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Design of a Solar Photovoltaic System to Power a Rice Threshing Machine

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Abstract *– The design of a solar photovoltaic (PV) system to power a rice threshing machine was undertaken. The PV system was designed to power a 750 W electric motor that drives a thresher. The PV array, battery capacity, charge controller and inverter were designed, connected and some parameters measured. The measured parameters were the insolation upon the modules, output current and voltage of the PV array, charge controller, battery bank and inverter. These were measured daily at 30 minutes interval from 1000H to 1200H for 20 days. The PV system was used to power the machine. Correlation analysis was used to determine the degree of relationship between the insolation, current and voltage output of the PV array. The measurements showed that the current output from the PV array responded linearly and in step to the insolation (R^2=1) while the voltage output was constant. The output current from the PV array was equal to the output current from the charge controller. The PV system successfully powered the rice thresher, making it useable in remote on-farm rural locations.*

Keywords: Design, Solar, Photovoltaic, Rice, Thresher

1. INTRODUCTION

The lack of electricity in remote rural locations in Developing Countries is largely responsible for the poor state of agricultural infrastructures and almost zero mechanization of agriculture. The lack of grid electricity has hindered the mechanization of agricultural activities such as milling, threshing and pumping of water. Nigeria currently generates 2,300 MW of grid electricity which is about 9% of the minimum of 25,000 MW of electricity required to sustain civilization. There is, therefore, a deficit of about 22,700 MW of electricity (ECN, 2005). The increasing food insecurity and crisis necessitates the compulsory mechanization of agricultural tasks by providing electricity on remote farms for on-farm machines.

Solar photovoltaic systems offer the best alternative solution to providing electricity for many on-farm agricultural operations like rice threshing. Photovoltaic systems have found widespread application in agriculture because they are simple, compact and have high power to weight ratio. They have no moving parts and probably yields the highest overall conversion of solar energy into electricity. The PV system requires modest amount of skilled labour to install and maintain making them well suitable to village power systems. In order to supply the required power, PV arrays should be capable of producing sufficient current and voltage to run the applications, and can be connected in series and in parallel to obtain the desired voltage and current respectively. The solar photovoltaic system for rice threshing consists of batteries, modules, a 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 charges the batteries and the thresher performs the threshing operation.

The installation of PV systems and its use in agriculture has been growing by 20 - 25% per annum over the past twenty years (Eltawil and Samuel, 2007). Beshada et al (2006) used a PV system to drive a stone mill with a diameter of 150mm and a maximum capacity of 3kg/h. 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 a seed oil extraction equipment using a solar powered screw press. The relative compatibility of solar powered technologies with small systems suggests that it may hold promise for many of the world's small farms. The rapidly decreasing unit cost of photovoltaics also

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suggests that it may soon become a competitive source in agriculture.

Threshing rice easily, inexpensively and neatly remains a problem for the poor farmers who cannot afford the highly motorized threshers such as the combine harvester. The threshing of rice is currently accomplished by manual means. The farmers use sticks to beat and release paddy rice from the harvested stalk. This is ardous and back-breaking. These small-farmers make up more than 80% of Nigeria's farmers population (Itodo, 2013). Postharvest activities take place in rural areas where electric grid connection is not available and cost of providing fuel for the prime mover is also very high. The current manual on-farm threshing is labour intensive with its associated high drudgery. This makes the investment and operation costs higher with fuel and spare parts supply unrealizable. An electric motor with a power supply from a PV generator is a cost effective alternative.

Solar energy produces no emissions and uses no fuel other than the storage batteries. PV system components are all solid states with no hazardous materials involved. They require virtually low or no maintenance, are long lasting, highly reliable and are an economical source of power. The generation of electricity using PV is, however, fraught with the problem of variability of solar radiation. The objective of this study is to design and install a solar PV system to power a rice thresher for use on Nigerian small-scale farms that are in remote rural locations.

2. MATERIALS AND METHODS

2.1 Methodology

A hold-on Votex rice threshing machine at the Farm Machinery Shed, Department of Agricultural and Environmental Engineering, University of Agriculture, Makurdi, Nigeria was powered from a solar PV system that was arranged in a designed two-wheel tractor drawn trailer (Fig. 1). The power rating of the electric motor on the thresher was used to design a solar PV system. The design of the solar PV system was to determine the array sizing of the modules, appropriate size of inverter, charge controller, the capacity and number of storage batteries. The insolation upon the modules, output current and voltage of the PV array, charge controller, battery bank and inverter were measured daily at 30 min intervals from 1000H to 1200H for 20 days. The current was measured using an ammeter while the voltage was measured using a voltmeter. The insolation was measured using a sun meter. Each measurement was done three times and the mean taken as the value for that parameter. The degree of relationship between the insolation, current and voltage output of the PV array was determined by correlation analysis using Microsoft Excel 2013.

Fig. 1: Picture of the solar powered rice thresher mounted on a tractor-drawn trailer

2.2 Description of the solar PV system

The solar PV system consists mainly of solar modules, a charge controller, a battery bank and an inverter. The modules receive and convert the insolation upon them to direct current electricity. Three (3) solar modules (module 1 = 80 W @ 24 V; module 2 = 80 W @ 24 V; module 3 = 200 W @ 24 V) were connected in parallel to give an output of 298 W @ 17.5 V. The three modules were connected to a 20A charge controller to prevent over charging and prolong the life of the connected batteries. The charge controller was connected to a battery bank of four (4) batteries each of 100 Ah capacity all connected in series. The batteries were connected to a 3.5kVA @ 48V inverter, which converts the stored d.c charges from the batteries to a.c. electricity. The a.c. electricity from the inverter powers the 750W electric motor that drives the thresher. Fig. 2 is the schematic diagram of the solar PV system.

2.3 Design of solar PV system

Design of the solar PV system for the rice threshing machine was undertaken to determine the array size of the system, battery capacity and number, select charge controller and inverter. The power required for threshing operation using motorized equipment is the summation of the power needed to overcome the starting torque posed by the mass of the drum and the power needed to beat the grain off the panicle. The manufacturer of the Votex paddy rice threshing machine recommend the use of a 750W @ 240V a.c. electric motor.

2.3.1 Array sizing of the PV system

The current from the electric motor (I_{em}) was determined from equation 1.

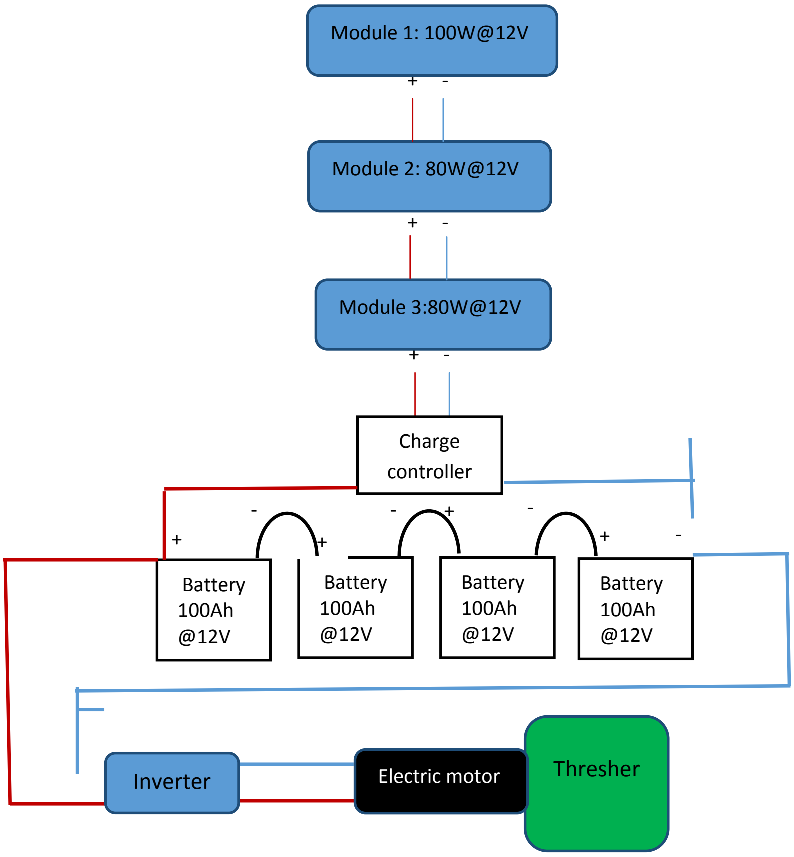


Fig.2: Schematic diagram of the solar PV powered rice threshing machine

$$I_{em} = {P_{em}}/{V_{em}} \quad ---------------- 1$$

where:

P_{em} is the power output of the a.c. electric motor, W

V_{em} is the voltage output of the electric motor, W

The daily energy (E_d) use taking into consideration the inverter efficiency was determined from equation 2.

$$E_d = e_i P_{em} h \quad ----------------2$$

where:

e_i is the inverter efficiency, which is 0.9

h is the hour of use of the PV system, h

The Ampere - hour (Ah) requirement of the machine is the charge to be generated by the modules and was estimated from equation 3.

$$Ah = {E_d}/{V_s} \quad ----------------- 3$$

where:

V_s is the system voltage, which is 48V

The PV array power (P_{pv}) was determined from equation 4 (Solar Energy International, 2013).

$$P_{pv} = {E_d}/{h_p} \; x \; F_d \; x \; F_t \; x \; e_b \quad ---------- 4$$

where:

e_b is battery efficiency, which is 0.8

F_t is PV temperature loss factor, which is 1.0

F_d is derate factor, which is 0.85

h_p is peak sunshine hour for the location, which is 7h for Makurdi

The number of modules connected in parallel (M_p) and in series (M_s) were determined from equations 5 and 6 respectively.

$$M_p = {P_{pv}}/{P_m} \quad ---------------- 5$$

$$M_s = {V_s}/{V_m} \quad -----------------6$$

where:
P_m is the power rating of the module, W
V_m is the module voltage, V
The array size of the system, which is the total number of module (M_t) connected in series and in parallel was determined from equation 7.

$$M_t = M_p \; x \; M_s \text{ ---------------- } 7$$

2.3.2 Capacity and number of batteries

The battery used (b_{st}) was a 100Ah @ 12V capacity. The battery capacity (B_c) required to power the system, the number of batteries to be connected in parallel (b_p), number of batteries to be connected in series (b_s) and total number of batteries (b_t) was determined from equation 8, 9, 10 and 11 respectively.

$$B_c = {}^{Ah \; x \; d_c}/_{DOD} \text{ -------------- } 8$$

where:
d_c is number of days of cloudiness for the location, which is 2 days
DOD is the depth of discharge of the battery, which is 0.5

$$b_p = {}^{B_c}/_{b} \text{ ------------------- } 9$$

where:
b is the capacity of the battery used, which was 100 Ah

$$b_s = {}^{V_s}/_{V_b} \text{ ------------------ } 10$$

where:
V_b is the battery voltage, which was 12 V

$$b_t = b_p \; x \; b_s \text{ ----------------- } 11$$

2.3.3 Charge controller

The input current (I_{cci}) which is the controller Array Amp was determined from equation 12.

$$I_{cci} = I_m \; x \; M_p \; x \; 1.25 \text{ ------------ } 12$$

The controller should be capable of handling the maximum d.c. load. Its output voltage should be equal to the nominal battery voltage, which is 12V. The charge controller input current must be less than its output current to the batteries. The controller output current (I_{cco}) was determined from equation 13.

$$I_{cco} = {}^{W_{mcc}}/_{V_{cco}} \text{ -------------- } 13$$

where:
W_{mcc} is the maximum watts the charge controller must pass and was determined from equation 14.

$$W_{mcc} = P_m \; x \; M_t \text{ -------------- } 14$$

V_{cco} is the charge controller output voltage = 12V

The number of charge controllers (N_{cc}) was determined from equation 15.

$$N_{cc} = {}^{W_{mcc}}/_{W_{ccr}} \text{ -------------- } 15$$

where:
W_{ccr} is the watt rating of the charge controller

2.3.4 Inverter

Inverters are rated on continuous and surge wattages. Continuous watts is the total watts the inverter can support continuously while surge watts is the watts the inverter can support for a brief period. The inverter is expected to supply a 750W electric motor, which is the minimum watts output from the inverter. The surge capacity of the inverter (P_{si}) is usually 1.5 to 4 times the continuous rating of the electric motor, which was determined from equation 16 (Solar Energy International, 2013).

$$P_{si} = 3P_{em} \text{ ------------------- } 16$$

The DC input voltage from the battery is 48V while the AC output voltage from the inverter is 240V. The maximum d.c. current from the batteries, which is the inverter input current (I_{iv}) was determined from equation 17.

$$I_{iv} = {}^{P_{em}}/_{V_s} \text{ --------------- } 17$$

2.3.5 Determining the hours of usage of the PV system

The AC daily electrical consumption will depend on the hours of usage of the machine, which in turn will determine the array size of the modules, number of batteries, size of charge controller and inverter. Table 1 is summary of the analysis of the hours of use of the PV system to power the threshing machine. Table 2 is summary of designed PV system parameters used to power the machine for 2 hours.

Table 1: Analysis of hours of use of machine

System specification	Hours of use of machine		
	1h	**2h**	**3h**
Daily ac electrical consumption	750W	750W	750W
Total daily load	675Wh	1,350Wh	2,025Wh
System Ah requirement	14.1 Ah	28.1Ah	42.2Ah
PV array watt	142W	284W	425W
Charge controller capacity	21A@12V	21A@12V	21A@12V
Inverter capacity	16A, 2.3kW	16A, 2.3kW	16A, 2.3kW
Battery capacity	56Ah	112Ah	169Ah
Number of batteries	4No. 100Ah@12V	4No. 100Ah@12V	8No. 100Ah@12V

Table 2: Summary of designed PV system parameters

Component	Specification	Symbol	Value
	Power rating	P_{em}	750W
Electric	Voltage	V_{em}	240V
motor	Daily hours of usage	h	2h
	AC daily electrical consumption		1,500Wh
	Total daily load	E_d	1,350Wh
	Ah		28Ah
	Peak sun hour per day	h_p	7h
	PV array, watts	P_{pv}	284W
Module	Maximum module power	P_m	298.4W
	Module Voltage	V_m	17.5V
	Array size	M_t	3
	Input current	I_{cci}	21A
	Output current	I_{cco}	25A
Charge	Max watt charge controller must pass	W_{mcc}	298W
Controller	Input Voltage	V_{cci}	17.5V
	Output Voltage	V_{cco}	24V
	Power rating of selected charge controller	W_{ccr}	341W
	No. of charge controller	N_{cc}	1
	Selected charge controller		298W@12V
	AC output watts		750W
	DC Voltage from battery		48V
Inverter	Max DC current, Amp continuous	I_{iv}	16A
	AC output Voltage		240V
	Surge capacity	P_{si}	2,250W
	Nominal size		192W
	Battery AH capacity	b_{st}	100Ah
	Battery Voltage	V_b	12V
Battery	System battery capacity	Bc	112Ah
	No. of batteries in parallel	b_p	1
	No. of batteries in series	b_s	4
	Total number of batteries	B_t	4
	Output Voltage		48V

3. RESULTS AND DISCUSSION

Table 3 is summary of regression analysis of current output from the PV array versus the solar insolation. The table showed that there was a linear relationship (R^2 = 0.999) the insolation and current output of the PV array. Table 4 is summary of measured PV system parameters. Table 4 showed that the insolation increased from 282.0 W/m^2 at 1000H to 617.0 W/m^2 at 1130H and decreased to 530 W/m^2 at 1200H; the corresponding PV array current was 3.1A, 7.0A and 6.4A respectively. Fig. 3 showed that the PV array current responded in step to the insolation (Solar Energy International, 2013). Table 4 also showed that the voltage output from the PV array was 19.0V, 19.1V and 19.2V at the insolation of 282.0, 456.0 and 530.0 W/m^2 respectively (Fig. 4). Fig. 4 showed that the insolation did not affect the PV array voltage since the voltage output was constant. These results agree with the findings of Rupert et al., (2012) and Glasnovic and Margeta (2007). Table 4 also showed that the output current from the PV array was equal to the output current from the charge controller.

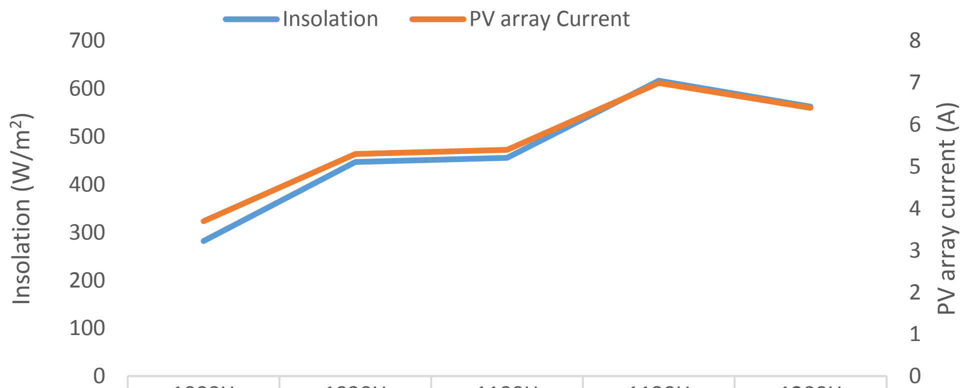
The output current from the PV array at 1000H, 1100H and 1200H was 3.7A, 5.4A and 6.4A respectively, and these were also the output current from the charge controller at these hours. The designed maximum allowable current through the charge controller was 21.0A. The controller, therefore, discharged its input currents from the PV array, which were less than 21.0A. The charge controller is a voltage regulator. Its primary function is to prevent the battery from being over charged by the array. The input voltage from the PV array to the charge controller was 19.0V while the charge controller delivered a constant 22.0V to the battery bank, thus ensuring the charging of the batteries at a constant voltage. The charge controller also prevents the battery from being overly discharged by the d.c load. The battery bank delivered a steady 49.0V to the inverter, thus ensuring that the batteries were not over discharged by the inverter.

Table 3: Summary of regression analysis of current output from the PV array versus solar insolation

R	R^2	Adjusted R^2	Standard Error
1.000	0.999	0.999	0.03195

Table 4: Summary of measured PV system parameters

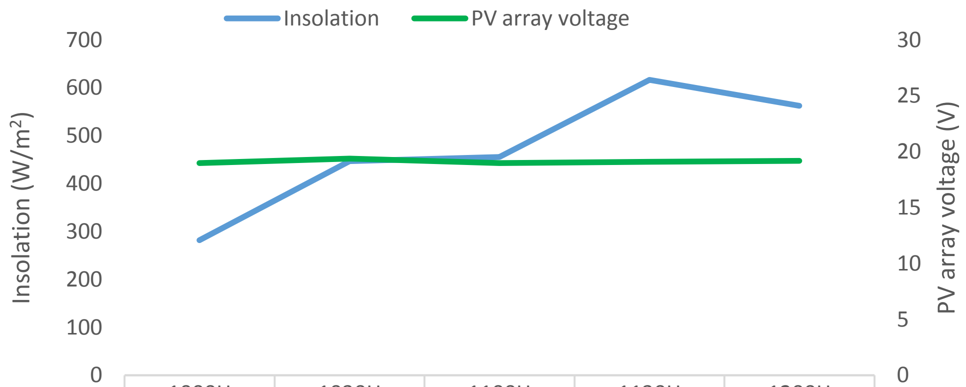
Parameter	1000H	1030H	1100H	1130H	1200H	Mean
Insolation (W/m^2)	282.0	447.0	456.0	617.0	563.0	473.0
Output current from PV array (A)	3.7	5.3	5.4	7.0	6.4	5.6
Output voltage from PV array (V)	19.0	19.4	19.0	19.1	19.2	19.1
Output current from charge controller (A)	3.7	5.3	5.4	7.0	6.4	5.6
Output voltage from charge controller (V)	22.0	22.0	22.0	22.0	22.0	22.0
Output current from battery bank (A)	7.5	7.5	7.4	7.4	7.5	7.5
Output voltage from battery bank (V)	49.3	49.2	49.1	48.7	48.5	49.0
Output current from inverter (A)	2.2	2.2	2.2	2.2	2.2	2.2
Output voltage from inverter (V)	220.0	220.0	220.0	220.0	220.0	220.0



	1000H	1030H	1100H	1130H	1200H
Insolation	282	447	456	617	563
PV array Current	3.7	5.3	5.4	7	6.4

Time (hour)

Fig. 3: Relationship between solar insolation and PV array currrent



	1000H	1030H	1100H	1130H	1200H
Insolation	282	447	456	617	563
PV array voltage	19	19.4	19	19.1	19.2

Time (hour)

Fig. 4: Relationship between solar insolation and PV array voltage

4. CONCLUSION

It is concluded that there was a linear relationship (R^2=1) between the insolation and the output current from the PV array. The array responded in step to the insolation. The PV array voltage was not affected by the varying insolation as the array voltage was constant. The PV array current was equal to the output current from the charge controller. Therefore, the array current can be used in the design and selection of charge controllers. Also, the PV system successfully powered the threshing machine for the designed number of hours of use of two (2) hours.

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