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SOLAR-POWERED LAWNMOWER DESIGN AND DEVELOPMENT

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Abstract: The increasing fuel costs and environmental issues associated with greenhouse gas emissions from gasoline-powered equipment have necessitated the investigation of sustainable alternatives. This study presents the design and development of a solar-powered lawnmower that uses abundant solar energy as a renewable power source. The design process involved the careful selection of components based on criteria such as energy efficiency, durability, and compatibility. Key components include an electric DC motor, a charge controller, a revolving stainless-steel blade directly coupled to the motor shaft, a 12V/14Ah rechargeable battery, an 18V/50W solar panel, and a microprocessor for operational control. The microprocessor is responsible for managing power distribution, monitoring battery status, and ensuring optimal performance. The system is activated through an onboard switch, which initiates current flow to the motor to drive the blade, while the battery is recharged via a solar charging controller. Performance evaluations were carried out under controlled conditions, using standardised grass types and ensuring consistent sunlight exposure. The results demonstrated an operational efficiency of 85% and a runtime of 3.36 hours when the battery was fully charged at 12V. Although the system presents a cost-effective and environmentally friendly alternative to gasoline-powered lawnmowers, it is subject to certain limitations, including reliance on sunlight availability and restricted cutting capacity for larger lawns. Future research should prioritise the enhancement of battery efficiency, the improvement of system adaptability to diverse environmental conditions, and the integration of advanced features such as automated controls and real-time monitoring.

Keywords: Battery, efficiency, greenhouse gas emissions, lawn mower, solar energy, sustainability.

Introduction

A lawnmower is an electromechanical machine designed to maintain the grass in a lawn by trimming it to a desired height (Septian, 2022). A gasoline-powered internal combustion engine that operates on the four-stroke cycle (intake, compression, combustion, and exhaust) serves as a power source for rotary force to the blades, which cuts across the grass for even cutting and beautification (Dutta *et al.*, 2023). Due to emerging technologies and economic impact assessment, new ways of power sources for lawnmowers have been developed and found efficient in terms of reduced pollution, energy conservation, lower operating costs, and energy independence (Khaetan *et al.*, 2021; Olajide *et al.*, 2024).

The earlier method of grass cutting involved manual operation with hand tools such as pruning shears and scissors. However, these tools proved inefficient as they demanded increased human labour and time (Khodke *et al.*, 2018; SatheeshKumar *et al.*, 2024). Currently, there's a growing fascination with harnessing solar energy for power generation, driven by the escalating expenses associated with traditional energy sources such as electricity and fuel (Hanafi *et al.*, 2023; Kang *et al.*, 2022). The introduction of lawnmowers in grass cutting significantly reduced the need for human effort and time (Soyoye, 2021). The rise of grass cutter machines, including trimmers and mowers, reflects the growing desire for well-maintained lawns. These machines are especially effective for cutting and shaping softer types of grass (Tahir *et al.*, 2022) Harnessing sunlight, a direct-current (DC) battery is charged in the photovoltaic-driven lawnmower. This battery then supplies power to the motor using stored chemical energy, enabling the blades to rotate for mowing. The photovoltaic cell captures solar energy and generates power during sunny conditions. This solar power is then transferred to the charge controller. Both the battery and the panel are linked to the charge controller. The primary responsibilities of the charge controller include managing, regulating, and then monitoring the flow of current to charge the battery (Adelakun *et al.*, 2021; Jabbar *et al.*, 2021). Fig. 1 presents block diagram of the lawn mower system.

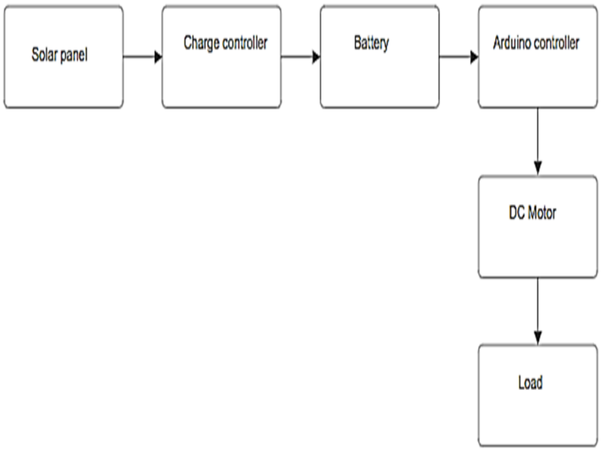

Fig. 1: Block diagram of the system

i. **Solar panel:** Photovoltaic cells in solar panels make use of sunlight to convert light energy into electricity, generating renewable energy for use.
ii. **Charge controller:** In solar power systems, a charge controller controls the voltage and current that goes from solar

panels to batteries, preventing overcharging and prolonging battery life.

iii. **Battery:** The battery powers the engine, electric starters, lights, and accessories. For electric mowers, the battery powers the motor directly while cutting grass.

iv. **Arduino controller:** In a solar-powered lawnmower, the Arduino controller regulates the motor, keeps track of the battery life, and plans the motion to maximize energy efficiency while harnessing solar power (Adelakun and Omolola, 2023).

DC motor: The lawnmower's DC motor powers the blades, supplying the mechanical force required for effective grass cutting. The mower's mechanism regulates its speed and direction to ensure efficient cutting.

Design and Analysis of Circuits

The design considerations for the various units that make up the solar-powered lawn mower system consist of the following: power source, charging and storage unit, control section, DC motor, and blade. All the components involved in the circuits have to be analyzed and proved mathematically. The research conducted a more in-depth design analysis to understand the cost-benefit and performance associated with implementing a solar-powered lawnmower, along with battery storage between charging periods. This includes the integration of solar cells to capture energy from sunlight and the right choice of materials that are lightweight and resistant while at the same time being user-friendly. Further, the assessment would take into account such aspects as climate and scalability, besides maintenance costs. The entire circuit has the following sections, and the complete circuit diagram is presented in Figure 2:

i. Power source
ii. Charging and storage source
iii. Control source
iv. Load output

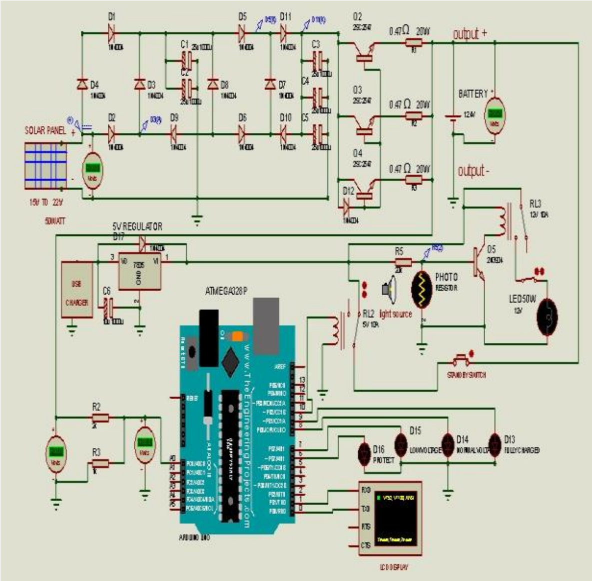

Fig. 2: Complete circuit design

A. Power Source

The power supply unit comprises only solar power supply. The supply will be gotten from a solar panel, which produces current from the absorption of sun rays. The voltage in this case varies as the temperature variation occurs, and therefore a dynamic voltage regulator, also known as a charge controller, will be connected to the output of the solar panel. The charge controller produces a constant voltage of 12V.

B. Charge Controller Calculations

The model of solar power charger controller used is the maximum power point tracking because of its better efficiency and facilitates the maximum harness of solar power.

i. **Sizing of MPPT**

Solar panel power output = 50W
Solar panel voltage = 22V
According to the formula of Power

$$P = IV \tag{1}$$

$$I = P/V \tag{2}$$

I = 50/22 = 2.27A

Therefore, the suitable charge controller rating is 10A (MPPT) charge controller.

C. Charging and Storage Source

The storage device for solar energy is the battery, which is an electrochemical device that converts the stored chemical energy into electrical energy. The charging and discharging of the battery are controlled through the Maximum Power Point Tracking (MPPT) controller. The battery is rated 12V, 14Ah cells, which are connected in series in order to achieve a longer period of operation. The input to the battery is the charge controller output, and it is charged through a constant-current charging mode. When the battery is fully charged, the charge controller keeps charging in float current to compensate for losses due to leakage resistance and also prevents reverse charging, which may discharge the battery overnight.

The complete circuit in Figure 2 consists of a battery voltage level detector that helps to control overcharging and overloading as well. The positive terminal of the level detector is connected to the battery, and then the negative is connected to a reference voltage. The charging voltage is 14.0 volts and the low voltage discharge (LVD) is 10.4 volts, as it was programmed for the controller; once the voltage falls within those ranges, it should shut down for 10 minutes.

i. **Calculations**

Operational hours would be calculated using the Watthour method

Since the battery is rated 12v 14Ah, the watthour is:

$$Voltage * Ampere-hour = Watthour \tag{3}$$

= 12 * 14 = 168Wh

The power of the DC motor is 96W

ii. **Operational hours**

$$Operational\ hours = Battery\ Watthour/Motor\ watts \tag{4}$$

= 168Wh/96W = 1.75 Hours

$$Operational\ hours = Battery\ Ampere-hour/Motor\ current \tag{5}$$

= 14Ah/8A = 1.75 Hours

iii. Charging Period

$$Charging\ hours = Battery\ Watthour/Solar\ rating \quad (6)$$

$$= 168Wh/50w = 3.36\ Hours$$

iv. Control Source

The Arduino microcontroller ATMEGA328P is programmed in C++ language, the code is presented in Appendix (A-F)

However, in the output ports 0 and 1 is connected to LEDs in which D16 is the PROTECTION LED, D15 is the LOW VOLTAGE LED, D14 is the NORMAL VOLTAGE LED and D13 indicates FULLY CHARGED.

Port 10 is connected to Relay 2 to close contact in case of any fault/ protection of the circuit from external effects in which the current flows to activate the light source which is radiated upon the photoresistor in which the resistance occurs and it closes the relay 3 is closed and LED 50W is turned on via NPN transistor.

a. Dc Motor

This unit consists of the load which is in this case DC motor. The specification and analysis of the load is in the table 1

Table 1: Technical specification of the mower.

Voltage(volts)	12	**RPM**	3000
Blade weight(kg)	0.377	**Blade diameter**	400
Fuel Type	Rechargeable Battery	**Operational time**	1 hr 45 mins
Lawn mower Type	Walk behind	**Start type**	Electric
Maximum cutting height(inches)	3.5	**Motor model**	12V D.C.
Motor Power	96W	**Battery charging time**	3.36 hours
Battery specification	12V,16Ah	**Cordless**	Yes
Cutting height(inches)	3cm	**Solar rating**	22V, 50W
Motor phase frequency	50Hz	**Maximum operating temperature**	300K

b. Material Consideration of Blade

A flat blade will be employed in the construction of the suggested lawnmower. Known by most as normal blades, these are intended to produce enough lift to push grass off the mower deck. Other types of blades, including sickle bars and tapered blades, might also be utilized, but for this project, a flat blade is picked because of its mass, which fits the machine's size, weight, and motor speed well. The sickle bar and tapered blades are lighter but exert more pressure when cutting. To avoid instability caused by the heavy rotating shaft, the blade needs sufficient weight. For the flat blade, mild steel is preferred due to its compatibility with the deck size and rotating shaft, as well as its strength and mass suiting the motor's speed. Stainless steel and angle bar iron are excellent options for blade crafting due to their durability and longevity. In contrast, mild steel is primarily favoured for its robustness and superior ability to resist corrosion.

i. Mass of Blade

Dimensions of the blade
Blade Length= 400mm
Blade Breadth = 30mm
Blade Thickness = 4mm
Diameter of the blade (D) = 400mm
Radius of the blade (r) = 200mm
Speed of motor (N) = 3000rpm
Mass of the blade (M) = 0.377kg
Density (ρ) = 7850kg/m^3
Acceleration due to gravitational Force (g) = 9.81m/s^{-2}

To calculate the blade's area

$$Area = length * width \quad (7)$$

$$= 400 * 30 = 12000\ mm^2$$

To determine the volume of the blade

$$Volume = Area * Thickness \quad (8)$$

$$= 12000 * 4 = 48000mm^3$$

To determine the mass of the blade

$$Mass = density * volume \quad (9)$$

$$= 7850kg/m^3 * 4.8*10^{-5}m^3 = 0.377kg$$

ii. Weight and Torque on Cutting Blade

To determine the blade's weight

The weight of the blade = W

Acceleration due to gravitational force, g = 9.8m/s^2

$$W = Mg \quad (10)$$

$$= 0.377 * 9.8ms^{-2} = 3.7N$$

To determine the torque of the cutting blade

Hence torque (T) produced by the blade is

$$T = W * r \quad (11)$$

$$= 3.7*0.2 = 0.74Nm$$

iii. Angular velocity and force period by the blade

To determine the angular velocity

Universally angular velocity (ω) is given as
Where, ω is angular velocity?
N is the rotational speed of the motor = 3000rpm
π = 3.142

$$\omega = 2\pi N/60 \quad (12)$$

$$\omega = (2 * 3.142 * 3000)/60 = 314.2\ rad/s$$

Fig. 3a: Developed lawnmower System

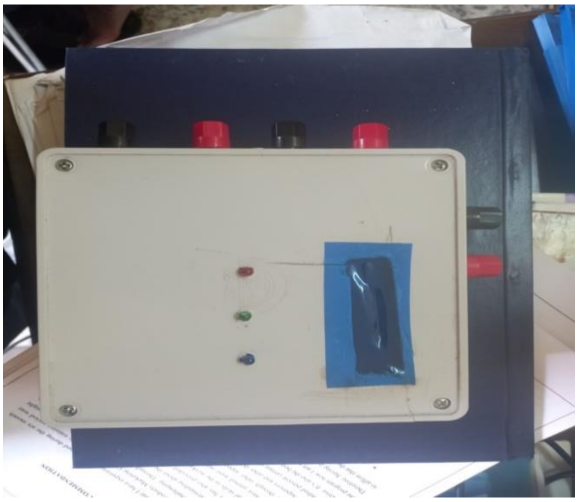

Fig. 3b: Developed MPPT Charge Controller

Result

This research provides a comprehensive overview of the project architecture designed to meet the requirements for creating a solar-powered lawn mower. The hardware implementation yields the following specifications.

A. Solar Panel Testing Result

The research determines the value of current and voltage in solar modules, which are always located posteriorly to the panel. Ensure your system has adequate sunlight exposure for accurate measurements. Optimal panel performance requires direct, intense sunlight. Keep in mind that without sunlight, the solar panels cannot generate electricity. A good knowledge of using the multimeter is sought. The setting chosen on the multimeter should be appropriate for the power levels being measured. The battery should not be fully charged before assessing the controller for charging, since if it is, it won't be able to take in more current.

When taking apart a solar power system, first disconnect the solar panel from the charge controller. Then, unplug the charge controller from the battery. It's important to follow this sequence when disassembling the solar panel, controller, and battery components. For reassembly, connect the charge controller to the battery first, and then attach the solar panel to the controller. Adhering to this order helps protect the charge controller from possible damage. Table 2, present average daily reading between the hour of 8:00am to 6:00pm

B. Open Circuit Voltage Test

i. Shut off the solar panel's connection to the battery and the solar regulator or controller entirely.
ii. Before completing the final series connection on a partially shaded panel, connect your voltmeter and record the reading. Attach the negative (black) wire to the negative terminal and the positive (red or white) wire to the positive terminal.
iii. Put the solar panel in, installing it at 30° east of south towards the sun.
iv. The voltmeter has to be put on DC volts.
v. A well-functioning panel should yield voltmeter readings of 19–21 volts or higher.

C. Short Circuit Test

i. Shut off the solar panel's connection to the battery and the solar regulator or controller entirely.
ii. Put the solar panel in, installing it at 30° east of south towards the sun.
iii. Before completing the final series connection on a partially shaded panel, connect your voltmeter and record the reading. Attach the negative (black) wire to the negative terminal and the positive (red or white) wire to the positive terminal.

D. Solar Panel Parameters

A photovoltaic panel's primary characteristics are:

i. **Short circuit current**: This is when the peak current is produced by the modules, assuming the terminals remain short circuited. The short-circuit current solar panel used for this project is 4.45A.
ii. **Open circuit voltage**: This is the maximum voltage the panel can deliver when there is no load connected to the terminals, known as an open circuit. For a panel designed for 12-volt systems, this value is 21.7 volts and is directly related to the number of cells connected in series.
iii. **Maximum power point**: The maximum power point (MPP) of a solar cell is the voltage at which its power output is maximized. This MPP voltage can vary due to factors such as the level of irradiance, operating temperature, or even the ageing of the device.

Where; $$Pmax = Imax * Vmax \qquad (13)$$

iv. **Fill Factor**: The quality of a solar cell is assessed by its Fill Factor, which is calculated by dividing the actual power produced by the cell by its maximum potential power output.
v. **Efficiency**: The term "efficiency of solar panels" describes the relationship between the panels' electrical power production and the amount of solar radiation they absorb. It gauges how efficiently sunlight is converted by the panels into electrical energy that may be used.

a. Solar Panel Daily Reading

Table 2: Solar panel reading during the day (08:00am to 6:00pm)

Time(hrs)	**Voltage**(V)
08:00	18.30
09:00	17.50
10:00	18.90
11:00	19.87
12:00	19.98
13:00	20.35
14:00	20.00
15:00	20.67
16:00	18.40
17:00	16.98
18:00	13.67

b. Battery Testing

i. Battery Parameters

The most common parameters of a battery are:

i. **Voltage nominal**: Mostly 12V

ii. **Capacity nominal:** This calculates a battery's total energy storage, which is commonly given in ampere-hours (Ah). It shows how much power the battery can provide at a certain rate of discharge.

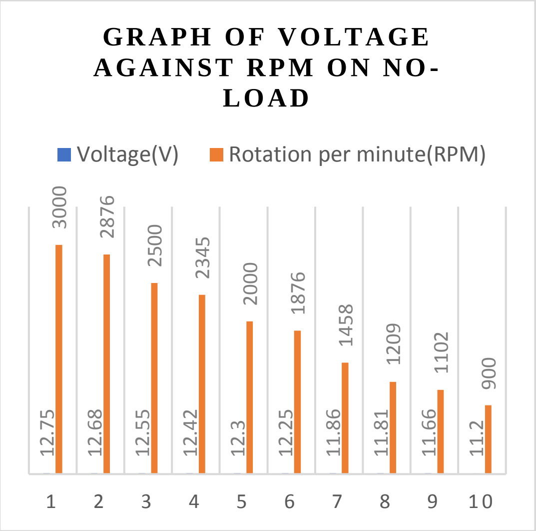

Fig. 4: Graph of voltage against rpm on no-load.

iii. **Peak depth of discharge**: Depth of Discharge (DOD) of a battery indicates the portion of power that can be extracted from it.

Table 3, presents the percentage charge of the battery and the measured voltages

Table 3: Battery reading parameters

% of charge	Measured voltage
100	12.75
90	12.68
80	12.55
70	12.42
60	12.3
50	12.25
40	11.86
30	11.81
20	11.66
10	11.2

c. DC Motor Testing

i. **No-Load Test:** The no-load test is a way to indirectly figure out how efficient a DC motor is and understand its internal workings. To do this, the motor is run without any load connected, using its normal power supply. We measure the electricity going into the motor, which mainly accounts for the motor's internal heat losses and the energy used to overcome friction. We also measure how fast the motor spins. By doing this without a load, we can study the motor's basic properties without outside influences.

Table 4.: No load test on motor

Voltage(V)	**Rotation per minute** (RPM)
12.75	3000
12.68	2876
12.55	2500
12.42	2345
12.3	2000
12.25	1876
11.86	1458
11.81	1209
11.66	1102
11.2	900

ii. Load Testing of DC Motor

To establish a DC machine's performance rating, load testing is essential. As the machine operates, energy losses occur, generating heat and increasing temperature. This heat build-up can be detrimental, potentially harming the insulation and risking machine failure. Therefore, it's crucial to adjust the load to a level that maintains the machine's temperature within safe operational boundaries.

Table 5: Load test on motor

Voltage(V)	**Rotation per minute** (RPM)
12.75	2900
12.68	2820
12.55	2420
12.42	2260
12.3	1900
12.25	1790
11.86	1398
11.81	1187
11.66	1052
11.2	803

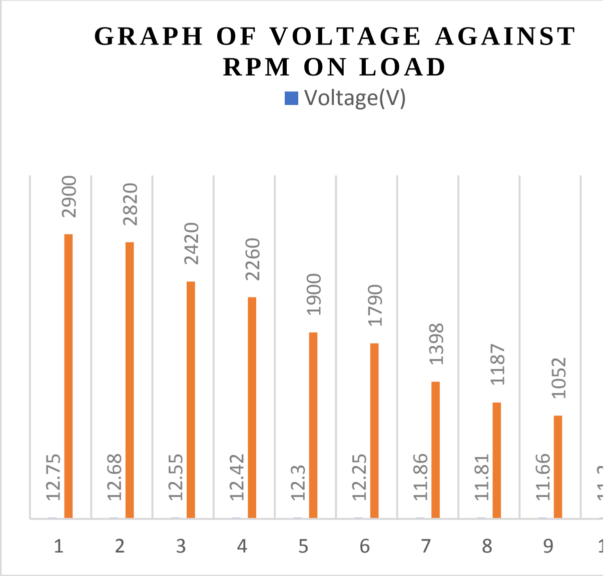

Fig. 5: Graph of voltage against rpm on load.

Discussions

Based on test results, it is possible to identify some significant conclusions from this work.

These include the following:

1. The cutting area and battery duration are influenced by factors such as lawn conditions, grass density, moisture content, grass length, and the height of the cut.
2. Frequently turning the product on and off while cutting will also decrease the cutting area (battery duration).
3. To extend the cutting area (battery duration), it is advisable to cut more often, increase the cutting height, and walk at a steady pace.
4. The highest cutting height is 3 inches.

The operation time is 3 hours, 36 minutes when fully charged.

Conclusion

A solar-powered lawn mower with a power rating of 96W and a 12V/14Ah battery has been successfully developed and tested to evaluate its performance. The charging and discharging of the battery, powered by a 50W solar panel, are efficiently controlled through a Maximum Power Point Tracking (MPPT) controller specifically designed for the system. The lightweight blade, weighing 0.38 g, enabled the motor to achieve an RPM of 300, ensuring optimal grass cutting performance. While the designed operational period was 4 hours, the system achieved an average runtime of 3 hours and 36 minutes during testing. This innovative system was designed to reduce or eliminate greenhouse gas emissions, a significant contributor to climate change. Additionally, the availability of materials for production, coupled with the low operational cost due to the elimination of fuel expenses, demonstrates the potential of this solar-powered lawn mower as an efficient and sustainable replacement for traditional gasoline-powered models.

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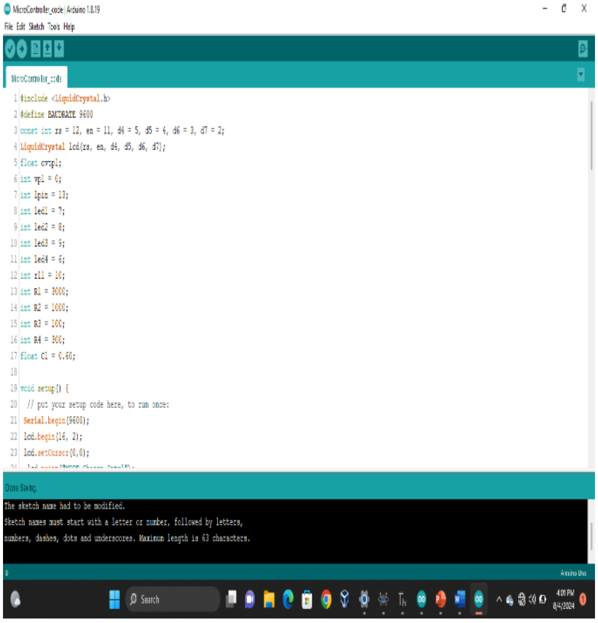
APPENDIX

(A)

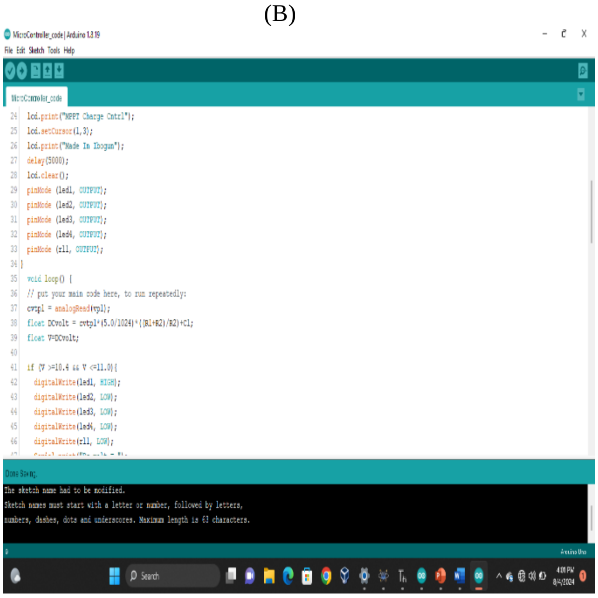


```
#include <LiquidCrystal.h>
#define BAUDRATE 9600
const int rs = 12, en = 11, d4 = 5, d5 = 4, d6 = 3, d7 = 2;
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);
float cvtpl;
int vpl = 0;
int lpin = 13;
int led1 = 7;
int led2 = 8;
int led3 = 9;
int led4 = 6;
int rll = 10;
int R1 = 3000;
int R2 = 1000;
int R3 = 100;
int R4 = 300;
float C1 = 0.60;

void setup() {
  // put your setup code here, to run once:
 Serial.begin(9600);
 lcd.begin(16, 2);
 lcd.setCursor(0,0);
```

```
Done Saving.
The sketch name had to be modified.
Sketch names must start with a letter or number, followed by letters,
numbers, dashes, dots and underscores. Maximum length is 63 characters.
```

(B)

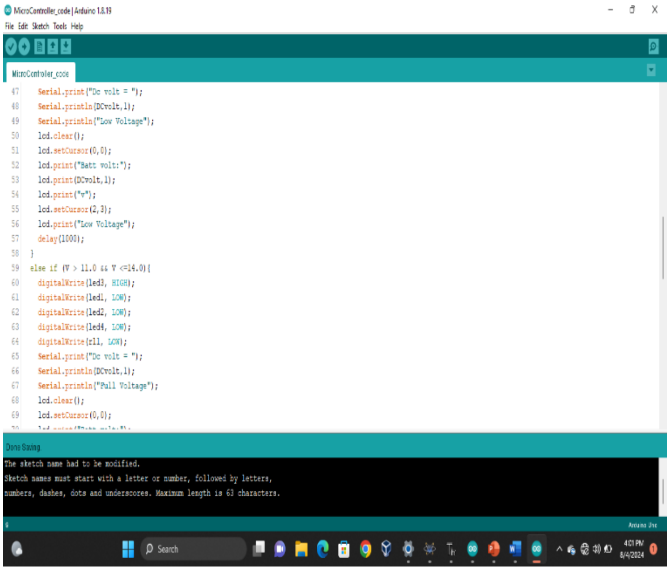


```
  lcd.print("MPPT Charge Cntrl");
  lcd.setCursor(1,3);
  lcd.print("Made In Ibogun");
  delay(5000);
  lcd.clear();
  pinMode (led1, OUTPUT);
  pinMode (led2, OUTPUT);
  pinMode (led3, OUTPUT);
  pinMode (led4, OUTPUT);
  pinMode (rll, OUTPUT);
}
  void loop() {
  // put your main code here, to run repeatedly:
  cvtpl = analogRead(vpl);
  float DCvolt = cvtpl*(5.0/1024)*((R1+R2)/R2)+C1;
  float V=DCvolt;

  if (V >=10.4 && V <=11.0){
    digitalWrite(led1, HIGH);
    digitalWrite(led2, LOW);
    digitalWrite(led3, LOW);
    digitalWrite(led4, LOW);
    digitalWrite(rll, LOW);
```

```
Done Saving.
The sketch name had to be modified.
Sketch names must start with a letter or number, followed by letters,
numbers, dashes, dots and underscores. Maximum length is 63 characters.
```

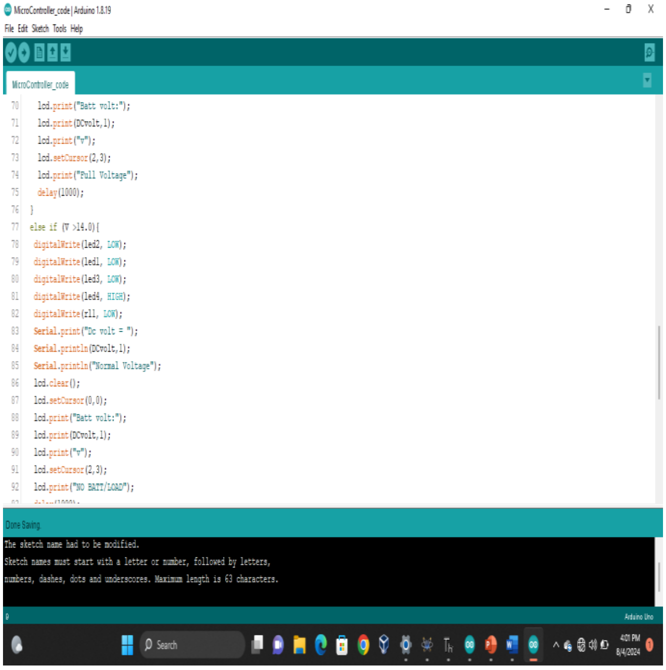
(C)



```
    Serial.print("Dc volt = ");
    Serial.println(DCvolt,1);
    Serial.println("Low Voltage");
    lcd.clear();
    lcd.setCursor(0,0);
    lcd.print("Batt volt:");
    lcd.print(DCvolt,1);
    lcd.print("v");
    lcd.setCursor(2,3);
    lcd.print("Low Voltage");
    delay(1000);
  }
  else if (V > 11.0 && V <=14.0){
    digitalWrite(led3, HIGH);
    digitalWrite(led1, LOW);
    digitalWrite(led2, LOW);
    digitalWrite(led4, LOW);
    digitalWrite(rll, LOW);
    Serial.print("Dc volt = ");
    Serial.println(DCvolt,1);
    Serial.println("Full Voltage");
    lcd.clear();
    lcd.setCursor(0,0);
```

```
Done Saving.
The sketch name had to be modified.
Sketch names must start with a letter or number, followed by letters,
numbers, dashes, dots and underscores. Maximum length is 63 characters.
```

(D)



```
    lcd.print("Batt volt:");
    lcd.print(DCvolt,1);
    lcd.print("v");
    lcd.setCursor(2,3);
    lcd.print("Full Voltage");
    delay(1000);
  }
  else if (V >14.0){
   digitalWrite(led2, LOW);
   digitalWrite(led1, LOW);
   digitalWrite(led3, LOW);
   digitalWrite(led4, HIGH);
   digitalWrite(rll, LOW);
   Serial.print("Dc volt = ");
   Serial.println(DCvolt,1);
   Serial.println("Normal Voltage");
   lcd.clear();
   lcd.setCursor(0,0);
   lcd.print("Batt volt:");
   lcd.print(DCvolt,1);
   lcd.print("v");
   lcd.setCursor(2,3);
   lcd.print("NO BATT/LOAD");
```

```
Done Saving.
The sketch name had to be modified.
Sketch names must start with a letter or number, followed by letters,
numbers, dashes, dots and underscores. Maximum length is 63 characters.
```

(E)