grid electricity. This calls for the use of a solar photovoltaic (PVC) system for rice threshing machines. Photovoltaic systems have found widespread application because they are simple, compact and have high power to weight ratio. The PVC system has no moving part and probably yields the highest overall conversion of solar energy into electricity. PVC require only modest amount of skilled labour to install and maintain making them well suitable for village power system. In order to supply the required power, arrays should be capable of producing sufficient current and voltage to run the applications, and can be connected either in series or in parallel to obtain the desired voltage and current. The trailed solar photovoltaic stand-alone system for rice threshing consists of batteries, modules, charge controller, and an inverter. The batteries supply the power required by the electric motor that serves as the prime mover while the solar modules charge the batteries. The thresher performs the threshing operation.

The installation of PVC system and its use in agriculture has been growing by 20-25% per annum over the past twenty years (Eltawil and Samuel, 2007). The PVC system has great bright future in the recent years. Beshada et al (2006) constructed and optimized new PVC to drive a stone mill with a diameter of 150mm and a maximum capacity of 3kg per hour. Glasnovic and Margarita,(2007) optimized irrigation with a photovoltaic pumping system considering such factors as water intake, climate, soil, crop, and method of irrigation. Yano et al (2007) developed a greenhouse side-ventilation controller driven by photovoltaic energy. Mpagalile et al (2007) fabricated seed oil extraction equipment using a solar powered screw press to mention but a few. (http://www.fao.org/docrep/Q1085e/q1085e0d.htm.). The relative compatibility of solar powered technologies with small systems (no real economic of goals) suggests that it may hold promise for many of the world's small farms. Though, the generation of electricity using photovoltaic faces the problem of variation of supply of solar radiation. A product of space and age investigation suggests that the rapidly decreasing unit cost of photovoltaic may soon make it competitive among users.

Solar energy produces no emissions and uses no fuel other than the storage batteries. PVC system components are all solid states with no hazardous materials involved. They required virtually low or no maintenance, are long lasting, highly reliable and are an economical source of power. Solar photovoltaic systems will be the best alternative to power rice threshing machines on farms where electricity supply is not available.

A. Statement of the Problem

The cost of importing highly motorized threshers is so high; also in most rural areas where post-harvest activities takes place, electric grid connection is not available. The cost of providing fuel for the prime mover is very high. The current manual/on-farm threshing is labour intensive with associated high drudgery. This has made easy, inexpensive and neat threshing of rice a problem for the poor farmer who cannot afford the highly motorized threshers such as the combine harvester.

B. Objective

The objective of this study is to develop and evaluate the performance of trailed solar photovoltaic stand-alone system for rice thresher for use on Nigerian small-scale farms that are located in remote rural locations.

C. Justification

The cost of obtaining highly mechanized threshers such as the combine harvester for farm operation is high and cannot be afforded by Nigeria small-scale farmers who make up more than 80% of Nigeria farmers population (Kamla-Raj, 2010). Existing mechanical rice threshers require a source of power which is usually electricity for the prime mover or a spark ignition internal combustion engine. In contrast, electrically powered threshers are cheaper, in terms of the cost available at almost any power rating, require almost no maintenance and are simple in operation. However electric grid connection is not available in remote rural locations where these farms are located and the use of internal combustion engine increases the cost of operation in the face of scarcity of petroleum products; reducing the time and energy spent on threshing could increase the time available for other productive activities. Therefore the use of solar PVC powered inexpensive motorized threshers can help to improve the living conditions and livelihood in rural areas of Nigeria. The power required to drive such threshers is about 50 to 200W; alternatively the use of the smallest available diesel or petrol engine provides 200 to 300W of power. This makes the investment and operation costs higher with fuel and spare parts supply unreliable. Therefore, considering the low power requirement and a typically high daily solar radiation of about 4-6kWh/m^2 in many tropical and subtropical areas, an electric motor with a power supply from a photovoltaic generator is a promising and cost effective alternative. This will enhance performance of on farm threshing operation of paddy rice at affordable rate and increase the output per hour (kg/hr) of operation as compared to manual operation.

2. MATERIALS AND METHOD

A hold-on votex rice thresher at the Implement Shade of the Department of Agricultural and Environmental Engineering, University of Agriculture Makurdi, was used for the threshing operation.

The power requirement for rice threshing operation was determined and used to select an appropriate size electric motor to power the thresher. The power rating of the electric motor was used to design a solar PVC system. The design was to determine the array sizing of the modules, select the capacity and number of storage batteries, the appropriate size of inverter and charge controller. The solar photovoltaic powered rice thresher was fastened to a trailed platform with the help of bolt and nut to enable it be move to and fro the farms. The performance of the trailed standalone solar powered rice threshing machine was evaluated according to the NIAE standard for rice threshers. The Performance of the solar PV system was evaluated for a period of twenty one days by determining the hourly output of current and voltage available to the electric motor. The hourly insolation for the location was measured and related to current, voltage and power output from the PVC system. Threshing was undertaken between the hours of 0900h and 1200h in order to determine the performance of the thresher. The solar PV powered threshing machine was further evaluated by determining the threshing efficiency, seed breakage and rate of operation.

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A. Description and Operation of Trailed Photovoltaic Stand-alone System for Rice Threshing Machine

The photovoltaic powered rice paddy thresher is a tractor drawn system consisting of two main units namely the Solar Photovoltaic System and the threshing unit.

The solar photovoltaic system consists mainly of solar modules, charge controller, battery bank and an inverter. The modules receive and convert the insolation upon them directly to direct current electricity. Two solar modules each of the capacity of 200W @ 24V were connected in series to give an output of 400W @ 48Vdc. This direct current is made to pass through a charge controller which is design to regulate the voltage coming from the modules. The two modules were connected to a 40A charge controller to prevent overcharging and prolong the life of the batteries. The charge controller was connected to battery bank consisting of four (4) batteries each of capacity 12V, 150Ah all connected in series to each other. The stored charges from the batteries are converted to A.C electricity by a 3.5kVA @ 48V inverter. This a.c electricity from the inverter drives the 750W electric motor which powered the thresher.

The threshing unit is composed of a hopper, threshing drum which has spikes, beater bars and fan blades attached to it, main frame , belt drive, all mounted on a main frame of the thresher. The torque from the electric motor is transferred through a belt and pulley system connected to the threshing drum of the machine. The drum rotates when powered by the electric motor. Rice paddy is introduced into the machine through the hopper, spikes on the rotating drum conveys them through the chamber as they strike the stationary beater bars they occur separation of the grains from the portion of plant that hold them. Incorporated on the drum, are fans that blow off the chaffs to ensure discharge of clean rice. Fig. 1 shows the picture of trailed photovoltaic stand – alone system for rice threshing machine. Fig 2 shows the picture of clean rice sample threshed by the trailed solar PVC powered stand-alone system for rice threshing machine. The thresher, battery bank, Inverter, charge controllers, and the solar panels were all mounted on a trailed platform that has a drawbar to enable it be moved from one point to another when hitched to a tractor.

Figure 1: picture of the photovoltaic powered tractor-drawn rice threshing machine

Figure 2: rice sample threshed by tractor - drawn photovoltaic powered rice threshing machine

B. Power Requirement for the Threshing

The power requirement to comb off grain from its stalk is 267.04KW (olugboji 2004). The power required for threshing operation using motorized equipment is the summation of the power needed to overcome the starting torque, the mass of the drum, and the power needed to beat the grain off the panicle. The appropriate size electric motor selected was a 1hp electric motor.

D. Design of Solar PV System

Design of the solar PVC system for rice threshing machine was undertaken to determine:

1. Energy requirement of the machine
2. Array sizing of the modules
3. Required numbers of batteries
4. Selection of inverter
5. Selection of charge controller.

1. Energy requirement of the machine

An electric motor of 750W, 240V was used.
I_M was determine from equation 1

$$P_M = I_M V_M \qquad \ldots\ldots\ \ldots\ldots\ldots\ldots (1)$$

Where: P_M is power of the electric motor (W),

V_m is voltage of the electric motor (V),

I_M is current of electric motor (A).

The hours of use (h) is estimated to be 8h daily. The daily energy use D_E was estimated from equation 2.

$$D_E = hP_M \qquad \ldots\ldots\ldots\ \ldots\ldots\ldots\ldots (2)$$

Energy loss in PV system is usually estimated to be 25% to correct for inverter loss and battery efficiency

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Taking this into account the daily energy use becomes *Daily energy use x Energy loss (to correct for inverter loss and battery efficiency).* The daily energy requirement (D_E) was therefore estimated from equation 3

$$D_E = 1.25 D_E \quad \ldots\ldots\ldots\ldots\ldots (3)$$

The Ah requirement of the machine is the charge to generated by the module and is estimated from equation 4

$$Ah = \frac{D_E}{(V_s)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

2. *Array sizing of the modules*

Peak sunshine hour for Makurdi location is 7h (Chineke and Igwiro, 2008). The charging current (I_g) was determined from equation 5.

$$I_g = \frac{Ah}{P_{sh}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The module to be used is 200W, 24V therefore the module current I_m is 8.3A. The number of modules in parallel (M_p) was determined from equation 6

$$M_p = \frac{I_g}{I_M} \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

The number of modules in series(M_s) was determined from equation 7.

$$M_s = \frac{V_s}{24V} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

3. *Required Number of Batteries*

1. Maximum number of days of cloudiness (d_c) for the location is 2days.
2. Depth of discharge of battery (DOD) is 0.8.
3. Capacity of selected batteries (b_c) is 150Ah
4. The battery capacity (B_c) was determined from equation 8.

$$B_c = \frac{Ah \ x \ b_c}{DOD(P_M)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

No. of batteries was determined from equation 9.

$$B_N = \frac{B_c}{b_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

4. *Selection of inverter*

Inverters are rated in continuous wattage and surge wattage. Continuous watts is the total watts the inverter can support continuously while surge watts is how much watts the inverter can support for a brief period. 2. The inverter in this study is expected to power a 0.75kW electric motor. This is the minimum wattage required. 3. The potential surge wattage is usually 1.5 to 5 times the continuous rating when using electric motor. With this, the inverter selected was a 3500W inverter. 4. Therefore the selected inverter was estimated from equation 10

$$I_N = 5P_M \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Where: I_N is the inverter rating.

5. *Charge controller selection*

The charge controller that was used in this study was of the capacity 40amps.
.067kg. Wheel diameter = 25.5cm. Table 3 show the ideal performance of farmland tractor in 3 gears.

E. *Design of trailer*

1. *Design consideration of trailer*

The design considerations of the trailer were:

1. Load bearing capacity of the trailer taking into consideration the weight of the thresher, electric motor, batteries, inverter, and the modules.
2. The availability of material.
3. Rigidity of the machine and
4. Ease of maintenance.
5. Structural stability of the trailer considering a strong main frame.

F. *Determination and analysis of tractive force*

The trailed cart was pulled by a tractor and the following parameters were measured and obtained. Speed = 2350rpm, torque = 80NM, drawbar pull = 17.71KN, travel speed = 4km/hr; and the total weight of the machine was measured to be 602at maximum governor setting. The ideal engine speed, engine torque, drawbar pull, travel speed and the gear ratios at different speed were obtained and applied in the calculation.

Assuming there are no losses in forward motion due to wheel slip and drawbar pull due to rolling resistance, and assuming all the power from the engine is available at the drawbar to be used in the pulling of the trailed cart. The travel speed of the tractor will be equal to the travel speed of the trailed cart.

The power available at the drawbar (Q_d) was determined from equation 11.

$$Q_d = P \ X \ V \quad \ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Engine power Q_e was determined from equation 12

$$Q_e = 2\pi T_e N_e \quad \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

The tractive coefficient ψ was determined from equation

$$\psi = \frac{\text{drawbar pull}}{\text{weight on driving wheels}} \quad \ldots\ldots\ldots\ldots (13)$$

The gross tractive coefficient ψ' was determined from equation 14

Gross tractive co-efficient

$$\psi' = \frac{\text{tractive force}}{weight \ on \ wheel} \ldots\ldots\ldots\ldots\ldots\ldots (14)$$

The tractive force T_f was determined from equation 15

$T_f = \psi' \times w_w$ . . . . (15)

Soil reaction H was determined from equation 16

$$H = \frac{2qTe}{D} \quad \ldots\ldots (16)$$

$$= \frac{17.71 \times .0255}{2 \times .08} = 2.8$$

Wheel torque T_w was determined from equation 17

$T_w = q\,T_e$ . . . . (17)

Tractive efficiency η_t was determined from equation 18

$$\eta_t = \frac{PV}{2\pi TwNw} \quad \ldots\ldots (18)$$

G. Performance evaluation of the thresher

The performance of the threshing machine was evaluated according to NIAE standard for evaluating rice threshers. The parameters include:

1. Threshing efficiency,
2. Seed breakage,
3. Rate of operation.

1. *Determination of threshing efficiency*

The weight of three samples A, B, and C of rice with panicle were measured before threshing. The weight of threshed rice of the samples was also obtained.

The threshing efficiency was determined from equation 19.

$$\text{Efficiency} = \left[\frac{A}{B}\right] x10 \ldots\ldots (19)$$

Where:

A = Mass of total rice with panicle input per unit time [30minutes].
B = Mass of threshed rice.

2. *Determination of seed breakage or damage*

Observation shows that there was no seed breakage.

3. *Rate of operation*

1. The rate of operation of the photovoltaic rice paddy thresher was estimated from equation 20.

$$R = \left[\frac{Q}{3600}\right] \ldots\ldots (20)$$

Where Q = Quantity of paddy threshed for an hour
R= Rate of operation of the thresher in (kg/s)

4. *Determination of moisture content*

The moisture content of paddy rice was determined using the oven drying method. The initial mass (M_o) of four samples A, B, C and D, were obtained by using digital weighing machine. The paddy samples were then oven dried for three hours at the temperature of about 100^{o}C to obtain the mass of dried rice (M_1). The moisture content of the grain before threshing was estimated from equation 20.

$$\left[\frac{Mo-M1}{M1}\right] x100 \ldots\ldots (20)$$

H. Performance evaluation of the solar photovoltaic system

The performance evaluation of the photovoltaic system was carried out by measuring hourly insolation, current, and voltage available for the threshing system. The voltage stored at the battery banks as a result of the charging process of the system which determines the power available to be use was also measured at thirty minutes interval between 0900h and 1200h. Each reading was taken three times and the average value obtained.

3. RESULTS AND ANALYSIS

Pearson coefficient of correlation analysis and regression method of analysis were used to estimate if insolation(S) or solar intensity has significant effect on current (I) voltage (V) and power output from PV system.

A. Correlation analysis

Data analytical software called SPSS was used for the analysis.

Table 1 summary of measured insolation(s), current (i) and voltage (V) and power output from PVC.

Mean Parameter	1000H	1030H	1100H	1130H	1200H
Insolation (W/m^2)	282.0	447.0	456.0	617.0	563.0
Current from PV array (A)	3.7	5.3	5.4	7.0	6.4
Voltage from PV array (V)	19.0	19.4	19.0	19.1	19.2
Current from charge controller(A)	3.7	5.3	5.4	7.0	6.4
Voltage from charge controller(V)	22.0	22.0	22.0	22.0	22.0
Current from battery bank (A)	7.5	7.5	7.4	7.4	7.5
Voltage from battery bank (V)	49.3	49.2	49.1	48.7	48.5
Current from inverter (A)	2.2	2.2	2.2	2.2	2.2
Voltage from inverter (V)	220.0	220.0	220.0	220.0	220.0
Power from PV array (W)	70.3	102.8	102.6	133.0	122.9

Table 2 correlation analysis of measured insolation and current from PV array

		Insolation	Current from PV array
Insolation	Pearson Correlation	1	1.000**
	Sig. (2-tailed)		.000
	N	5	5
Current from PV array	Pearson Correlation	1.000**	1
	Sig. (2-tailed)	.000	
	N	5	5

**. Correlation is significant at the 0.01 level (2-tailed).

Table 3 correlation analysis of measured insolation and output voltage from PV array.

		Insolation	Voltage from PV array
Insolation	Pearson Correlation	1	.255
	Sig. (2-tailed)		.678
	N	5	5
Voltage from PV array	Pearson Correlation	.255	1
	Sig. (2-tailed)	.678	
	N	5	5

Table 4 correlation analysis of measured insolation and power from the PV array

		Insolation	Power from PV array
Insolation	Pearson Correlation	1	1.000**
	Sig. (2-tailed)		.000
	N	5	5
Power from PV array	Pearson Correlation	1.000**	1
	Sig. (2-tailed)	.000	
	N	5	5

**. Correlation is significant at the 0.01 level (2-tailed).

Table 5 regression ANOVA for measured insolation and current from PV array

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	6.329	1	6.329	6902.420	.000[a]
Residual	.003	3	.001		
Total	6.332	4			

a. Predictors: (Constant), insolation

b. Dependent Variable: array current

B. *Regression analysis*

Table 6 regression ANOVA for measured insolation and voltage from PV array

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	.007	1	.007	.209	.678[a]
Residual	.105	3	.035		
Total	.112	4			

a. Predictors: (Constant), insolation

b. Dependent Variable: array voltage

Table 7 regression ANOVA for measured insolation and power output

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	2308.089	1	2308.089	3011.556	.000[a]
Residual	2.299	3	.766		
Total	2310.388	4			

a. Predictors: (Constant), insolation

b. Dependent Variable: array power

4. DISCUSSION

A trailer for the tractor-Drawn photovoltaic rice threshing machine was designed and fabricated using local raw materials having length of about 326cm, and width of about 120cm, height of about 235cm with a clearance of 51.1cm from the ground. Votex rice fan thresher, 1horsepower electric motor, inverter, charge controllers, batteries, were all mounted on the trailer. The power needed for the operation of the thresher was determined and used for the operation of the tractor-Drawn photovoltaic powered rice threshing machine. Solar panels generate dc voltage which was used to charge the batteries at the battery bank through the charge controller designed to protect the life of the batteries. The energy available to the machine is dependent on the amount of insolation, wattage of the panels used, the number of cells that constitute the battery bank and the size of inverter used. The power rating of electric motor used was 750watts @ 24V, design load current was 15.6A. The daily energy use was estimated to be 6000Wh the daily energy requirement was 7500Wh. The Ah estimated was 312.5Ah. The module rating was determined to have a charging current of 44.6A, (200watts x 2) @ 24V, module current was 8.3A. Numbers of modules in series was two (2). 40amps charge controller, the battery capacity was 780.5 the numbers of battery were five (4) and a 3.5KVA inverter was able to drive the thresher. Table 1 shows the summary of measured insolation (S) current (I) and voltage (V). Increase in amount of insolation leads to the corresponding rise in amount of current generated by the module. The general performance of this photovoltaic system is dependent on type of module, the capacity of the module, solar intensity, battery charging rate, charged level of battery bank, as the stored charges goes down from optimal level, the speed of the electric motor slows down.

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The summary of the results for all the parameters measured and calculated for the moisture content of rice at the time of the experiment was 9.8%, the rate of operation was 10.17Kg/s. No seed breakage was recorded at the time of threshing. Correlation analysis of measured insolation and output current, power output from PVC system in table 2, and 4, were significant at $P \leq 0.01$. While correlation analysis of insolation and voltage as in table 4 shows no significantly effect. Simple linear regression analysis of measured insolation and output current, and power output from the PVC system in table 5, 7 shows significant relationship, while regression analysis of measured insolation and output voltage shows no significant relationship at $P \leq 0.05$.

5. CONCLUSION

The contribution of this study to the literature is the development and evaluation of a model tractor-drawn solar PVC rice thresher which harnessed the abundant solar energy of this location to enhance on-farm rice threshing that would not have been possible because of lack of a power source.

1. It was established that increase in insolation leads to a corresponding rise in current generated by the modules.

2. The performance of a photovoltaic system is dependent on a number of factors such as type of module, solar intensity, capacity of module, charging rate, battery bank capacity, and location.

Since the design and fabrication of this machine was done primarily to test the possibility of using photovoltaic energy to power agricultural machines. It is therefore imperative to obtain optimal output, high efficiency, at a minimal cost, and good separation between paddy seeds and the debris.

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