A Piezoelectric Green Energy Source for Powering Traffic Lights and Charging Mobile Phones

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Abstract
Electricity has become a major need of present day civilization and its demand is increasing rapidly. This increasing demand renders some electrical loads unable to function; these loads may be the traffic lights on our roads which use the national grid as their main source of power supply. In order to satisfy the rising energy demands of electricity, a cleaner and renewable power source needs to be explored. This paper emphasized on one of the promising electricity generation methods using piezoelectric materials. In this work the Navy type III Lead Zirconate Titanate (PZT) material was employed. A circuit was designed to convert the pressure from moving vehicles on our roads into an electric power to power the traffic lights and also charge mobile phones. In the design, microcontroller was used to read the charging rate of the battery and the result was displayed on a Liquid Crystal Display (LCD). The design was simulated using Proteus 8.3 Professional software. The results from the simulations indicated that the power generated is sufficient to power the traffic lights and also charge mobile phones.

Keywords: *Microcontroller, mobile phones, pressure generator, PZT, traffic lights*

INTRODUCTION

Traffic lights are devices mounted on our roads to regulate the vehicles and pedestrians that use the road. They basically operate day and night to determine the vehicle that is supposed to pass a junction at a particular time and also stop vehicles for pedestrians to cross the road safely. Most of these traffic lights in many countries such as Ghana, take their source of power from the national grid and a handful relies on solar energy for their operation. When the power supplied to these traffic lights are cut due to high demand on the national grid or faults on the service line, it renders these traffic lights not able to function effectively. This in effect, leads to traffic jams on our roads making driving very uncomfortable and at times leads to road accidents. The consequence of these road accidents have led to the loss of innocent lives and properties.

Other scenario is that, most pedestrians and hawkers on our roads use mobile phones. In most cases, the batteries of these mobile phones may go low or completely drained rendering the pedestrian not able to make phone calls when there is an emergency. This also has led to the loss of human lives and opportunities as a result of not being able to make calls in critical conditions. It is therefore necessary to design a system that will power traffic lights and also charge mobiles phones using an alternative source of energy in order to eliminate the stated challenges. Hence in this work, pressure from moving vehicles on the highways and piezoelectric transducers were used to generate electrical energy to power the traffic lights and also charge mobile phones at the bus terminals. This electrical energy is generated when the transducer is subjected to vibration from the pressure

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generated by the moving vehicles. Use of renewable energy sources to power traffic lights have been reported in the literature in recent times [1−3].

DESIGN CONCEPT

The proposed design is presented in Fig. 1. The piezoelectric transducer employed in this work is the Type III PZT transducer. It has a high mechanical strength; it is able to withstand high level of electrical excitation and mechanical stress; it has best power handling capacity; and it also has higher Curie temperature [4]. When pressure is exerted on the transducer as a result of the moving vehicle, it generates an AC output voltage in accordance with the piezoelectric effect. The voltage is then rectified and charges stored in a lead acid battery. The power stored in the battery is discharged to the traffic light and part is regulated to 5 V for the charging of the mobile phones at bus terminals as seen in Fig. 1.

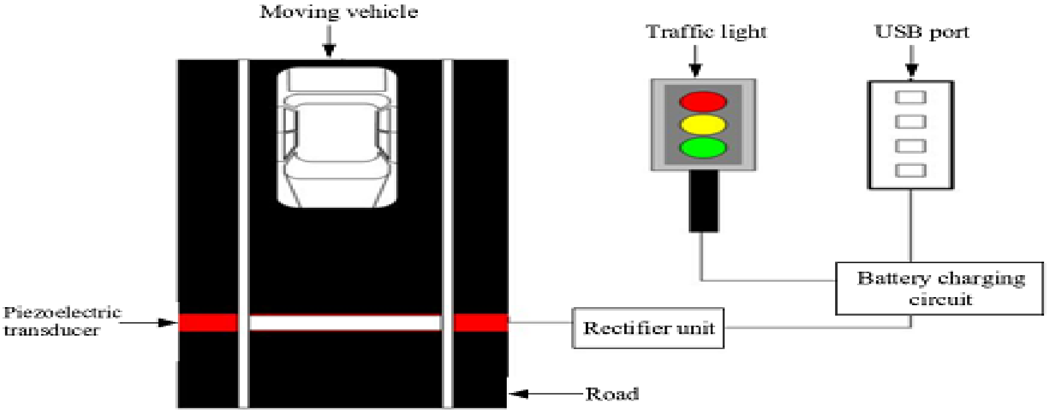

Figure 1: *Diagram of the proposed design.*

The flowchart for the system operation and charging circuit are shown in Fig. 2 and Fig. 3 respectively.

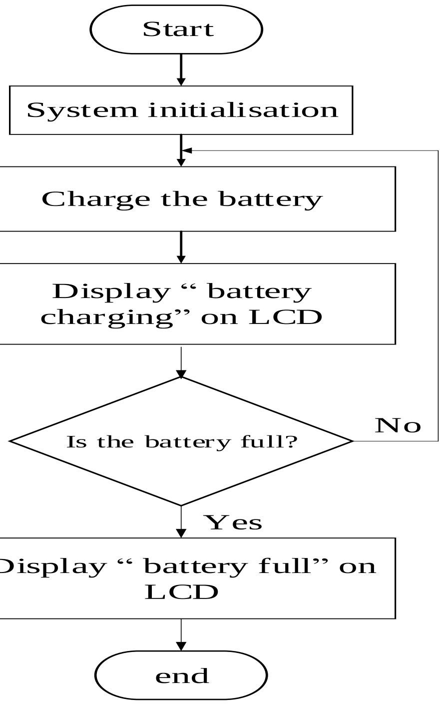

Figure 2: *Flow chart for the charging circuit.*

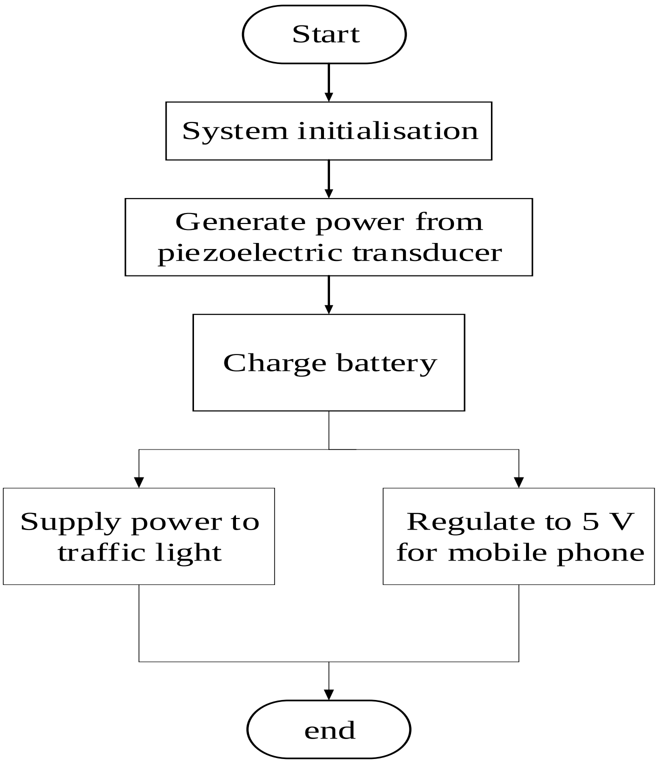

Figure 3: *Flow chart for the system operation.*

DESIGN CALCULATIONS

Battery Sizing

A 12 V lead acid battery was utilised, due to its low cost, easy availability and reliability. It is also able to discharge to very low levels continually without being damaged. Also, it has the ability to withstand overcharging, vibration and shock. Furthermore, the design of lead-acid batteries ensure that they are leak-proof, possess exceptional charge acceptance and exhibit low self-discharge [5]. These properties make the lead-acid battery an ideal choice for the design. The energy required by the battery is determined by the energy consumption of the various loads, that is the load demand of the traffic light and the mobile phones. Batteries are not rated in watt-hour but rather in Amp-hour. To determine the Amp-hour rating, equation (1) was employed.

$$Ah = \frac{Wh}{V} \quad (1)$$

where, Ah= Amp-hour; Wh= Watt hour; and V= the voltage rating of the battery that is 12 V.

The watt-hour of the battery was calculated using equation (2):

$$E = V \times I \times t \times \eta \quad (2)$$

where, V = voltage required; I = current demand; t = time in hours; and η = efficiency.

From the data sheet of the traffic light [6], the following information were deduced;

Power rating of traffic light = 10 W, Voltage rating = 12 V, Current rating = 0.833 A, Duration of operation = 24 hrs, Efficiency = 85%.

Also, from the data sheet of the mobile phone [7], the following information were deduced:

Power rating of phone battery = 7.5 W, Voltage rating = 5 V, Current rating = 1.5 A, Duration of operation = 8 hrs.

From theory, energy demand of the traffic light per day was calculated using equation (2)

$= 12 \times 0.833 \times 0.85 \times 24 = 204$ Wh

Also, energy demand to charge mobile phone per day

= 5 × 1.5 × 8= 60 Wh
Therefore, total energy demand per day for both loads is
204 + 60= 264 Wh
The lead acid battery has an efficiency of 85%, therefore the watt- hour
= 264/0.85= 310.59 Wh
Hence,

$$\text{Amp hour} = \frac{310.59}{12} = 25.88 \text{ Ah}$$

Therefore a battery of 12 V, 26 Ah was selected.

Energy Calculation
The amount of energy required on a daily basis from the battery was calculated using equation (2) and an energy of 264 Wh was needed. Niraj et al. [2] carried out an experiment on a PZT piezoelectric material by analysing the weight to power relation of the material. When a weight of 50 Kg was applied to the transducer, a deflection was sensed which read a voltage of 3 V and a current reading of 0.0015 A. Then from equation (3), the power generated was calculated as shown:

$$P = VI \tag{3}$$

P = 3×0.0015 = 0.0045 W
This implies that a weight of 50 Kg would generate a power of 4.5 mW. The experiment was repeated for several values of weight and it was concluded that the weight applied to a transducer is directly proportional to the power generated. The correlation between then was found as P α Wt.

Taking the constant of proportionality as K, the power generated is expressed by equation (4).

$$P = KWt \tag{4}$$

where, K = constant of proportionality; Wt = weight applied; P = power generated.
Now taking a weight of 50 Kg and the power of 0.0045 W and from equation (4) the value of K was calculated as:
K = P/ Wt = 0.0045/50
K = 0.00009

Table 1 gives the various weights applied to the transducer and the corresponding power generated.

Table 1: *Power and corresponding weight of transducer [2].*

Sr. No.	Power (W)	Weight (Kg)
1.	0.0009	10
2.	0.0018	20
3.	0.0036	40
4.	0.0045	50
5.	0.00675	75
6.	0.00765	85
7.	0.009	100

The amount of energy generated from a single transducer is just a portion of its total input energy. A force applied to a piezoelectric transducer, generates an open circuit voltage as given by equation (5) below [8];

$$V_{oc} = \frac{g_{33} \times t \times f}{A} \tag{5}$$

where, g33 = piezoelectric constant of the material for the case in which the force is applied in the same direction as the polling axis of the material; A = cross-sectional area of the piezoelectric material; t = thickness of the individual layers; and f = compressive force applied.

This work was accomplished using the weights of moving vehicles on the Accra-Kasoa roads in Ghana. Table 2 shows a sample data of the weight of various cars that use the road.

Also, Table 3 depicts the time interval vehicles ply the Accra-Kasoa road.

Table 2: *Weight of class of vehicle [9].*

Sr. No.	Vehicle Class	Curb Weight (Kg)
1.	Compact car	1354
2.	Midsize car	1590
3.	Large car	1985
4.	Compact truck	1577
5.	Midsize truck	1936
6.	Large truck	2460
Average weight of Vehicle		1817

Table 3: *Time interval vehicles ply the accra-kasoa road.*

Sr. No.	Time Interval	Total Number of Vehicles
1.	5:00 am to 9:59 am	500
2.	10:00 am to 2:59 pm	200
3.	3:00 pm to 7:59 pm	500
4.	8:00 pm to 4:49 am	200
Total Vehicle per Day		1400

The average weight of vehicles from the Table 2 is 1817 Kg.
Substituting the average weight of 1817 kg into equation (4);
P = 0.0009 ×1 817=1.64 W
Therefore, the power generated by one transducer per vehicle = 1.64 W.
Hence, the total power generated per day by one transducer:
=1.64 ×1 400= 2 296 W ≈ 2.3 kW
A total number of 16 transducers were employed in this work. Therefore, the total power generated per day by all the transducers:
= 2 296 × 16= 36 736 W ≈36.7 kW
Also, the open circuit voltage for the system was calculated using equation (5).
Average force from moving vehicle = 1 817 kg
From data sheet of piezoelectric transducer [10]:
Piezoelectric constant = 24.0 × 10^{-3}, Thickness of piezoelectric layer = 0.002 m, Diameter of transducer = 0.035 m
Therefore, the area of the transducer equals
= 9.621 × 10 - 4 m^2
Therefore, the open circuit voltage was calculated as

$$V = \frac{24.0\times10^{-3}\times0.002\times1817}{9.621\times10^{-4}}$$

$= 90.65 \text{ V} \approx 91\, V$

Circuit Design

The designed circuit consists of the generation part that is the piezoelectric connections and the battery charging circuit. From the equivalent circuit of a piezoelectric transducer shown in Fig. 4, an AC source is connected in series with a capacitor C1. This is because the piezoelectric transducer has a capacitor property, which is the ability to charge and discharge when pressure is applied to it. This capacitance can be calculated using equation (6).

$$C_S = \frac{K^T{}_{33}\times\varepsilon_o\times\pi r^2}{t} \quad (6)$$

where, $K^T{}_{33}$ = relative dielectric constant; ε_o = absolute permittivity; r = radius of the transducer; and t = thickness of the transducer.
From the data sheet of piezoelectric transducer [10].
Relative dielectric constant = 1000, Absolute permittivity = 8.85 × 10^{-12}, Radius of the transducer = 0.0175 m and Thickness of the transducer = 0.002 m
Therefore, using equation (6),

$$C_S = \frac{1\,000\times8.85\times10^{-12}\times9.621\times10^{-4}}{0.002}$$

= 4.257 ×10 - 9 F = 4.3 nF

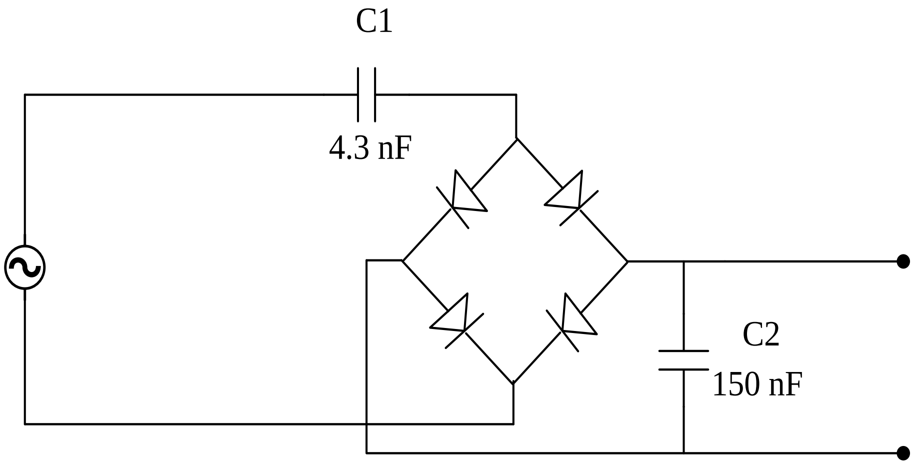

Figure 4: *Equivalent circuit of piezoelectric transducer.*

Circuit Description

In the generation part of the circuit, 16 equivalent circuits are connected in parallel to get the right voltage and current that will be sufficient to charge the battery and mobile phone. The circuit diagram is shown in Fig. 5. The transducers are supposed to be connected in series-parallel to yield maximum current and power. However, in this work, all the transducers were connected in parallel because the output voltage per transducer is enough to charge the battery. The current generated by one transducer is very small, therefore to get higher current, the transducers were connected in parallel. The generated voltage is then given to the battery charging circuit shown in Fig. 6.

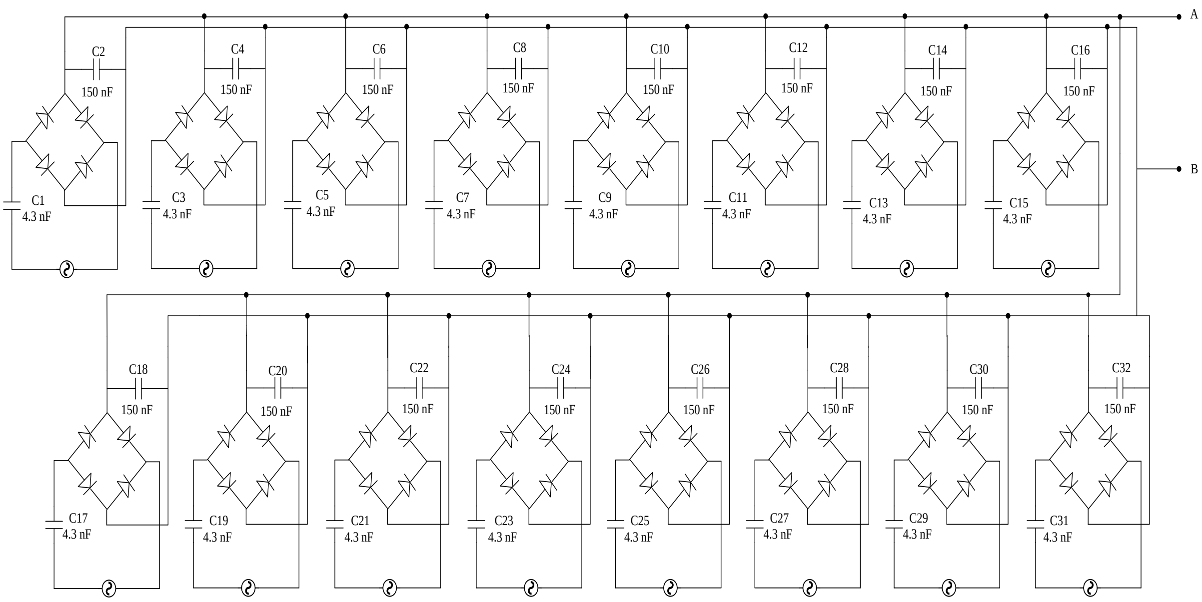

Figure 5: *Piezoelectric circuit design.*

For the battery charging circuit, an AC source from the piezoelectric transducers were rectified using bridge diodes, the rectified DC comes with some ripples which are smoothened by the filtering capacitor. The LM317T voltage regulator regulates the voltage. The output DC voltage is transferred from the battery to the diode D1. Also, the diode D1 prevents the back flow of current when the

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piezoelectric transducers are not producing power. When the battery is fully charged, the zener diode D3 connected in reverse bias mode begins to conduct thereby delivering sufficient base current to the BD139 NPN transistor which in turn grounds the battery charging current. As a result, the red LED is turned on as an indicator for a fully charged battery. The green LED is used to indicate the charging for the battery. Resistor R4 is used to limit the base current, R1 and R3 are used to limit the current to the respective LEDs preventing them from successive failure. The percentage charging of the battery is calculated and displaced on LCD with the aid of a microcontroller.

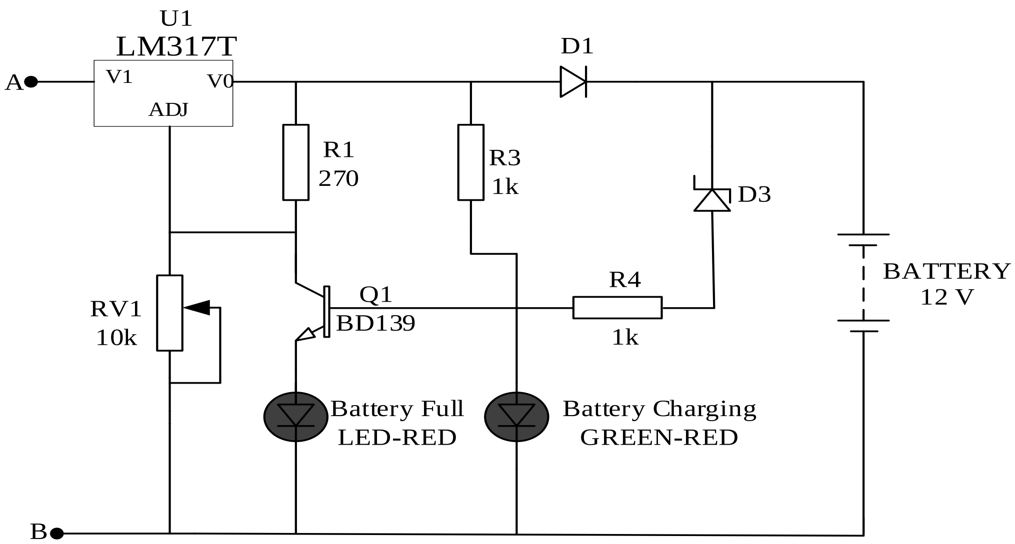

Figure 6: *Battery charging circuit.*

RESULTS AND DISCUSSION

Simulation and Results

Simulations were done using Proteus software. The results from the simulations are shown in Fig. 7 and Fig. 8 respectively.

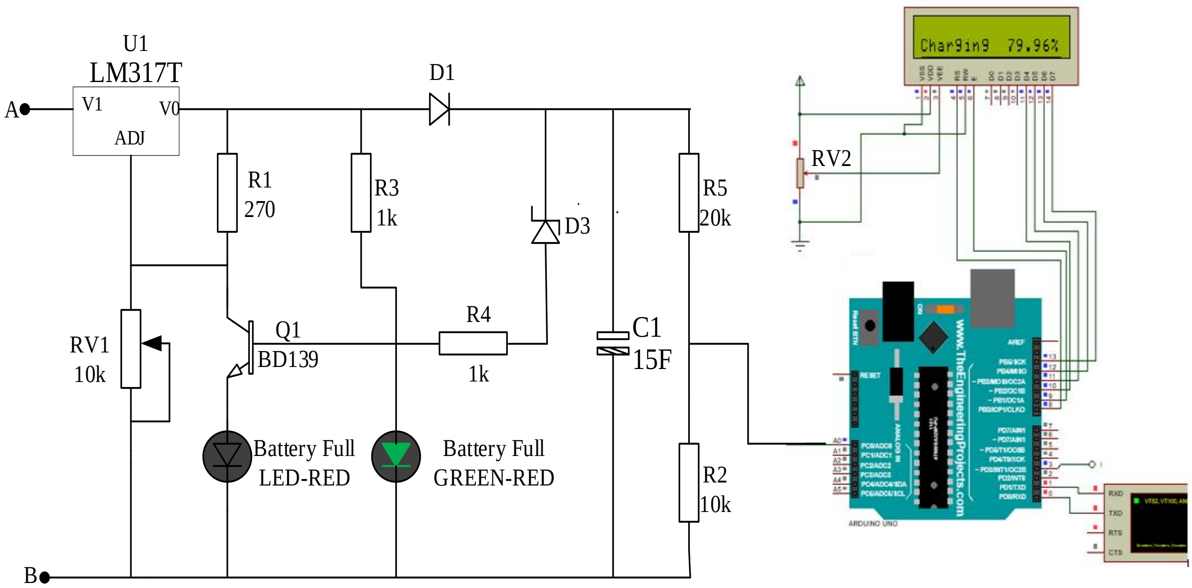

Figure 7: *Simulation result when the battery is charging.*

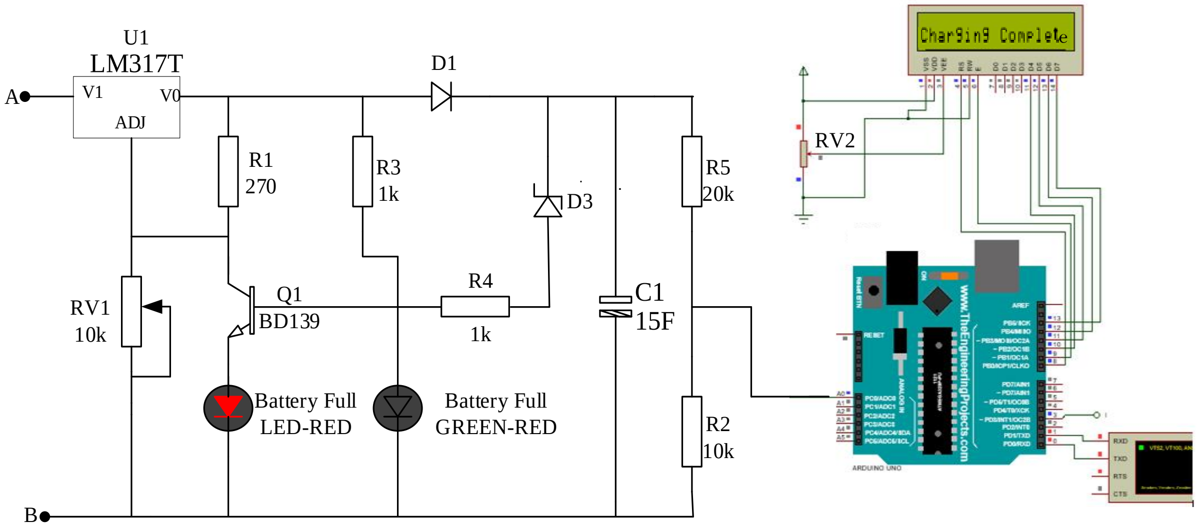

Figure 8: *Simulation result when the battery is fully charged.*

Discussion

Due to the fact that 12 V batteries in Proteus cannot be charged when simulation is in progress, use was made of 12 V 15 F capacitor in place of the battery to indicate charging characteristics of the lead acid battery in real life situation. When the battery is charging, the green LED remains activated and the LCD indicates the charging percentage as depicted in Fig. 7. When the battery is fully charged, the green LED is deactivated and the red LED is activated. The LCD then displays charging complete as shown in Fig. 8.

Cost Analysis

The cost analysis for the designed system amounted to USD $ 73.34. Summary of the detailed cost of the individual components used and respective quantities are presented in Table 4.

Table 4: *Cost analysis.*

Sr. No.	Components	Quantity	Unit Cost (USD $)	Total Cost (USD $)
1.	Piezoelectric Transducer	16	1.00	16.00
2.	Arduino Uno	1	20.00	20.00
3.	Passive Components	1	6.67	6.67
4.	Lead Acid Battery	1	25.00	25.00
5.	USB Port	1	0.11	0.11
6.	PC Board	1	5.56	5.56
Total Cost				**73.34**

CONCLUSION

The design of a pressure generator to power traffic lights and charging of mobile phones has been achieved. The system is simple and cost effective, yet able to generate the required voltages and power for powering traffic lights and charging of mobile phones. This upon implementation will free the national grid for other industrial and domestic purposes, prevent accidents and traffic jams and make charging of mobile phones easily accessible to pedestrians. It is therefore recommended that prior to implementation; further work should be done to overcome excessive pressure that the PZT material cannot handle.

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