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Solar Power Design, Analysis, and Operation for Developing Countries

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Abstract

The outcome this study is to design is an electrically operated blender to a solar operation. There is an increasingly intense need to harness solar energy due to an ever growing shortage of conventional energy sources, the instant invention is concerned with method and apparatus for solar concentrator micro-mirrors on solar power satellites and the moon to focus and reflect large quantities of solar energy. Method and apparatus are taught for directly reflecting solar energy to the Earth; reflecting solar energy to a microwave converter in space which transmits microwave energy to the Earth; and reflecting solar energy to a laser radiation converter which beams laser radiation to the Earth. The concentrated energy received at the Earth may be converted directly to electricity or indirectly by thermo-mechanical means. The advantages and disadvantages of the different means of sending such concentrated energy to the Earth are discussed. A particularly important objective of this invention is the focusing of sunlight for solar power conversion and production. The instant invention can contribute to the goal of achieving environmentally clean solar energy on a large enough scale to be competitive with conventional energy sources.

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Keywords: Solar energy, Power transmission Design criteria; D.C. motor; Cable sizing.

Introduction

The rising cost of electricity has led people to search for ways to cut costs relating to powering their homes and appliances. The free energy provided by the sun, makes the use of solar appliances a cost-effective way to offset utility bills. Solar energy from the sun is clean and infinitely renewable and can be defined as a beaming light and heat that is generated from the sun which is extracted by using solar power plants. The application of this type of power is spreading as the environmental costs and limited supply of other power sources such as fossil fuels and electricity from the grid are increasing. Many new technologies have been developed to make good use of solar energy. These technologies are classified as direct or active and indirect or passive systems. In general, direct or active solar power involves a single transformation of sunlight into a useable energy by using electrical and mechanical components such as photovoltaic panels to process sunlight into useable power outputs [3]. Solar energy is not only utilized by government and industry to produce power, but is of many uses to household as well. There is an array of solar equipment to be used in home. The basic purpose of domestic solar equipment is that the end users can also benefit from these free sources of energy and conserve the electricity produced by using fossils, hydro, thermal or other forms of energy sources. The design of solar equipment is really simple and small. Domestic solar equipment are adjusted according to the needs of the home [1]. The use and production of solar equipment is increasing as the world is shifting to alternative and renewable energy sources and the use of solar appliances can save a lot of energy and make life easy for rural people who do not have access to electricity. In order to make the use of solar equipment common, it is important to come out with more and simple solar appliances or try to convert the existing electrical appliances to solar appliances such as solar blenders which will be of tremendous help to the rural people in Ghana and this would also help shift our next generation towards the desire for solar appliances.

Rural electrification as well as the over dependence on hydro and thermal power is a major problem faced by past and current governments in Ghana, but one area many have not thought of is the need to look for other sources of energy such as solar. Solar energy products are becoming common these days and there is the need to adjust to the use of these modern technologies. There are many solar equipment ranging from solar cookers, solar lights, solar lanterns, solar lamps, solar water pumps and many more. The use of all this solar equipment do not put much pressure in the pocket of the users once they are installed. Hence, the need to add to the existing ones, a solar operated blender to help improve the standard of rural dwellers in developing countries.

Materials and Methods

Conceptual design

This is the art which gives precedence to hypothetical function; it is the creation and exploration of new ideas[2]. In view of this, a conceptual design has been developed in order to find a suitable solution to the research problem, as shown in following picture.

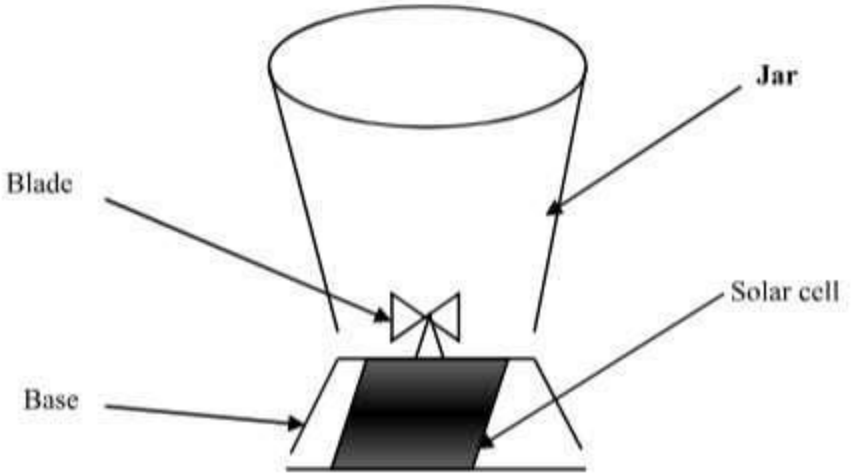


Figure 1: Conceptual design A

Design Evaluation

This is a list of measurable characteristics or criteria such as Function, Safety, Quality, Aesthetics, environmentally friendly, etc. which are used to select the best design from other alternatives [4,6].

Table 1**: **Desirable ranges of each criterion

Design criteria	Questions to spark ideas	Design 1	Design 2
Customer	Who is the product intended for?	3	5
Aesthetics	What appealing features would it have?	4	7
Environment	How will the product relate to the environment – recycling parts, the manufacturing process	3	3
Safety	How will you ensure that the product is safe?	4	5
Ergonomics	How will the product relate to people's size, shape, etc.?	3	5
Quality	What design and manufacturing features will ensure a quality product?	4	5

Table 2: Design criteria values of solar operated Blender

Design criteria	Design A	Design B
Rated power	700 W	750 W
Aesthetics	5	8
Environment	20	25
Safety	8	10
Ergonomics	8	8
Quality	5	7

Table 3: Evaluation of result of each design

	Design A	Design B
Total score	746	808
Rank	2	1

Selection of the better alternative

Considering the two designs, and taking into account the criteria assigned to each, design B has the higher score and ranked 1. Therefore, design B is selected.

Design Calculation and Parameters

The scope of the study lies on latitude 120.8 ^{o} N and longitude 0.25 ^{o} E. The land is relatively flat with a few hills. The natural vegetation is that of the savannah woodland characterized by short scattered drought-resistant trees and grass. In order to realize the design, a survey was conducted, and it was established that the absence of electricity in the community has compounded the problems of house wives and traditional caterers as they have no other options than to grind their tomatoes and other ingredients manually, which is generally drudgeries. Also, the Peak Sun Hour (PSH), which is the total number of hours per day in which solar irradiance averages 1000 W/m^2 [6], was also determined. The average amount of solar radiation on a horizontal surface was 5.51 kWh/m^2, and this was used to calculate the peak sun hours, using the following relation:

A peak sun hour of 1.53 kWh/m^2 was used to determine the sun exposure in order to select the most appropriate photovoltaic module for the design.

This means that the radiation will have to stay at the rate of 1 kW/m^2 for 1.53 hours.
Now, readings of the site's irradiance levels for one day from 9 am to 4 pm were taken and a result of 5 peak sun hours (5 PSH) was obtained. This would mean that, the energy received for the whole day will equal the energy that would be received had the irradiance for 5 hours been 1 kW/m^2.

Selection of D.C. Motor

A direct current (DC) motor is a fairly simple electric motor that uses electricity and a magnetic field to produce torque, which causes it to turn; it requires two magnets of opposite polarity and an electric coil, which acts as an electromagnet. DC motors can be used in areas where there is no electricity and for a variety of purposes. Their simple design and reliability make them a good choice for many different uses [8].

A brushless DC motor which has more torque per weight, more torque per watt, increased reliability, reduced noise and longer lifetime and has similar features to that of electric blender motor was used for the solar blender [7,10].

Table 4: Specification of the DC motor used for the solar blender

Type	**BLDC (Brushless DC Motor)**
Model Number	DSCN0276
Rated Voltage	24 volts
Rated current	31.25 A
Rated Power	750 W
Rated Speed	3000 rpm

Determination of the motor torque

Torque is the force that produces rotation. It consists of force acting at a distance [Torque (Nm) = Force (N) x
Distance (m)]. Torque, like work, is measured in Newton meter (Nm).
Full-load torque is the torque to produce the rated power at full speed of the motor [11]

To calculate full-load torque, apply this formula:
Where;
T = torque (Nm)
P = power = 750 W
A DC motor rotating at 3000 rpm and having a power of 750 W will have a torque of 1.5 Nm which is equal to an AC motor rotating at 2500 rpm and having a power of 500W.
(This indicates that the DC motor will work the same way as the AC motor in the electric blender. Hence, the lower the speed the higher the torque and vice visa.).

Cable sizing

Solar panels use low voltage DC wiring and connectors that are able to carry high currents.Thicker cable should therefore be used for long runs to minimize voltage drop. To determine the suitable size of cable for the solar panel wiring, it is important to note that, all conductors and cables have some amount of resistance.This resistance is directly proportional to the length and inversely proportional to the diameter of conductor,i.e. $R \propto L/d$.

[Law of resistance, $R = \rho (L/d)$][8].

Whenever current flows through a conductor, voltage drop occurs.According to [13], at any point between power supply terminal and installation, voltage drop should not exceed 2.5% of supply voltage and that of sub circuit and final sub circuit should be half of the allowable voltage drop.

Therefore, since our supply voltage is 24 V, the value of allowable voltage drop should be;
Allowable Voltage Drop = 24 x (2.5/100) = 0.6 V, and that of sub circuit and final sub circuit allowable voltage drops is 0.3 V (i.e. 0.5 of 0.6 V).

Determination of the actual cable size
For the wiring of the solar blender, (from solar panel to the blender motor), the following conditions were considered;
Load of 0.75 kW = 750 W
Total length of cable (from solar panel to blender motor) is assumed to be 5 meters.
Supply voltage = 24V
Ambient temperature is assumed to be 40°C
Additional load of 2% was assumed = 15 W
Total Load of 765 W (750W + 15 W) and a total Current (I) of 32 A was used.
Therefore, to select the size of cable for load current of 32 A (from Table 5), the nearest value is 7/1.04 (31 Amperes) which means we can use 7/ 1.04 cable according to Table 5.

Table 5: Current rating of copper cables

Current carrying Capacity (in Amp)	Number of wires and Thickness of each wire	Area (in mm^2)
11	1 / 1.13	1
13	1 / 1.38	1.5
18	1 / 1.78	2.5
24	7 / 0.85	4
31	**7 / 1.04**	**6**
42	7 / 1.35	10
56	7 / 1.70	16
73	7 / 2.14	25
90	19 / i.53	35
145	19 / 1.78	50
185	19 / 2.14	70
230	19 / 2.52	95

Next, check the selected cable (7/ 1.04) with temperature factor in Table 6,the temperature factor of 0.94 at 40 °C corresponds to a current carrying capacity of 31A.Therefore, current carrying capacity of this cable at 40°C would be determined as;
Current rating (at 40°C) = 31 x 0.94 = 29.14 Amps

Since the calculated value (29.14 Amp) at 40°C is less than that of current carrying capacity of (7/1.04) cable which is 31A, this size of cable (7/1.04) is suitable with respect to the ambient temperature.

Table 6: Temperature factor

Temp. Factor	1.02	1	0.93	0.94	0.91	0.88	0.77	0.63
Temp.^{O} C	25	30	35	**40**	45	50	55	60

Finally, find the voltage drop per ampere meter for this cable. The voltage drop is 7mV, but in our case, the length of cable is 5 meter. Therefore, the actual voltage drop for 5 meter cable would be:
Actual Voltage drop (for 5 meter) = Voltage drop (mV) x Current carrying capacity at 40 ^{o}C (I) x Length of cable (m) = mV x I x L = (7/1000) x 29.14 ×5 = 1 mV

Since this drop is almost equal to that of maximum allowable voltage drops of 0.9mV this cable is the most
appropriate and suitable cable size to use [14].
Cable Specification
The selected cable used for the design has the following
specification Length of Cable (L) = 5 m
Cross Sectional area (A) = 6 mm^2
Material = copper

Solar panel selection
The following pre-requisite information is required in order to select the appropriate solar panel for the design:

Loads required to be supported by the solar PV system
Autonomy time or minimum tolerable downtime (i.e. if there is no sun, how long can the system be out of service?)
Measurements of the solar
irradiation at the site Output voltage.
(DC) [12][16]

The calculation is based onAS/NZS 4509.2 (2002) "Standalone power systems - System design guidelines". The following four steps were considered in the design;

Step 1: Estimate the solar irradiation available at the site (based on GPS coordinates or measurement)

The estimated solar radiation available at the site based on data collected fromRet screen is 4.61 Kwh/m^2/day.

Step 2: Determine the loads that will be supported by the system

The type of load that the solar panel needs to support is the solar blender motor which has a power of 750 W.

The consumed apparent power of the loads (in watts), is calculated as follows:

Where;
is the consumed apparent power (W)
is the actual load (W) = 750 W
Cosø is the load power factor (pf) = 0.85
ηis the load efficiency = 75 %
Therefore;
= 1000 watts.

Step 3: Calculate design load and design energy

The design load is the instantaneous load for which the power conversion, distribution and protection devices should be rated. It is calculated as follows:

$$S_d = S_p (1 + K_g) (1 + K_c) \ldots\ldots\ldots.. (3)$$

Where
S_d is the design load (W)
S_p is the peak load = 765 W (from cable sizing)
K_g is a contingency for future load growth = 2% of 765 = 15 W
K_c is a design margin (for inaccuracies in load estimation) = 3% of 765 = 23 W

The design energy demand is used for sizing energy storage devices such as the battery; the total energy (in terms of Kwh) is calculated by assuming 2 hours operational time for the blender. It is calculated as follows;

$$E_d = E_t (1 + K_g) (1 + K_c) \ldots\ldots.. (4)$$

Where;
E_d is the design energy demand (kWh)
E_t is the total load energy, = 0.765 kW x 2 = 1.53 kWh
$K_g$is a contingency for future load growth as defined above (%)
K_c is a design contingency as defined above (%)

Step 4: Estimate the output power of a single PV module at the proposed site location

A PV module with the following characteristics is chosen:
Peak module power (p_{peak}) = 270 W
Nominal voltage (V_{dc}) = 36.65 V
Solar PV Standard temperature (T_{stc}) = 25 ^{o}C
Manufacturer's power output tolerance

(Tt) = 5 % If we assume that the average ambient

temperature (T_{amb}) is 40 ^{o}C Then the effective PV cell

temperature (T_{pv}) = $T_{amb} + T_{stc}$

Given a medium dirt reduction factor (f_{dirt}) of 0.97, the power output of the solar P.V (P_{panel}) will be:

$$P_{panel} = P_{peak} \times T_{stc} \times T_t \times f_{dirt} \ldots\ldots\ldots (5)$$
$$= 270 \times 25 \times 0.05 \times 0.97$$
$$= 327 \text{ W}$$

Number of solar PV panels needed to power the DC motor

Number of solar PV panels needed to power the DC motor is 2. Therefore, the design will need two solar models with the following specifications: [15].

Table7: Solar panel specification of 270W polycrystalline solar modules.

Model number	CNSDPV-270P
Rated maximum power(P)	270 W
Open circuit voltage (Voc)	44.50 V
Short circuit current (Isc)	8.28 A
Maximum power voltage (Vmp)	36.65 V
Maximum power current (Imp)	7.64A
Cell efficiency (%)	14.74
Solar cell and configuration	72 cells 6*12 crystalline solar cell
	(156*156)
Dimension	1940*996*50 mm
Weight	8kg
Operating temperature	40°C

Construction

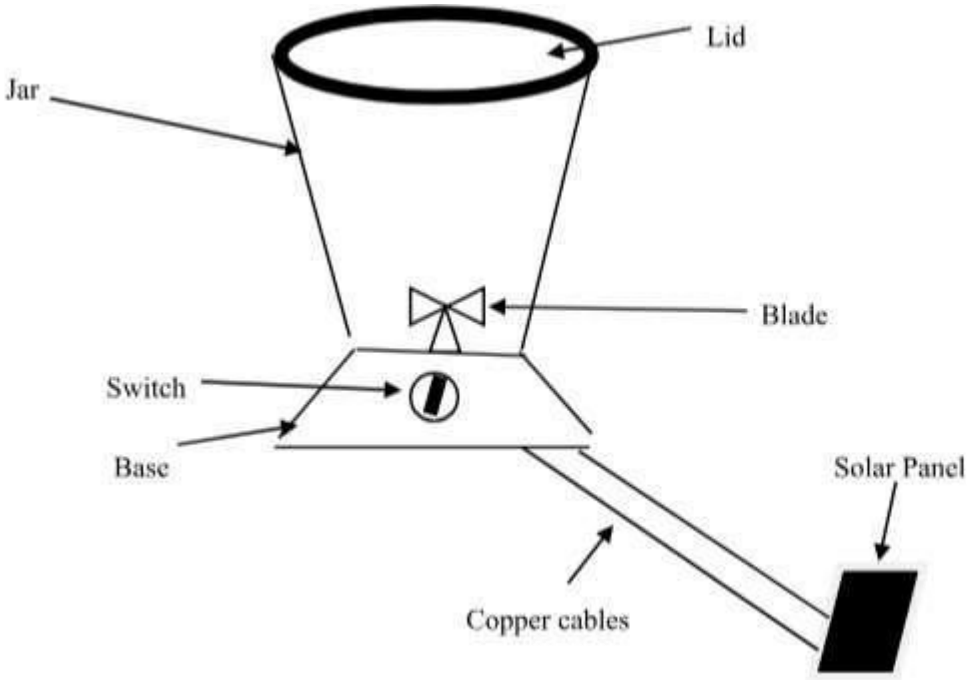


Figure 3: Final design of the solar operated blender to be constructed

The final design of the solar operated blender showing the solar panel and how it will be connected to the DC motor which is housed in the base of the blender was constructed by replacing the A.C. motor of an electric blender with a D.C motor whose specifications are shown in Table 4. The solar panel was then connected to the blender motor using cables with the following specifications;

Length of Cables (L) = 5 m
Cross Sectional area (A) = 6 mm^2
Material = copper

The base of the blender which is the mechanical heart of the unit houses the DC motor as well as the switch. The blade of the blender was attached to the motor shaft with screws to ensure it stays in place. The individual components of the solar blender were then assembled together. When the sun rays fall on the solar panel, it produces a direct current which causes the DC motor to operate when the switch is turned on, thereby causing the blade to rotate for the blender to work [15,17].

Discussion

The DC motor

The DC motor selected has a rated voltage of 24 volts, rated power of 750 watts and runs at a speed of 3000rpm. The output torque at this speed is 2 Nm, which is similar to the AC motor used in electric blender. Since the motor has similar specifications as the AC motor, it will be able to perform the task in much the same way as the AC motor in the electric blender.

The solar panel

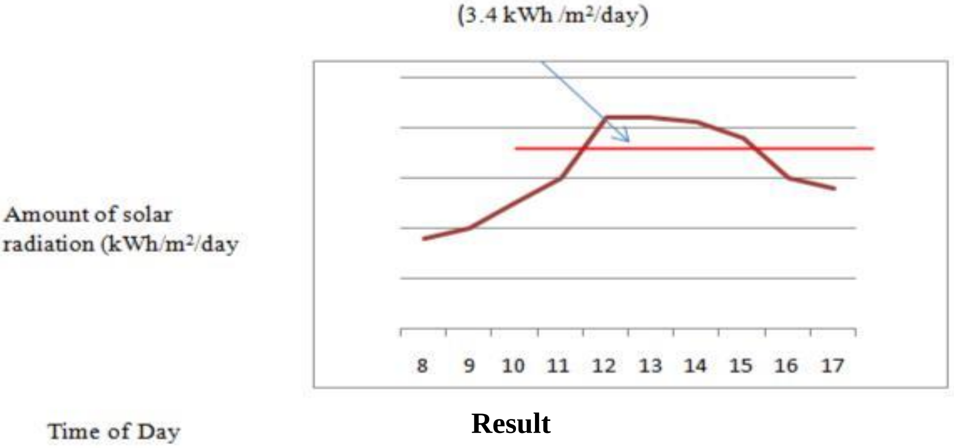
The solar panel (270 W polycrystalline, model CNSDP – 270P) is selected for the solar blender. It has a maximum operating power of 270 watts, while the power required by the DC motor for effective operation of the blender is 750 watts. It is therefore important to note that, in order for the solar panel to produce the required power to operate the DC motor; two solar panels of the same specifications will be required to be connected in series to produce the required power to meet the demand of the DC motor.

Amount of solar radiation on site

The data for the performance of the Solar Blender was taken at Yipaala, a farming community in the Upper East Region of Ghana which has no electricity. The data was taken in August,which according to[7], has the lowest solar radiation in Upper East Region. The data was taken for three weeks and the daily solar radiation were recorded as shown in Table 8. From Figure 5, drawn from Table 8, it can be seen that the average solar radiation for the Yipaala community was high in the afternoon (between 11.00 and 15.00 GMT) than in the morning and evening and this indicates that there was enough solar energy during those periods to power the solar blender.

TABLE 8:Yipaala community

Week	One	Two	Three
Solar radiation ($kWh/m^2/day$)	4	4.6	3.8



Result

Figure 5: Average solar radiation recorded at Yipaala

Daily operational hours
Various deductions were made from the analysis of the data to ascertain the operational period of the blender. In view of this, the blender was made to run for 10 hours, and during that period, the blender received 6 hours of continuous sunlight (9am – 3pm), which represented 60% of the total time of the day.

From Figure 5, it can be seen that the solar energy was high in the afternoon than in the morning and evening, thereby resulting in higher power produced during the peak sun hours in the afternoon by the solar panel as shown in Figure 6.

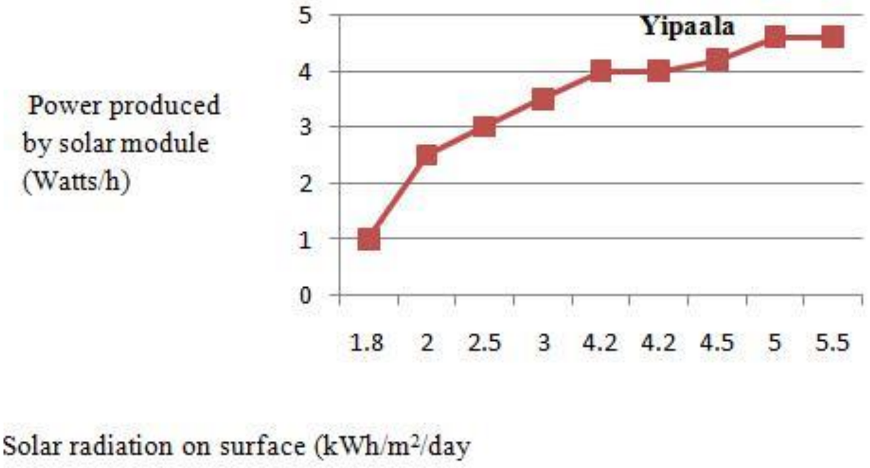


Figure 6: The amount of power produced by the solar panel on sites

Conclusion and Recommendation

The emergence and continuous increase in the dependence on solar energy provide evidence that solar appliances can become a leading domestic appliance in the future. The success of this technology depends mainly on the capability of meeting targets such as the enhancement of manufacturing procedures, while at the same time accomplishing increase in demand and cost reduction. With the vast variety of PV technologies present on the market, it is important to design a blender that can operate on solar to help meet the electricity needs in the rural communities. The main purpose of the solar operated blender was to ascertain if the amount of solar radiation in Yipaala was enough to power a D.C motor to operate the solar blender and to select the correct type and size of solar panel to produce the required power. Performance parameters which include the determination of the correct type of D.C motor to replace the existing A.C motor in the electric blender, determine the viability and or otherwise of the design and to design a solar operated blender for that community has been carried out. The outcome of the design also showed that these technologies have enormous potential even in areas with unreliable electricity supply. The following recommendations need to be done to improve the operational performance of this type of blender:

i. A test under full loading condition should be carried out in order to know if all the design parameters have been met.
ii. Laboratory experiment should be carried out to ensure that the effects on the nutritional values of the ingredients is not compromised when solar operated blender is used to grind them.
iii. As a matter of our economic situation, the government of Ghana and other individuals or corporate organizations should consider taking up the design as a business project and come out with mass production of such products for the rural communities that have no electricity. This will help to move the economy from import dependent to an industrial or a manufacturing economy and also help to reduce the overdependence on the national grid.

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