Design and Development of a Solar Powered Lawn Mower

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ABSTRACT: *Due to the continuous increase in the cost of fuel and the effect of emission of gases from the burnt fuel into the atmosphere, this necessitated the use of the abundant solar energy from the sun as a source of power to drive a lawn mower. A solar powered lawn mower was designed and developed, based on the general principle of mowing. The designed solar powered lawnmower comprises of direct current (D.C) motor, a rechargeable battery, solar panel, a stainless steel blade and control switch. Mowing is achieved by the D.C motor which provides the required torque needed to drive the stainless steel blade which is directly coupled to the shaft of the D.C motor. The solar powered lawnmower is operated by the switch on the board which closes the circuit and allows the flow of current to the motor which in turn drive the blade used for mowing. The battery recharges through the solar charging controller. Performance evaluation of the developed machine was carried out with different types of grasses. The machine was found to have an efficiency of 93% and a field capacity of 1.11 × 10 -4 ha/hr. No significant difference was observed with the height of grasses at 5% confidence level.*

KEYWORDS: Solar Power, Battery, Lawn, Mower, Dc Motor, Mowing, Emission

INTRODUCTION

Solar powered lawn mower can be described as the application of solar energy to power an electric motor which in turn rotates a blade which does the mowing of a lawn. Different designs have been made; each to suit a particular need or convenience. Making the process of cutting grass easier over the years, many individuals have added modification to the original design speed, efficiency and power of a mowing machine. The solar powered lawnmower is an improvement on cordless electric lawn mower. The sun provides sustainable amount of the energy used for various purposes on earth for atmospheric system. Every minute the sun radiates about 5.68×10^{26} calories of energy and the earth intercepts only 2.55×10^{18} calories (NRF, 2010). This represents only 2000 millionth of the total solar energy sent into the space. The total solar energy is estimated to be 30,000 times greater than the total annual energy of the world (Mgbemu, 2005). The solar powered lawnmower is based on the same principle that other early inventions of lawn mowers works on. The difference is just the application of the energy source. It uses the photovoltaic panel to generate the energy needed to power the mower. It is assumed that a lawnmower using solar as the energy source will address a number of issues that the standard internal combustion engine and electric motors lawn mowers do not. A lawnmower with solar energy will be easier to use, it eliminates down time by frequent trips to the gas station for fill-ups and danger associated with gasoline spillage. The dangerous emissions generated by the gasoline spillage and that of the internal combustion engine into the atmosphere are eliminated. The solar powered lawnmower will help to reduce air pollution as well as noise pollution produced by other types of lawnmowers. In addition, it will help to reduce the running cost of using and maintaining a lawnmower.

NYSDEC (2012) were of the opinion that lawnmowers must be designed to reduce pollutions generated than at present. This was further buttress by the ARB (2011) proposing the ease of electricity to power lawnmower. However, most electric mowers available at present are very inconvenient in that they require the use of an extension cord which invariably gets in the way of mowing the lawn. Rotary mowers are based on the use of small but powerful engine that provides enough torque to spin a very sharp horizontal blade that cuts the grass upon contact. The blade is located in the deck that prevents grass from flying all over the place when struck. In most cases, the motor is situated at the top of the deck, which is usually mounted on four wheels. There is also a bag connected to the deck that is used to collect cut grasses (Jain and Rai, 1995). Traditionally used lawnmowers do not use gas or electric power cord. Pushing it turns a number of curved blades (Omoniyi, 2010). They have no engines, quite inexpensive, relatively safe and it requires little blade adjustment and sharpening. Some models have battery powered motor to spin the blade while pushing the mower. Cutting tends to be uneven and some could not cut grasses taller than 1.5 inches or trim closer than 3 inches around obstacles, while the electrically operated mower uses an electric mechanism (motor) to spin a blade in a rotary form. Cords are potential problems on lawns with trees and other obstacles. Today's cordless models run longer per charge than previous models types. This requires little upkeep beyond blade sharpening. Most offers a side or rear bag and mulching mode that cut clipping finely enough they settle within the lawn and fertilizes it as they decompose. The best electric mowers perform as well as some gas mowers. Electric mowers

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typically cut an 18-20 inches swath (Hollis, 1991). Tractor drawn (semi-mounted or mounted type) mowers are operated by power take-off shaft (Jagdishwar, 2008). A shaft is connected with power take-off shaft which drives a pulley on the crank shaft of the machine and the reciprocating motion is transmitted to the cutter bar. Solar energy is a time dependent and intermittent energy source. There is need for the storage of energy for later use when there is no further supply of the sun energy. An optimally designed solar electric system will collect and convert when the isolation is available during the day. Photovoltaic is the direct conversion of light into electricity at atomic level. When free electrons are captured, an electric current is produced and can be used as electricity (Knier, 2010). The series and parallel electrical arrangements to produce any required voltage. Photovoltaic modules and arrays produce direct-current (DC) electricity and current combination.

MATERIALS AND METHODS

In designing the cutting blade, the force required to cut the lawn as well as the force acting on the blade was considered. The force required by any sharp object to have impact on the grass is less than 10 Newton. It is also dependent on the height, density and the area covered by the object (Atkins, 1984). Therefore, in designing the blade of the solar powered lawn mower, the force required for effective mowing should be greater than 10 Newton.

A stainless steel was used in the construction of the cutting blade because of its strength and weight which can transmit same speed as that of the DC motor or a little less cause of friction. **Mass of Blade**

The area of the blade = length × width (i)

n by

$T = Wr$ (iv)

Where, W is the weight

r is the radius of the blade

$r = 450/2 = 255mm$

Therefore, $T = Wr$

$= 0.14 \times 225$

$= 31.5Nm$

Angular Velocity and Force Produce by the Blade

Universally known that angular velocity (ω) is given as

$\omega = 2\pi N/60$ (v)

Where, ω is the angular velocity

N is the rotational speed of the motor = 1450 rev per minute

$\pi = 3.142$

solar photovoltaic cells are essentially semi-conductors, which have electrical transmission properties like metal or salt water and insulators like rubber. Panels are constructed with sheets of doped silicon, primary element in beach sand with impurities added like phosphorus that allows electrons to flow. When the protons from the solar energy hit a photovoltaic cell, a flow of electrons starts which can be drawn off by a pair of wires, thereby creating direct current. A number of solar cells electrically connected to each other and mounted in a support structure or frame is called a photovoltaic module. Modules are designed to supply electricity at a certain voltage. The current produced is directly dependent on how much light strikes the module. They can be connected in both

$= 450 \times 40$

$= 18000mm^2$

Volume = area × thickness

$= 18000 \times 0.1 = 1800mm^3$

Mass of the blade = density × volume (ii)

The density of a stainless steel (Singh, 2005) is 7922kg/m

$= 7922 \times 1800 \times 10^{-9}$

$= 0.014kg.$

Weight and Torque on the Cutting Blade

The weight of the blade, $W = Mg$ (iii)

Where, M = mass of the blade = 0.014kg

g = acceleration due to gravity = 9.8 m/s²

Therefore, $W = Mg$

$= 0.014 \times 9.81$

$= 0.14N$

Hence, the torque (T) produce by the blade is give

$\omega = 2 \times 3.142 \times 1450/60$

$\omega = 151.86$ rad/s.

Power Developed

The Power (P) developed is be the product of torque and angular velocity

$P = T\omega$ (vi)

Where T is the torque = 0.0315N

ω is angular velocity = 151.86 rad/s

$P = 0.0315 \times 151.86$

$P = 4.78W$

Motor Size

The Power (P) required by the blade was used in the selection of the electric motor.

From the power developed, = 4.78W

= 0.00478KW

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Converting the determined power to horsepower;

$$= 0.26 \text{ hp.}$$

For design purpose 1.5 hp D.C motor was used, so that it provides the required torque in other to cut all type of lawns and also it increases the efficiency of the machine.

The force produced by the blade with the speed of the motor is the centrifugal force (F_c). Hence, the centrifugal force according to Khurmi and Gupta (2000)

$$F_c = m\omega^2 r \quad \text{(vii)}$$

Hence, $F_c = 0.014 \times 151.86 \times 0.225$

$$= 72.47\text{N}$$

Charging Station

In practice, the maximum voltage is in the range of 0.6 volt and this occurs in open circuit, when no power is produced. The maximum power of a silicon cell occurs at an output voltage of approximately 0.45 volts when there is bright sunlight, the current from a commercial cell is then roughly 270 amperes per sq.m of exposed surface. The power is thus about 0.45 × 270 = 120 watts. The rate at which solar energy reaches the top of the atmosphere is 1.353kW/sq.m (Kalyan, 2013). Part of this energy is reflected back to the space and part is absorbed by the atmosphere (Nelson, 2012). In bright sunlight, Amos (2013) asserted that the solar energy may reach the ground at the rate of roughly 1kW/sq.m.

Calculating the estimation of average solar radiation monthly is given by Agbo (2010) as

$$H_{av} = H_o\,(a^i + b^i\,(n/N)) \quad \text{(viii)}$$

Where, H_{av} is the average solar radiation available for conversion.

H_o is the monthly average horizontal solar radiation for a clear day.

a^i and b^i are arbitrary constants 0.35 and 0.61 respectively.

n is the average hours of bright sunlight for same period.

N is the maximum daily hours of bright sunlight for same period

The solar panel that was used in the construction of the solar powered lawnmower is rated 50watts, 12 volts, consisting of 24 cells. Hence, according to Khurmi and Gupta (2000)

$$\text{Power} = IV \quad \text{(ix)}$$

Where, I is the current

V is the voltage

$$I = P/V$$
$$I = 50/12$$
$$I = 4.17\text{A}$$

The solar panel is connected to the battery via a solar charging controller and from the battery to the motor. Also, an electric switch is connected to the circuit to control the flow of current.

Battery

Batteries are available in various volts and ampere hour range. To determine the one to use, consideration was given to the voltage and the ampere hour rating. Since the motor is 1.5hp, then a 12V battery was selected. The ampere hour measures the length of time the battery will discharge while in use and is not charging. A 17 ampere hour battery will give a 17 amp of current for one hour and the current required by the motor is less than that.

Design for the Frame

A mild steel plate was used in the construction of the frame due to its strength, workability, availability and cost effectiveness. The frame provides support for the electric motor, battery as well as the handle frame. The diameter of the deck is 500mm and height 100mm. The deck is also made of four hand lever adjusters which are used to raise and lower the deck to the desired height of cut. Each is made of flat metal with five spin hooks to aid the operation. They transmit the load of 20kg to the wheel equally and length of each is 700mm.

The bending moment M = PL/4

Where P is the load = 20 × 10 = 200N

But the load is equally shared, hence for each it will be 200/4 = 50N

Therefore M = PL/4 (x)

$$= (50 \times 700)/4 = 8.75\text{KNmm}$$

Yield stress = 200N/mm^2

Allowable shear stress = ultimate stress × yield stress

$$= 0.53 \times 200\text{N/mm}^2$$
$$= 106\text{N/mm}^2$$

The sectional modulus (z) according to Khurmi and Gupta (2000)

Sectional modulus, z = bending moment/ shear stress (xi)

$$= 8.75 \times 10^3/\,106$$
$$= 82.55\text{mm}^3$$

Design of the Handle Frame

The solar panel is located on the peripheral of the handle, and the weight of the solar panel is 10kg. In order to accommodate the length of the solar panel, a length of 1200mm tilted at an angle of 60^o was chosen. From Khurmi and Gupta (2000)

$$M_{max} = \frac{\sigma I}{y} \quad \text{(xii)}$$

Where,

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σ is the stress

I is the moment of inertia

y is the resolved length of pipe at an angle.

$\sigma = 0.53y_s$ Yield stress, $y_s = 200N/mm^2$.

Ultimate bending stress = $0.53y_s$

(xiii)

$$\sigma = 0.53y_s$$
$$= 0.53 \times 200$$
$$= 106N/mm^2$$

$$I = \pi (D^4 - d^4)/64$$

(xiv)

Where D = 200mm

d = 180mm

π = 3.142

Hence $I = 3.142 (200^4 - 180^4)/64$

$$I = 27 \times 10^6$$

Also $y = x \cos \Theta$

$$y = 1200 \cos 60^o$$
$$y = 600mm$$

Therefore, $M = \frac{\sigma I}{y}$

$$M = (106 \times 27 \times 10^6)/600$$
$$M = 4.8 \times 10^6 Nmm$$

Sectional modulus, z = bending moment/shear stress

$$Z = 4.8 \times 10^6/106$$
$$Z = 45 \times 10^3 mm^3$$

Figures 1 and 2 respectively show the isometric view and the exploded view of the solar powered lawn mower.

Experimental Test Procedure

The solar powered lawnmower was tested on four different species of elephant grass, stubborn grass; spare grass and carpet grass of 4500mm by 4500mm field noting the time spent cutting the field. Ten replicates of the test were carried out and the Performance Efficiency of the machine was then determined.

The field capacity was also determined by using

$$C = \frac{WSE}{10} \qquad \text{(xv)}$$

Where,

W = Width of cut (m)

S = Speed (km/hr)

E = Efficiency. (%)

RESULTS AND DISCUSSION

The solar powered lawnmower was designed and developed. Test was carried out using four species of grass and the result obtained is summarized as presented in Table 1.

Table1. Average height of grass before and after mowing of each sample plot

Sample plot	Average height of the grass before mowing (mm)	Average height of the grass after mowing (mm)	Expected height of the grass after mowing (mm)
Elephant grass	224	90	100
Stubborn grass	234	92	100
Spare grass	111	70	80
Carpet grass	70.5	56.5	50

Table: 2 Chi-Square Statistical Table $x^2 = (O - E)^2/E$

Average height of the grass after mowing (mm).O	Expected height of the grass after mowing (mm).E	O - E	$(O - E)^2$	$x^2 = (O - E)^2/E$	Time (s)
90	100	-10	100	1	490
92	100	-10	100	1	470
70	80	-10	100	0.8	450
56.6	50	6.5	42.25	1.18	430

From Table 1, the average height of the grasses after mowing was lesser than the expected after the machine have been adjusted to a height for the four species of grasses. Less time was spent in cutting the grasses. The efficiency of the machine was found to be 93% and the effective field capacity was 1.11×10^{-4} ha/hr.

The confidence level was calculated and Chi-square statistical analytical method was used to analyze the result at alpha level of 5%. The result shows that there is no significant difference between the effects of the machine on different types of lawns as shown on Table 2.

From Table 1, it can be deduced that the reduction in the height of cut grass occurred in the case of stubborn grass. The initial height being 234mm and the final height being 92mm giving a difference of 142mm. For elephant grass, the initial height being 224mm and the final height being 90mm, a difference of 134mm. for the spare grass, the initial height was 111mm and the final height was 70mm, a difference of 41mm. For the carpet grass, the initial height was 70.5mm and the final height was 56.5mm giving a difference of 14mm. From these figures, it shows that the machine performed best on stubborn grass followed by the elephant grass. The machine was able to reduce the height of the carpet to 56.5mm could be due to the very soft nature of this type of grass. In all, the machine has performed creditably well.

CONCLUSION

In the world today, all machines are designed with the aim of reducing or eliminating green house gas emissions which is the major causes of climate change. This solar powered lawn mower will meet the challenge of environmental production and low cost of operation since there is no cost for fueling. A solar powered lawn mower has been developed for the use of residences and establishments that have lawns where tractor driven mowers could not be used. The machine's capacity is adequate for its purpose. The machine has proved to be a possible replacement for the gasoline powered lawn mowers.

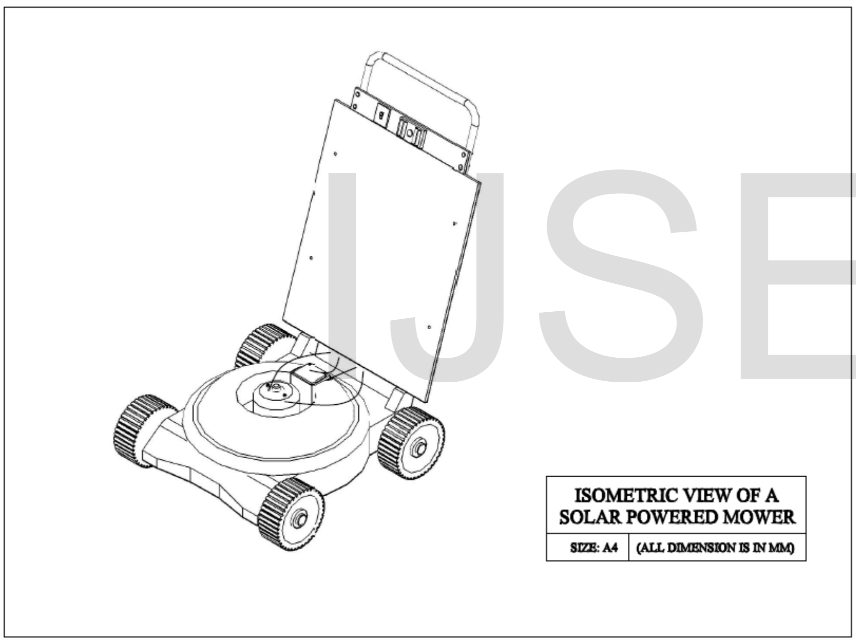

Figure 1: Solar Powered Lawn Mower

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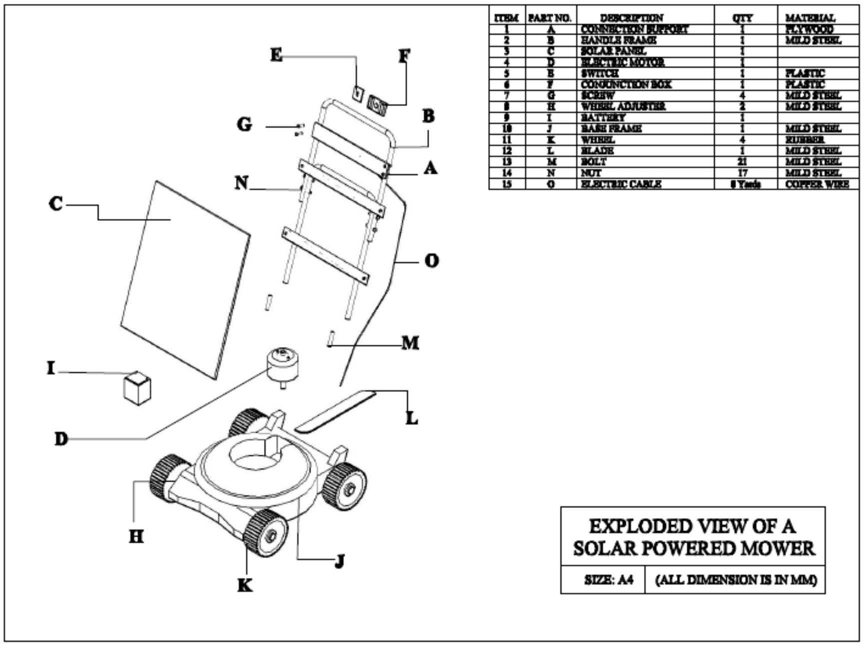

ITEM	PART NO.	DESCRIPTION	QTY	MATERIAL
1	A	CONNECTION SUPPORT	1	PLYWOOD
2	B	HANDLE FRAME	1	MILD STEEL
3	C	SOLAR PANEL	1	
4	D	ELECTRIC MOTOR	1	
5	E	SWITCH	1	PLASTIC
6	F	CONJUNCTION BOX	1	PLASTIC
7	G	SCREW	4	MILD STEEL
8	H	WHEEL ADJUSTER	2	MILD STEEL
9	I	BATTERY	1	
10	J	BASE FRAME	1	MILD STEEL
11	K	WHEEL	4	RUBBER
12	L	BLADE	1	MILD STEEL
13	M	BOLT	21	MILD STEEL
14	N	NUT	17	MILD STEEL
15	O	ELECTRIC CABLE	8 Yards	COPPER WIRE

Figure 2: Exploded View of Solar Powered Lawn Mower

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