International Journal of Latest Research in Engineering and Technology (IJLRET)
ISSN: 2454-5031(Online)
www.ijlret.com‖ Volume 1 Issue 4‖September 2015 ‖ PP 01-09

Thermoelectric power backup for Scooters for Emergency operation

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ABSTRACT : *The idea of this project is to utilise the waste heat energy being generated in scooters. It involves tapping the heat energy being generated at the exhaust in scooters and convert to electrical energy. The amount of heat energy and the temperature is being sensed by the thermocouple and monitored. It is converted to electrical energy by the device called Thermoelectric Generator which works on Seebeck effect. The electric potential produced in thermoelectric generator is boosted by the boost converter thereby increasing the magnitude of voltage, required for charging battery. Further, the battery is used to run the vehicle during low fuel, by closing fuel valve.*
KEYWORDS - *thermoelectric generator, thermocouple, Seebeck effect, electric potential.*

I. INTRODUCTION

In the present world, the vehicles are being used for commuting from one place to another. Even a common man in the society is in need of vehicles even for very short distances. These vehicles were considered once a luxury, but now it is a necessity. These vehicles provide an easy way for commuting from one place to another. The maximum number of vehicles runs primarily fossil fuels like petrol, diesel, etc. Only few of them run by solar power, etc. The fossil fuels are available naturally. These fuels, upon combustion, produce heat energy to run the automobiles. The fossil fuels are obtained as the products like petrol, diesel, gasoline, etc. obtained by the extraction of crude petroleum.

Now-a-days, many vehicles are being designed to run without fossil fuels and run on other sources of energy. But the efficiency of these vehicles running on other sources may be lesser than those vehicles running on fossil fuels. The power required to run these vehicles may not be sufficient to travel for long distances and in with the present technology, other than fossil fuels. Hence, the idea of this project is to couple the fossil fuel system and the use of electric power to run the vehicles. Normally in a vehicle, a large amount of heat energy is being generated at the exhaust. This heat energy is the result of combustion of fossil fuels, where a major portion of heat energy is being utilised and the remaining portion of heat is disposed through silencers. This heat energy though cannot be fully utilised, can be absorbed to maximum and can be used for producing electricity by a device called thermoelectric generator (TEG). This thermoelectric generator converts the waste heat energy to electrical energy. This electrical energy produced by the TEG module, upon boosting, can be used to run the vehicle during emergency conditions like low fuel, etc to support movement to nearest fuel station.

II. THERMAL ENERGY

The heat is a form of energy that is generated at the heat sources which include sun, induction stove, vehicle exhausts, etc. A major portion of heat energy can be obtained from the waste heat sources which can be continuously harnessed for producing the energy usable for human beings. Normally in any heat energy system, if there is a physical pathway, the heat flows from hotter junction to a colder junction. This process of flow results in an increase in entropy. The heat refers to the process of transfer, and it does not have relation with the property of the system. It has no relation with the energy contained in the system. In a conducting system, when the heat is applied to one point, all the molecules in the system absorb the applied heat energy and transfer it to the colder junction. At a particular stage, the other junction also gets heated and will have the same temperature as that of hot junction. This property is common in conducting materials like metals, where each atom in the metal absorbs and transfers heat from one point to another point.

The SI unit of heat energy is Joules (J). This quantity of heat energy can be measured by calorimetry, or it can also be determined by the calculations based on other quantities, relying on the first law of thermodynamics. There are three different types of heat energy transfer, namely conduction, convection and radiaton. There is an emission of heat when various processes are being undergone in the system. But the magnitude of heat energy generated at various sources is different; which implies that the temperature of these operating equipments is not the same. Some of the devices emitting heat energy include heat engine and heat pump. This heat energy when it is being exposed to the atmosphere can result in pollution, and many organisms cannot sustain this heat. Hence, the waste heat energy being exposed can be trapped and converted to electrical energy, which can be used by human beings.

III. THERMOELECTRIC POWER

The electrical energy that is obtained from the heat source is called thermoelectric energy. This thermoelectric energy can be harnessed from the waste heat sources, depending upon the amount of heat energy being generated at the heat source. The devices designed to generate thermoelectric emf works on the principle of Seebeck effect. The Seebeck effect states that, "When the two ends of a conducting element are maintained at different temperatures, the electrons at the hot junction diffuse into the cold junction". The two ends in the device form two junctions that are maintained at different temperatures. This temperature difference between the two junctions results in the generation of thermo-emf. Hence, the magnitude of the thermo-emf depends on the maximum difference in temperature between the two junctions. The thermo-emf can be calculated as $e= \alpha\Delta T$, where α is the Seebeck coefficient and ΔT is the temperature difference, which can be calculated as $\Delta T = T_h - T_c$, where T_h is the temperature of the hot junction and T_c is the temperature of the cold junction.

The magnitude and sign of the thermo-emf depends on the material of the conductor and the temperatures at the hot and cold junctions. The different pairs of metals are being arranged in series to form the thermoelectric series. The element Sb generates the higher value of thermo emf compared to other metals.

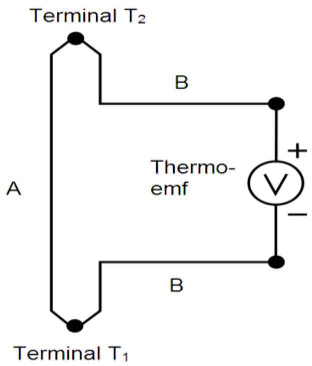

Fig (1) Seebeck effect

IV. THERMOCOUPLE

The thermocouple is a device which is made up of two dissimilar metals. These two dissimilar metals are joined to form the thermocouple. This thermocouple works on the principle of Seebeck effect. The emf being generated is called thermoelectric emf or seebeck voltage and the current generated is called thermoelectric current. The voltage generated by the thermocouple is extremely small and it is measured in terms of millivolts (one millivolt is equal to one thousandth of a volt). There are several methods of joining the two dissimilar metals. One is to weld the wires together. This produces a brittle joint, and if not protected from stresses, this type of thermocouple can fracture and break apart. During the welding process gases from the welding can diffuse into the metal and cause a change in the characteristic of the thermocouple. Another method of joining the two dissimilar metals is to solder the wires together. This has the disadvantage of introducing a third dissimilar metal. Fortunately, if both sides of the thermocouple are at the same temperature, the Seebeck voltage due to thermocouple action between the two metals of the thermocouple and the solder will have equal and opposite voltages and the effect will cancel. A more significant disadvantage is that the thermocouple is a desirable transducer for measuring high temperatures. In many cases the temperatures to be measured are higher than the melting point of the solder and the thermocouple will come apart. The thermocouples are of three different types namely base metal thermocouple, noble metal thermocouple and refractory metal thermocouples. Based on the thermocouple application, they can be further classified as type E, J, K, N, T, etc.

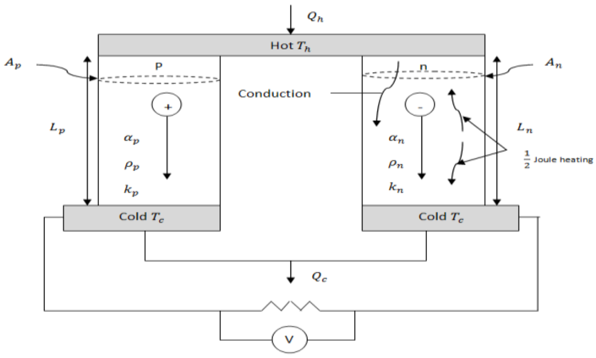

Fig (2) Single thermocouple model

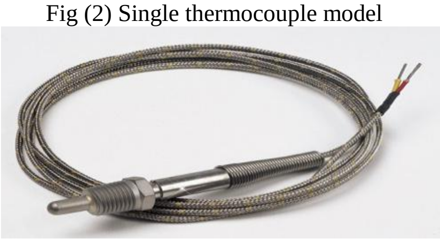

Fig (3) Thermocouple

V. THERMOELECTRIC GENERATOR

The thermoelectric generator is a device used to convert the heat energy into electrical energy. It works on the principle of Seebeck effect. The Thermo-electric generator module has two semiconductor materials, which are referred as the Seebeck cells or thermo elements. This module has semiconductor thermo elements that are connected electrically in series for elevating the resulting voltage and due to the temperature difference between the walls of the plate; the energy that is captured from the thermally excited electrons. A single thermocouple comprises of two thermo elements namely p-type and n-type elements. The themo-elements of the n-type and p-type semiconductors are connected thermally in parallel and electrically in series. The parameters of the TEG module at different temperatures are as shown below.

TABLE I. PARAMETERS OF THE MODULE AT DIFFERENT TEMPERATURES

Parameter	**Value**	
Hot side temperature (°C)	25°C	50°C
Q_{max} (Watts)	3.5	3.9
T_{max} (°C)	67	75
I_{max} (A)	3.0	3.0
V_{max} (V)	1.9	2.2
Module Resistance (Ω)	0.58	0.66

The TEG module can be used for the generation of electric power, whenever power shortage occurs. The efficiency of the thermo element depends on the value of resistance of load and the property of the semiconducting material used. Many TEG modules are made up of Bismuth Telluride (Bi_2Te_3) semiconductor. The heat flowing from one surface of the module involves three effects: heat associated with Seebeck effect, the half of Joule heating and thermal conduction of the semiconductor materials. The heterogeneous material composition inside the thermo elements and the dissimilar geometry introduces dissimilarity in both p-type and n-type materials and so the analysis of dissimilar elements is considered during calculation. The electric circuit defining the Seebeck coefficient of the p-type and n-type is given as $\alpha = \alpha_p - \alpha_n$, where α_p and α_n are the Seebeck coefficients of p type and n type material respectively.

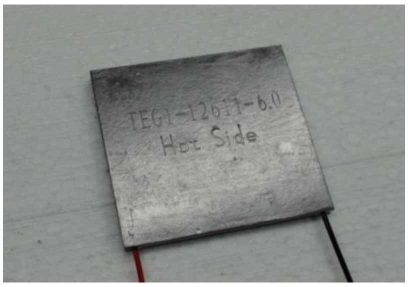

Fig (4) Thermoeletric generator

VI. EXPERIMENTAL SETUP

The experimental setup for the project is explained as shown. In this project, the Thermoelectric Generator (TEG) modules are placed at the heat source, which absorbs the heat. The output voltage from the TEG is boosted by a boost converter to around 12 V. This boosted voltage charges the battery to around 12 V. This battery charged from the boost voltage is used to operate the hub motor, for running the vehicle. The battery charges during the heat generated from the vehicle, whenever, the fuel level in the vehicle is low, the solenoid valve closes the fuel tank, and the battery operates for running the vehicle. The block diagram for the project is as shown in the fig (5).

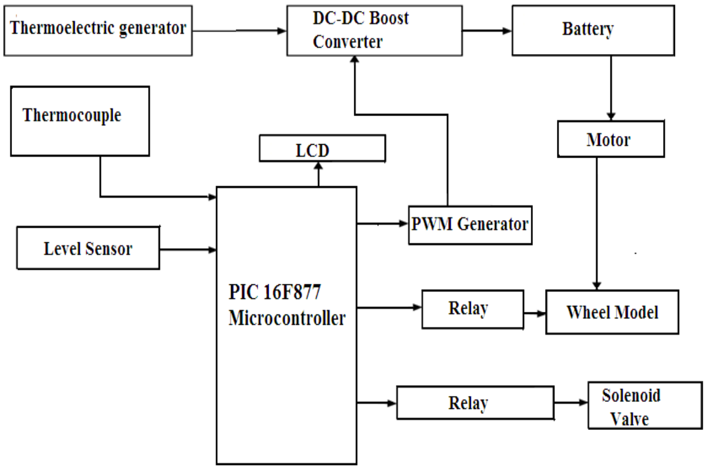

Fig (5) Block diagram of project

A. *Thermocouple Model:* The thermocouple is a device that works on the principle of Seebeck effect, as explained above. The thermocouple is made up of two dissimilar metals forming a junction. This emf produced from the thermocouple is amplified by the amplifier circuit, which consists of an IC LM324. This LM324 is a low power quad operational amplifier, which is used for signal conditioning application. In this project, it is used to provide the information about the temperature difference at the source. This operational amplifier IC consists of four operational amplifier circuits, thereby the number of power supplies and individual Op-Amps for this thermocouple unit is are reduced. The IC is provided 12 V supply for operation and there are limiting resistors and capacitors for current limitation and filtering ripples, etc. The input emf produced from the thermocouple is sensed and amplified b this IC and it provides the information about the temperature of the heat source. The thermocouple model circuit is as shown below.

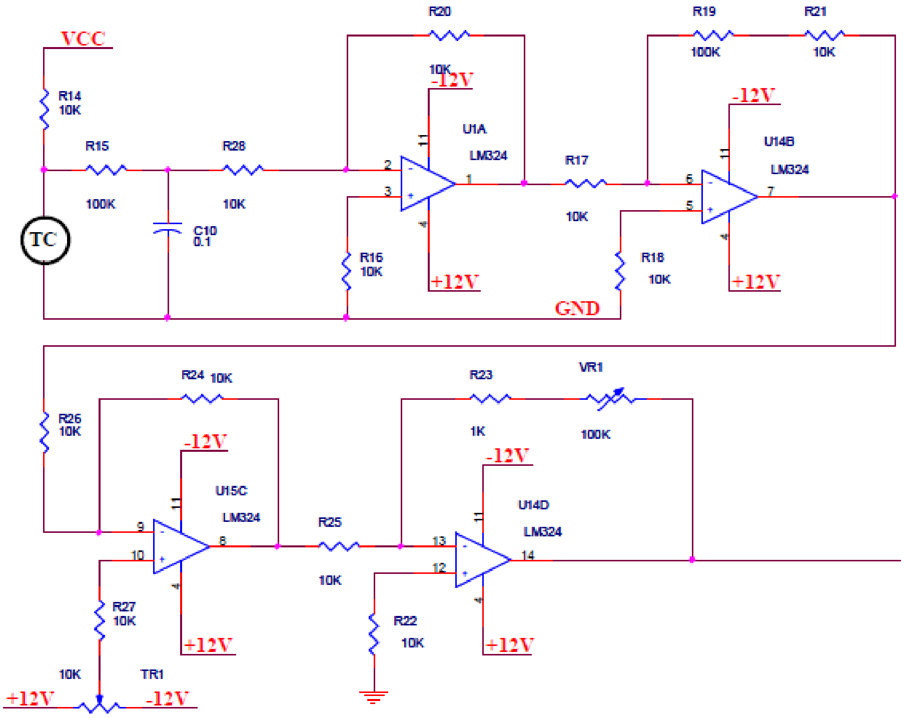

Fig (6) Thermocouple model circuit

B. *Boost Converter :* The boost converter is a power electronic circuit, which is used to step up or increase the magnitude of the input voltage provided. It converts the fixed DC input voltage into variable DC output voltage. The boost converter is used in this project for charging the batter of 12 V. The boost converter consists of an inductor, a diode and a transistor. The transistor is used for switching purpose. In this project, MOSFET is the transistor used for switching. This MOSFET consists of three terminals namely Gate, Source and drain. The PWM pulses are provided to the gate terminal of the MOSFET, by the MOSFET driver circuit. This MOSFET driver circuit consists of two bipolar junction transistors (BJT), in which, one transistor is pnp transistor and the other is npn transistors. They are connected in such a way that they provide pulses by switching alternatively. This operation of MOSFET driver circuit is controlled by PIC16F877 microcontroller. This driver circuit is connected to pin 40 of the PIC microcontroller. The inductor is used to store the energy from the supply and based on MOSFET switching; the energy from inductor is delivered to the system. The diode is used to enhance the flow of current in single direction. The circuit diagram for the boost converter is as shown below.

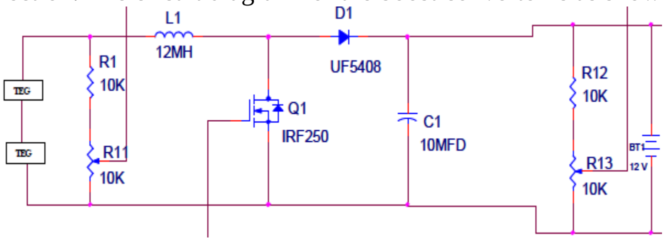

Fig (7) Boost Converter circuit

C. *Storage Unit:* The storage unit is a device capable of storing charges. The battery is normally used as the charge storing unit. The batteries used as storage unit is normally a rechargeable battery, as it is capable of storing the charges. In this project, the lead acid battery is used as the rechargeable battery. This lead acid battery consists of anode made of lead (Pb) and cathode made up of lead oxide PbO_2. A number of lead plates are connected in parallel and the lead oxide plates are adjacent to lead by insulators like rubber or glass fiber. The electrolyte used is dil. Sulphuric acid (dil. H_2SO_4) of density 1.30 g/ml. During the process of charging, the current from the boost converter is applied to this battery, in which the normal electrode reaction is reversed. The chemical reaction is as shown.

$$2PbSO_{4(s)} + 2H_2O + \text{Energy} \xrightarrow{\text{charging}} Pb_{(s)} + PbO_{2(s)} + 2H_2SO_{4(eq)}$$

During discharging, the reaction between lead and lead oxide in the presence of dil Sulphuric acid yields lead sulphate as the precipitate and 2 electrons are being produced. The reaction is as shown below.

$$Pb_{(s)} + PbO_{2(s)} + 2H_2SO_{4(aq)} \xrightarrow{\text{discharging}} 2PbSO_{4(s)} + 2H_2O + \text{Energy}$$

This energy produced from the battery is used to run the vehicles during emergency conditions.

D. *Wheel and Motor model:* The motor is used for the movement of the vehicle from place to place. The motor used for this project is the hub motor. The hub motor is an electric motor that is incorporated into the wheels and drives directly. The electromagnetic fields of the hub motor are supplied to the stationary windings of the motor. The outer part of the motor follows, or tries to follow, those fields, turning the attached wheel. The energy is transferred in a brushless motor electronically, eliminating physical contact between stationary and moving parts. This brushless motor is more efficient compared to the brushed motor configuration. These hub motors are installed between the hubs at the front wheel of the scooter. The hub motors are available in different configurations; here this hub motor is used to operate at 12 V.

Fig (8) Hub motor

E. *Microcontroller:* The microcontroller is the device used to control the whole process in the circuit. In this project the PIC microcontroller is used. The PIC microcontroller, also known as the peripheral interface controller, is used to control all the process in this circuit. This controller plays a major role in providing the PWM pulses to the MOSFET driver circuit. The commonly used PIC microcontroller is PIC16F877. The core features include high performance PISC CPU, eight level deep hardware stack, low power consumption (around 2mA, for 5V, 4MHz), wide operating voltage range. This microcontroller is a 40 pin device, with 5 ports present. The port A has 6 pins, port B, port C and port D have 8 pins respectively while port E has only 3 pins. The port E pins are individually configurable as inputs or outputs; they also have Schmitt triggered input buffers. These buffers act as Schmitt triggered inputs, when they are configured as external interrupts, whey are used in serial programming modes, when they are configured as general purpose inputs and TTL input and when operated in Parallel Slave Port Mode. For the peripheral functions of the device, some pins of this microcontroller are multiplexed with alternate function.

PROPERTIES OF PIC MICROCONTROLLER

Device	**Program Flash**	**DATA memory**	**DATA EEPROM**
PIC 16F877	8K	368 Bytes	256 Bytes

The pins 2 and 3 of this microcontroller are connected to the boost converter with resistances R11 and R13 of magnitude 10 kΩ. The thermocouple input is provided at pin 4 of microcontroller. The pin 1 is the reset pin, and the pins 11 and 32 are provided the supply of 5V. The corresponding pins 31 and 12 are grounded. The pins 13 and 14 are connected to the crystal oscillator. The pin 40 of microcontroller provides the triggering for producing PWM pulses to the MOSFET driver circuit. The pins 19, 20, 21, 22, 27, 28, 29, 30 are connected to 16x2 LCD display. The voltage measurement from the source and the boost converter are monitored and measured. The temperature of the heat source is measured and monitored from the thermocouple circuit in this microcontroller. The wiring of PIC16F877 microcontroller is as shown below.

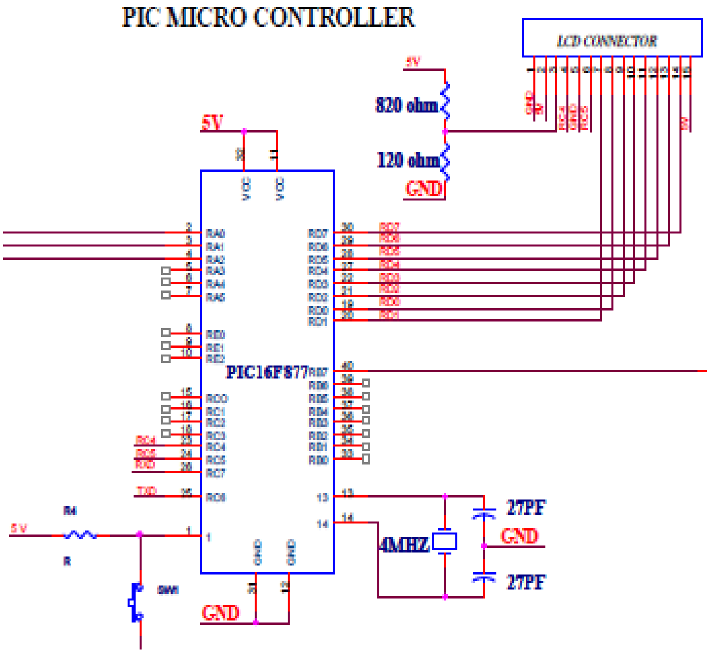

Fig (9) Microcontroller circuit

VII. WORKING

The heat from the source is generated in the scooters due to the combustion of fuels in it. This temperature is sensed by a device called thermocouple. The thermoelectric generator modules are normally present at the silencers, which generate a lot of heat during combustion. When present in the silencers, it produces a thermo-emf due to the difference in temperatures based on the principle of Seebeck effect. This output emf from the thermoelectric generator is boosted by the boost converter circuit, thereby increases the magnitude of the input voltage. The fixed input DC voltage is converted to a variable DC voltage, which is used to charge a battery. During the combustion process, the fuel level at each stage is monitored by the fuel level sensor. When the fuel level falls to a minimum value, the solenoid of the fuel tank closes by the relay operation and simultaneously, the vehicle is switched to run in electric mode by the charged battery. This operation is supported during emergency condition like low fuel for movement for smaller distances. The closing of solenoid, the operation of vehicle through battery and PWM pulses for the boost converter circuit is monitored by the PIC microcontroller. The sample vehicle model for placing components is as shown below.

Fig (10) Vehicle model

VIII. RESULTS

The magnitude input voltage obtained depends on the temperature of the heat source. Different TEG modules can be selected for power generation, depending on the performance and the temperature range of the source. For the temperature T_h=50°C, the performance curves shall be obtained as,

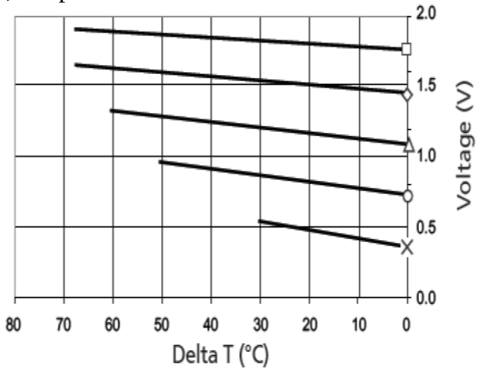

Fig (10) Performance curves at T_h=50°C

The magnitude of the increase in input voltage depends on the amount of difference of temperature obtained at the heat source. The temperature difference versus voltage graph is plotted as shown.

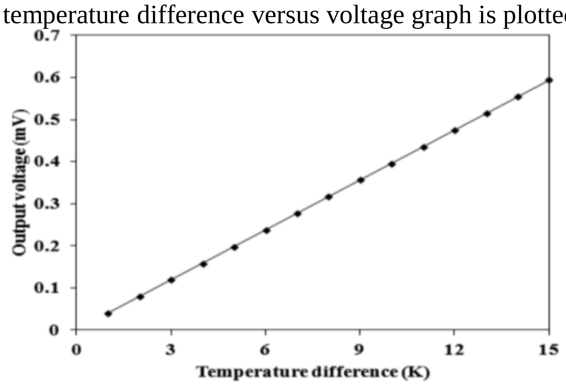

Fig (11) Temperature difference vs voltage

The input voltage is boosted by the boost converter circuit. The Simulink model for the whole circuit is developed and the simulation is done in the MATLAB. The output waveform for voltages and currents in the boost converter shall be obtained as shown.

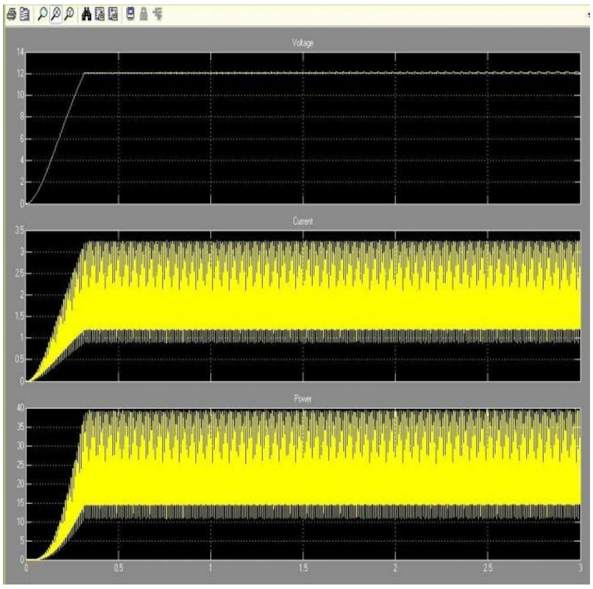

Fig (12) Boost Converter output

The output from boost converter is used to charge the batter and run the hub motor during emergency situation. The hardware output shall be obtained as.

Fig (13) Hardware Output

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