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Development of a Solar Powered Lawn Mower

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ABSTRACT

A domestic solar powered lawn mower of 0.13 m^2/s field capacity has been developed for operational convenience. It is made of a twin solar panel of 75A/130W capacity each, which charges the battery of the mower. The solar panels are connected in series to an improvised charge controller that serves to prevent complete discharge or overcharge of the battery. The lawn mower has its cutting bade attached to a 2.1kW, 24V DC electric motor, driven by two 12 volts, 75AH lead accumulators connected in series. The DC batteries (lead accumulators) are recharged using solar energy harnessed by the solar panels. Detailed design of the solar components were made and the test performance gave a field efficiency of 97 per cent which demonstrated ease of use as well as neat mowing of the grasses. Blade height is adjusted for a desired height of cut. The battery which takes approximately 2 days to recharge is capable of mowing a total area of 552 square metres of lawn.

Keywords: *Mower, Solar Power, Charge Controller, Field Efficiency, Field Coverage*.

1. INTRODUCTION

Energy has been defined as the ability to do work. This definition encompasses energy in its various forms as it is measured in terms of work done; be it lifting of a load with a crane, riding a bicycle, drying wet clothes or cooking a meal. All these will require various forms of energy. Mechanical energy is needed to lift a load with a crane, chemical energy from food is needed by the cyclist to ride the bicycle, heat energy is needed for cooking and for drying wet clothes. These various forms of energy may come from different sources. For instance, petrol when burnt will give heat energy used for powering the crane in lifting the load. When food energy is burnt through respiration, the cyclist will be able to ride a bicycle. When wood is burnt it provides the heat energy for cooking. The word 'solar' literary means connected with the sun. Hence solar energy is energy from the sun which can be in form of light for illuminating the earth and for photosynthesis or in form of heat (radiation) for heating up the earth, drying clothes and for preservation of some food crops. The term 'power' is not to be interchanged with energy. Just as energy is the ability to do work, power is the rate at which work is done. Hence power can be said to be how much energy is being utilized per unit time. Thus, power is what puts energy into use.
In general, when power is mentioned the famous formula; Power (P) = Current (I) x Voltage (V) comes to mind. This is because power is taken to mean the form of energy which makes it readily available to use; hence the electrical energy. Thus, electrical energy readily puts all other forms of energy into consideration in terms of their quick conversion and usage. Electrical energy is therefore a hub for other forms of energy since it is easily stored and readily available. Solar power therefore simply means solar energy for electricity or the sun for electricity (Alexander, (1989). It (solar power = solar energy being converted to electrical energy) therefore puts the vast energy of the sun into use. The solar powered lawn mower is better than that powered by internal combustion engines as it is pollution free. It is easy to use, less noisy and eliminates the unnecessary trip to filling stations. It does not require a gasoline engine mechanic or occasional replacement of spark plugs. The solar mower with a charge station running on battery is an improvement of the electric cord lawn mower because it can be used in rural areas where there is no electricity. Nigeria is located in the tropical region with daily long sunshine and is thus a good area for solar energy utilization.

2. CONCEPT DESIGN

Figures 2.1 and 2.2 show the assembly view of the solar powered mower and the solar panels respectively. Design analysis will be restricted to the solar component as detailed design of a mower has earlier been published by the researcher (Basil, 2013). Figure 2.3 shows the circuit diagram of the improvised charging station and Table 2.1 shows a summary of component parts of the solar powered mower.

Fig. 2.1 Assembly View of the Solar Mower

Fig. 2.2 The Solar Panels

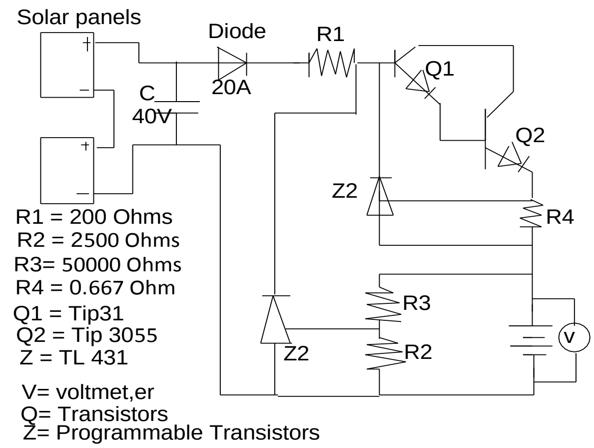

Fig. 2.3 Improvised Voltage Regulator

The purpose of the charge controller is to stop the battery from discharging through the solar panel when there is no sunshine. It also serves to prevent overcharging when the battery is fully charged and also regulates voltage to the battery.

Table 2.1 Component Parts of the Mower

S/N	Item	Qty	Remark
1	12 volts battery	2	
2	130 Watts, 7.5A solar panel	2	
3	Improvised charge controller	1	
4	24 volts DC motor	1	
5	Lawn mower deck with handle	1	
6	DC circuit breaker	1	
7	Switch	1	
8	Cables	Lump	
9	Bolts and nuts		
10	Stainless steel plate	Lump	5mm thick
11	Angle iron	Lump	1 inch x 1 inch

2.1. Principle of Operation

The solar powered lawn mower involves the application of solar power to charge batteries or for the purpose of using it to power a DC motor which in turn rotates the blades of the mower. The solar panel (or photovoltaic cell) harnesses the solar energy. The energy generated is stored by the battery in order to make it readily available for usage. The wet cell which is rechargeable is considered most suitable for storage of the generated energy. Precisely, the lead acid battery is the ideal storage facility considering its relative low cost and tolerance for abuse. When incident radiation (sunlight) falls on metals and semi-conductors, electrons are liberated from their surface depending on the frequency of the incident light. An attraction to positive charge will constitute a flow of electrons. This is the basic principle of the photovoltaic cell. Most metals would require ultraviolet light to produce this effect. However metals such as cadmium, zinc, cesium, and alkali metals like sodium, potassium, and rubidium emit electrons when visible light falls on them (Ikeobi et al, 1990). Semi-conductors such as silicon, compendium, gallium, arsenide and amorphous silicon have been found to exhibit this effect. The silicon conductor is the most efficient in use today.

2.2. Description

The solar lawn mower is made up of a lawn mower deck with handle, a 24 volts DC motor and 24 volts battery (Table 2.1). It has an improvised charging station coupled separately for charging the batteries. The solar panel is a photovoltaic cell that generates current when light falls on its surface. Two 130 Watts solar panels connected in series are used to charge the batteries.

3. DESIGN ANALYSIS

3.1. Power Selection

According to Atkins (1984), the force required to cut grass by a sharp object is less than 10 Newtons, depending on the height of the grass, type as well as grass density in the area. However a slightly bigger force will be required (or selected) for high efficiency.
Area of blade = 0.43m x 0.05m = 0.0215m^2

Volume of blade = Area of blade x Thickness = 0.0215 x 0.005

= 0.000108m^3

Density of steel (Sign, 2005) = 7922 kg/m^3
Thus, weight of blade = 7922 x 0.000108 = 0.852kg; Force = 0.852 x 9.81= 8.36N

Torque required to turn the blade = Force x Radius of blade = 8.36 x 0.215 = 1.80 Nm

Thus, depending on the density of grass, the minimum power required to move the blade in 1 second is 1.8Watts. This is quite a small value, but it plays an important role in selecting the power needed.

According to Tanimola, et al (2014), the greater the power, the greater the efficiency. Hence, considering the power required to move the blade, the strength and density of grass as well as efficiency and factor of safety in design, 2.1 kW is selected. This will be able to handle different types of grass at expectedly high efficiency.

3.2. Battery Size

According to Alexander (1989), Khurmi and Gupta (2000);
Design Power = (Current x Voltage) / Power Factor of the Machine
Where current is the expected current to be drawn by the motor, Voltage is the expected voltage of the battery, and power factor is 0.8.
Thus, Current = (2100 x 0.8) / 24 = 70 Amps
Available battery in the market is 75Ah. Thus, 75Ah is selected at 24 volts.
The battery is expected to discharge after; 75/70 = 1.07hours

3.3 Size of Solar Panel

The average sunshine in Owerri in Nigeria located at latitude 5º38^1 and 5º 1^1 North from January to December covering a period of 14 years is (Mfon et al, 2013);
(5.29 +5.45 + 4.48 + 4.84 + 5.84 + 4.60 + 3.12 + 2.47 + 3.9 + 3.95 + 5.34 + 5.50) / 12 = 54.78/12 = 4.56 hours
Solar panel available in the market = 7.5A charging and 130 Watts
Average battery charge per day = 7.5A x 4.56H = 34.2 Ah
Battery charge for two days = 34.2 x 2 = 68.4 Ah
Thus the battery will be fully charged in (2 x 75) / 68.4 = 2.19 days

3.4 The Voltage Regulator

Items include;
Two solar panels of 130 Watts,17.5 volts each = 35 volts
32,000 µF, 45 volts capacitor
Thus, average voltage input = (45 + 35)/2 = 40 volts

Voltage of two batteries connected in series (12 volts each) = 24 volts
Expected maximum voltage after charging = 28.8 volts
Each of transistors Q_1 and Q_2 = Tip 3055
Collector current (I_c) = 15 Amps
Forward current gain (h_{fe}) = 20 Amps
Transistor base voltage (V_B) = 7 volts
Charging current required = 7.43 Amps

The two transistors Q_1 and Q_2 form a Darlington transistor connection or a super alpha pair.

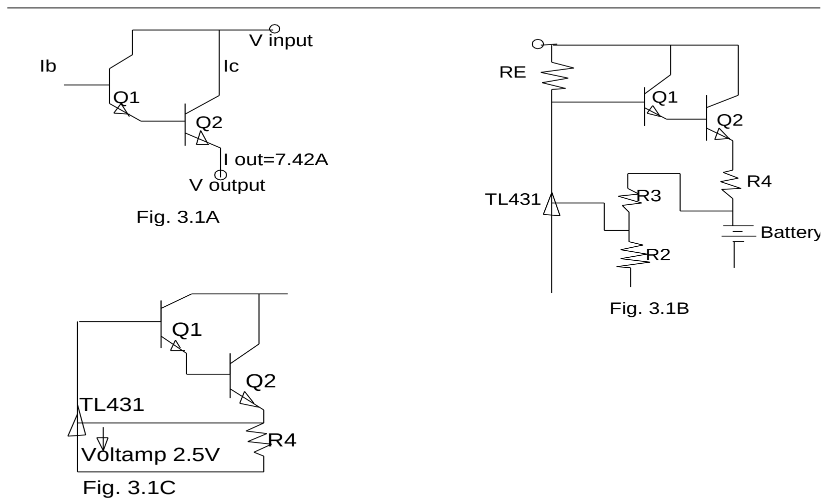

Fig. 3.1 Voltage Regulator

According to Noel (1984) and from Fig. 3.1A;
$I_{CQ1} = h_{fe1} \times I_{B1}$
$I_{B1} = I_{E1} = I_{B1} + I_C = I_B (1 + h_{fe1})$
$I_C = I_{C1} + I_{C2} = hf_{e1}I_{B1} + h_{fe2}I_{B2}$
$I_C = I_{B1} [h_{fe1} + h_{fe2} (1 + h_{fe1})]$
The combined current gain will be;
$I_C/I_{B1} = h_{fe1} + h_{fe2} (1 + h_{fe1})$
$h_{fe1} = h_{fe2} = 20$
$I_C/I_B = 20 + 20 (1 + 20)$
$I_C/I_{BQ1} = 20 + 20 + 400 = 440$; where $I_C = 15$ Amps
$I_{BQ1} = 15/440 = 0.034$ Amp
From transistor data book; TL431, reference voltage = 2.5 volts
Minimum current = 0.12 mA (shunt current)

According to Pippenge, et al (1986); assuming the worst of short circuit case (Fig.3.1B);
Equivalent Resistance, $R_E = (V_{IN} - V_{ref} - V_{BQ1}) / (I_{BQ1} + I_{Shunt+TL431})$
$R_E = (40V - 2.5V - 7V) / (0.0341A + 0.12A) = 197.9$ Ohms
Now R_E must be small enough to limit the base current of Q_1 at the desired current value of 7.42A and must also be large enough to limit the charge during shunt circuit condition. This means that R_E must be less than the base drive of Q_1 plus the shunt current (I_{shunt}).

But $Q_1 + I_{Shunt} = 0.0341 + 0.12 = 0.1541$ Amp
and maximum value of $R_E = 40/0.1541 = 260$ Ohms
The R_E value of 260 Ohms will be too much for current flow. This means that the R_E value must range between a minimum value of 197.9Ω and a maximum value of 260Ω in order to allow current to flow into Q_1.

R_E value of 220Ω is chosen.

From Fig.3.1C, the value of R_4 is;

$R_4 = 2.5/7.42 = 0.3369\Omega$

4. PERFORMANCE TEST

Table 4.1 shows the experimental result for mowing different types of grass.
Coverage area of each test sample = 4m x 4m = $16m^2$
Area of the four samples = 16 x 4 = $64m^2$

Table 4.1: Results for Mowing Different Types of Grass

S/N	Sample Plot	Coverage Area (m^2)	Battery Drop (V)	Time (s)	Lawn Height (mm)
1	Carpet grass	16	0.23	125	470
2	Carpet grass	16	0.15	115	130
3	Stubborn grass	16	0.28	130	600
4	Soft grass	16	0.22	125	400
Total			0.8 Volt	495 Sec	

4.1. Forward Velocity

Forward distance covered = 15.5m
Time taken = 50 Sec
Average Forward Velocity = 15.5/50 = 0.31 m/s

4.2. Field Efficiency

Theoretical Field Capacity (TFC) = Forward Speed x Theoretical width
But theoretical width of blade = 0.43m
TFC = 0.31 x 0.43 = 0.13333m^2/Sec

Effective Field Capacity (EFC) = Total Area Covered / Total Time = 64m^2/495 sec = 0.12929 m^2/sec
Field Efficiency = EFC/TFC = (0.12929/0.1333) x 100 = 97%

4.3. Approximate Field Coverage

Battery voltage before operation = 27.9V
Battery voltage after operation = 27.1V
Expected voltage after discharge = 21V
Voltage drop = 27.9 – 27.1 = 0.8V
Expected voltage drop to be discharged = 6.9V
Thus, field coverage = (64/0.8) x 6.9 = 552 Square Metres

5. CONCLUSION

The mower gave a very neat cutting of the grasses as height of the blade is adjusted to give a desired height of cut. It is obvious from Table 4.1 that the tougher the grass the more power needed for mowing operation. It takes approximately two (2) days to charge the battery capable of mowing 552 square metres of lawn. This is considered quite suitable for a domestic lawn.

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