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To cite this article: A Venkatesh *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **623** 012009

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Extraction and conversion of exhaust heat from automobile engine in to electrical energy

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Abstract. The ever increasing demand for energy is leading to rapid depletion of our resources. In spite of the advancement in renewable technology. It is therefore important that the available energy conserved and utilized efficiently. In automobiles about 60-70% of energy out of the total heat supplied by fuel is dissipated as waste heat and just about 30 to 40 percent is transformed into useful mechanical work [1-3]. This paper focus on the recovery and utilization of waste heat into useful electrical energy by using Seebeck effect where in Thermoelectric Generators (TEG) are placed on the exhaust surface for converting heat directly into electrical energy. Thermoelectric generators are highly doped semiconductor solid state devices. The voltage throughput of the thermoelectric generator is given to a dc super lift converter circuit. The output of the super lift converter is used for battery charging.

1. Introduction

1.1. General

The thermoelectric impact is an immediate transformation of temperature contrasts to voltage and vice versa. An output is produced by the thermoelectric device only in the presence of a temperature gradient. This can be explained due to the fact that, the temperature gradient causes electrons to gain more kinetic energy, leading to its diffusion from the hotter junction to the cooler junction. This impact can be utilized to create power. It depends on Thomson effect Seebeck effect, and Peltier effect. Large amount of hot flue gases is produced from boilers, kilns, ovens, IC engines and furnaces. The availability of waste heat from various sources is tabulated below:

Table I Availability of Waste Heat

Types of Device	Temperature (⁰ C)
Steam boiler exhausts	230-480
Nickel refining furnace	1370-1650
IC engine exhausts	120-250
Gas turbine exhausts	370-540
Heat treating furnaces	425 – 650
Steel heating furnaces	925-1050
Air conditioner condenser	32-43



Although it is not possible to completely recover the energy lost in waste gases, efficient revival and utilization of this waste heat could save a significant amount of primary fuel.

The advantages of waste heat recovery are:

1. Improved combustion process efficiency:
2. Most vehicles are still powered by either Compression Ignition (CI) or Spark Ignition (SI) engines. The waste heat usage is reflected in reduced primary fuel consumption, reduced process cost.
3. Reduction in Air pollution
4. Combustion of fuel releases toxic gases like Carbon Monoxide, Nitrogen Oxide and Hydrocarbons into the atmosphere. Since heat recovery reduces fuel consumption, it consequently reduces the amount of toxic gases that pollutes the atmosphere.
5. Increased battery efficiency:
6. The recovery and smart usage of waste heat can be used for energizing some of the circuits involved in the additional features of automobiles, such as rear view camera, and reduces the load on battery.

2. Proposed System

In this section, the block diagram of a thermo electric converter to convert waste heat obtained on exhaust surface is discussed and the working of various blocks in block diagram is explained in detail. Thermoelectric Generators are devices that work on the underlying principle behind the phenomenon called the Seebeck effect, to convert heat into electrical energy. These devices can be useful in multiple low power remote applications [5].

2.1 Existing System

Fuel cells and solar panels are used to generate the electricity to the vehicles. The Cost of this system is high. Regenerative braking system is applied to generate the power. The output voltage is very low in regenerative braking system.

2.2 Proposed system

The proposed system is used to generate the power from heat energy using Peltier device. Proposed system is interfaced with super capacitor and super lift converter. By using this system, it will distribute the power to the rechargeable battery. The charged Power is distributed to the vehicle power supply such as lamps and etc.

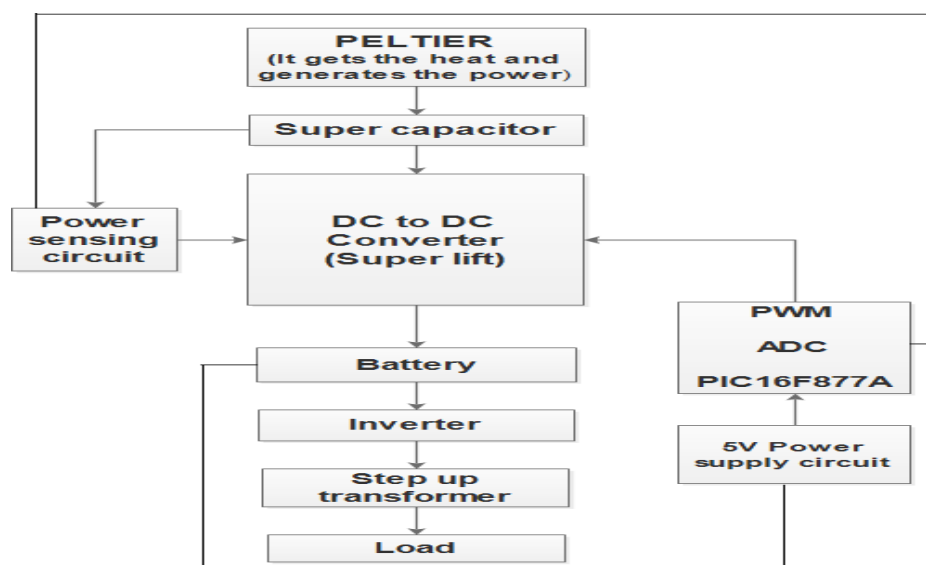


Figure.1 Block diagram of Heat to Electrical Energy Converter

The thermo electric energy harvester device used is Peltier. Based on Peltier Effect is heat energy is converted into electrical energy and the piezoelectric converts vibration energy into electrical energy. These electrical energies have been stored in super capacitor. The super capacitor works like a battery. The super capacitor is a fast charging and slower discharging capacitor than other types of capacitor. The super capacitor output is given to the Boost converter. The function of Boost converter is to convert the output voltage greater than the input voltage. The Boost converter output is given to the battery for battery charging purpose. The battery power is given to the Inverter. The Inverter output power is distribute to the load [4].

2.3 Components Description

The System consists of Thermo Electric Converter (TEC 1-12706), Power Mosfet-IRFP460, Boost Converter, Super Capacitor, Voltage Regulator-7805, Max232 IC, 6V Battery, PIC-16F877A Microcontroller, Single Phase Inverter using IGBT (FGA25N120ANTD), Single Phase Transformer and an LCD display.

2.4 Thermo Electric Generator(TEC 1-12706)

TEG uses one or more thermoelectric models as the primary components and either an active or passive cooling system, such as fan cooled, liquid cooled or open air heat sink, fabricated as a single functional unit. The block diagram is as shown in figure 2.

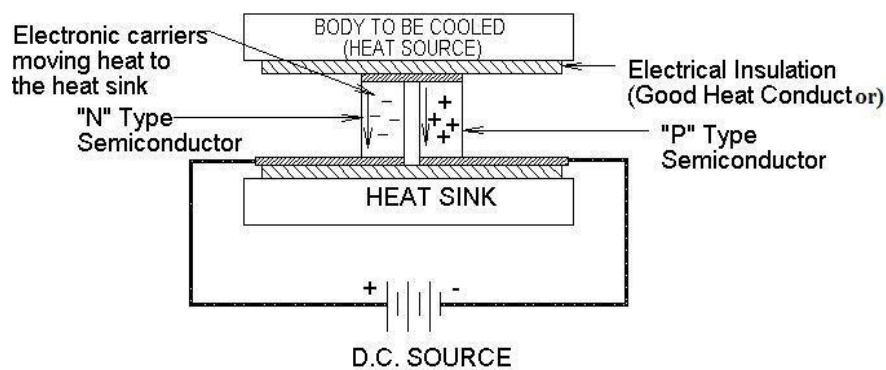


Figure.2 Thermoelectric Generator

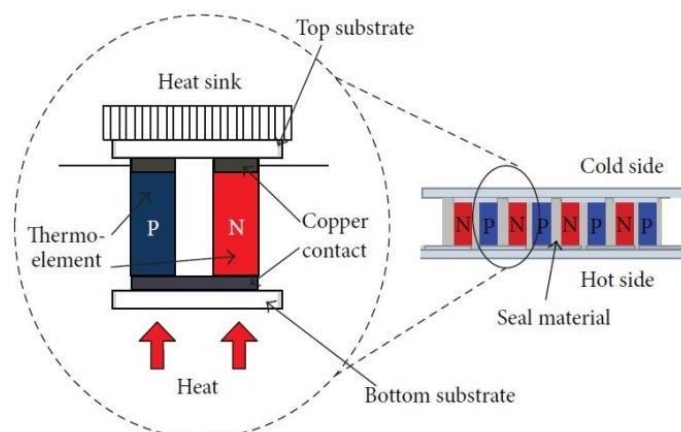


Figure.3 Thermoelectric Generator Internal View

Figure 3 shows the internal view of TEG module. When heat is given to the hot junction of a TEG, it produces electricity. TEC1- 12706 is a 40mm x 40mm sized, single stage module that is designed for

heating and cooling applications. It can be widely used in industries, coffee maker, portable refrigerators, and medical instruments.

2.5 Super Lift Converter

Super lift converters are advanced DC/DC converters that provide high efficiency, high voltage transfer gain and minimized ripple voltage and current. Super lift method that is set up by split capacitors; amplifies the output voltage in geometric progression. It is a type of Switched-Mode Power Supply (SMPS) which consists of semiconductor switches and energy storage element.

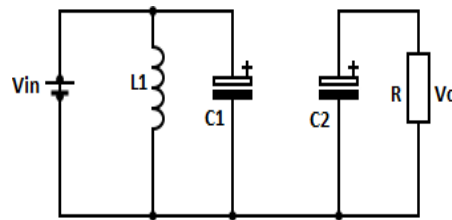


Figure.4 Super lift converter

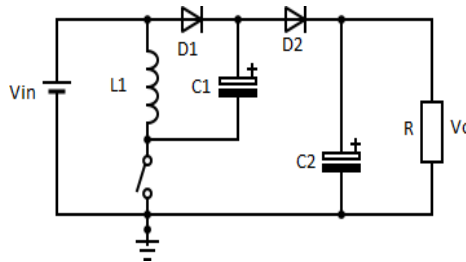


Figure.5 ON state working diagram

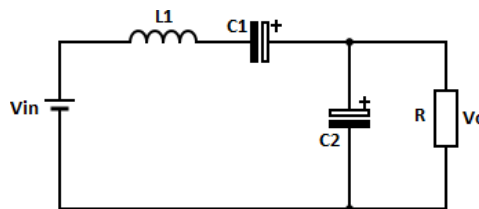


Figure.6 OFF state working diagram

Transfer gain of super lift converter is given by,

$$G = \frac{V_0}{V_{in}} = \frac{2 - K}{1 - K}$$

Where G – Transfer gain

V₀ – Output voltage

V_{in} – Input voltage

3. TEG Power And Efficiency Calculation

The conversion efficiency (η) is the ratio of the generated electrical power (oT) to the heat supplied to the module Qh

Qh – heat removed from the cooled side.

$$\frac{P_T}{Q_H} = \frac{P_T}{Q_C + P_T} \quad (1)$$

There are four basic physical entities that are involved in the operation of Thermo Electric Generators (TEG) namely, the Thomson effect, the Joule effect, the Seebeck effect and the Peltier effect. Under steady state conditions, these entities together explain the phenomena of energy flow below. [8]

$$TJ \frac{da}{dx} + \tau J \frac{dT}{dx} - \rho J^2 - \frac{d}{dx} \left(k \frac{dT}{dx} \right) = 0 \quad (2)$$

Where T - temperature
 J – Electrical current density
 α – Seebeck coefficient
 τ – Thomson coefficient
 ρ – Electrical resistivity
 k – Thermal conductivity of the material

The equation of heat flow at hot side is:

$$Q_H = K_T \cdot (T_H - T_C) + S_T \cdot T_H \cdot I - \frac{1}{2} I^2 R_T \quad (3)$$

Where $K_T = N(k_n + k_p)G$ – total thermal conductance of N couples.
 $S_T = N(a_n + a_p)$ – Total Seebeck coefficient.
 $R_T = N(\rho_n + \rho_p)/G$ – Total resistance.
 G = area/length – Geometry factor.

Heat flow at cold side is:

$$Q_H = K_T \cdot (T_H - T_C) + S_T \cdot T_C \cdot I - \frac{1}{2} I^2 R_T \quad (3)$$

Hence, the power generated by the module P_T is

$$P_T = Q_H - Q_C = S_T \cdot (T_H - T_C) \cdot I - I^2 R_T = [S_T(T_H - T_C) - IR_T] \cdot I = V_T I \quad (4)$$

The output voltage of the module, V_T is

$$V_T = S_T(T_H - T_C) - IR_T \quad (5)$$

Therefore, the P_T, Q_H, Q_C, η can be found, for known material properties. In practice, it is impossible to measure the temperature of both the hot and cold junction.

$$W_H = (W_{T1} + W_{T2} + W_{T3} + W_{CR}) \quad (6)$$

Where W_H - Total thermal resistance between T_1 and T_H .
 W_{T1}, W_{T2}, W_{T3} – Thermal conductivity resistances.
 W_{CR} – Thermal contact resistance.

The hot junction temperature T_H is given by

$$T_H = T_1 + Q_H W_{TC} \quad (7)$$

Similarly, the hot junction temperature T_H is given by

$$T_C = T_2 - Q_C W_{TC} \quad (8)$$

Where W_{TC} – Total thermal resistance between T_C and T_2 .

The following expressions show the relationship between the power output of Peltier module and the gain of the superlift converter.

$$P_O = P_T \cdot G \quad (9)$$

$$P_O = V_T I \cdot \frac{V_O}{V_{in}} \quad (10)$$

Where P_O – Stepped up output power of the superlift converter

4. Hardware Implementation

The hardware implementation of the proposed system using Peltier module and superlift converter is shown in figure 7.

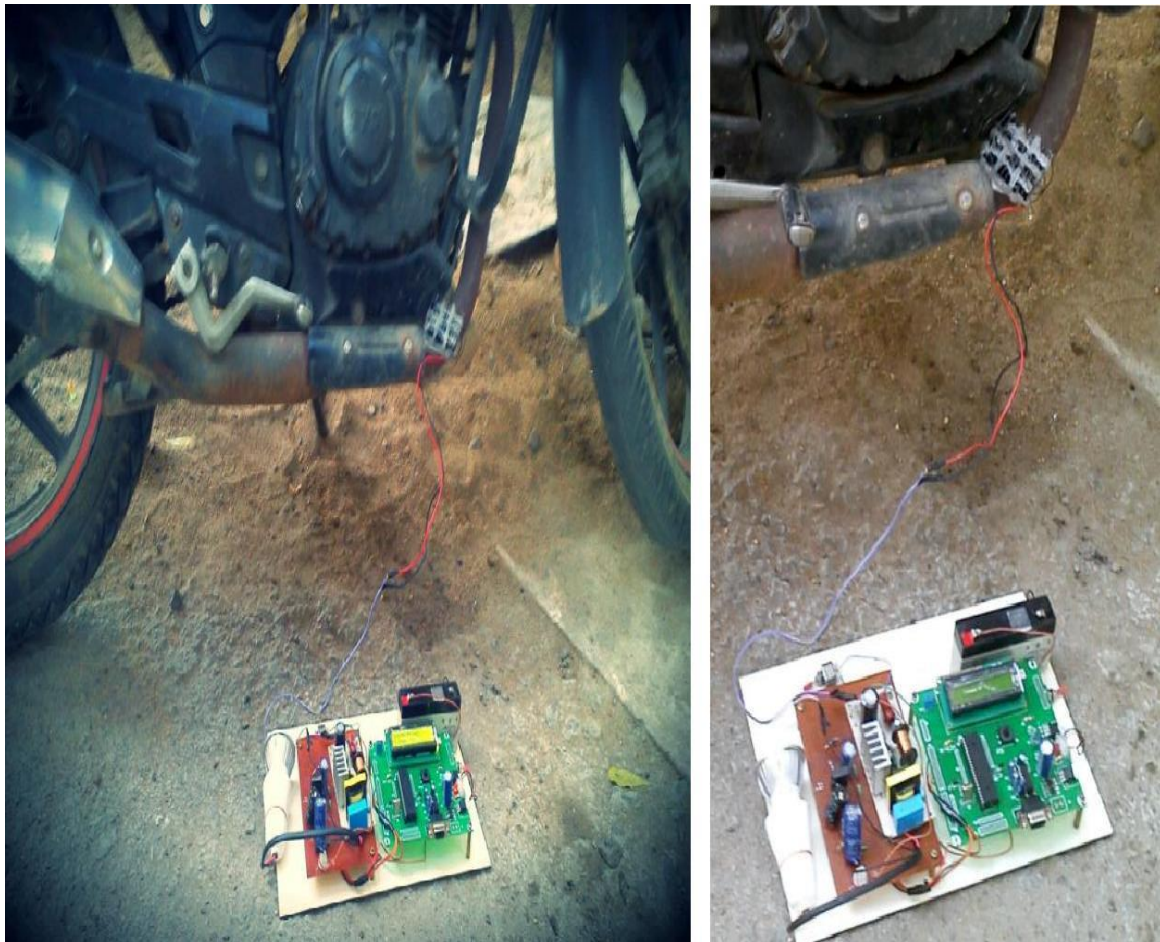


Figure.7 Hardware implementation in automobile two wheeler

Figure 9, circuit consists of Peltier device (TEC 1-12706), Boost converter with MOSFET switch IRFP460, PIC-16F877A Microcontroller interfaced with MAX232 and 16x2 LCD display, Voltage Regulator 7805 and X1 crystal Oscillator to maintain constant 20MHz frequency. In Figure 7 TEC1-12706 is placed on the exhaust surface of automobile two wheeler muffler as shown. It is also used to convert waste heat generated in hot waste gas exhaust industrial furnace, air conditioner outdoor unit and laptops. This setup was implemented in an automobile to utilize waste heat and generated electrical energy is used to charge the battery of the vehicle. [9]

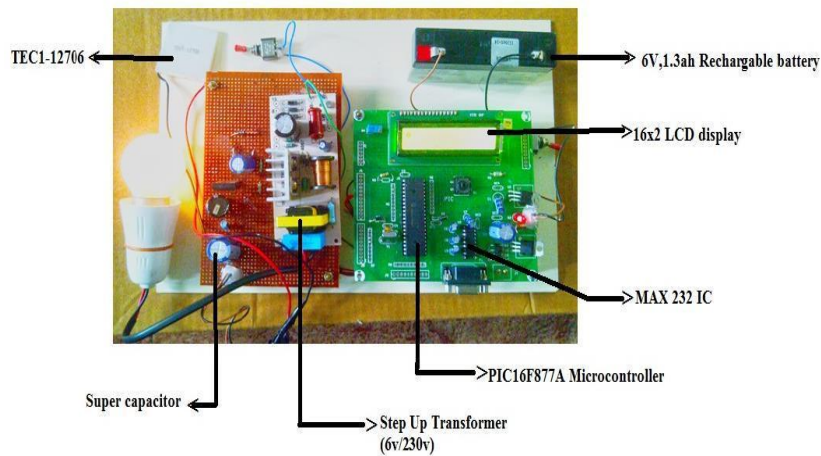


Figure.8 Hardware implementation

TABLE II Output Measurement

Temperature (°C)	Input Power (W)	Output Power (W)
42	1.684	2.873
56	1.928	4.973
87	2.45	9.5
71	2.148	5.278
58	1.72	3.554

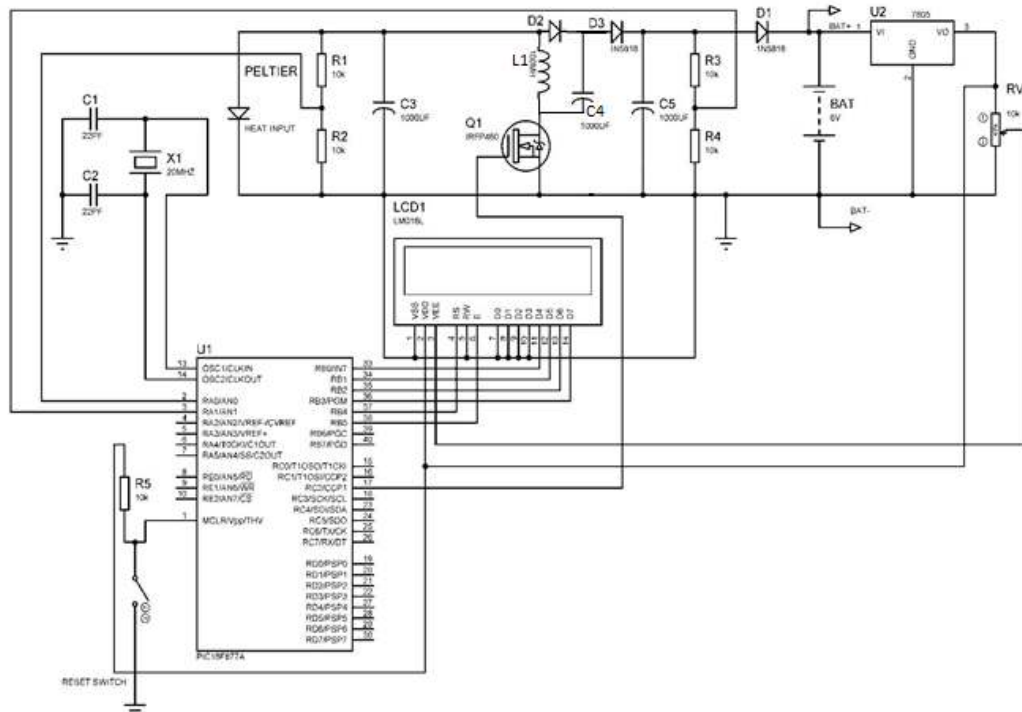


Figure.9 Schematic Diagram of Heat to Electrical Energy Converter



Figure.10 Temperature Measurement

5. Conclusion

The extraction and conversion of exhaust heat from automobile engine, into electrical energy, was successfully implemented on both hardware and software. From the results obtained, it can be concluded that Peltier device along with the concept of super lift converters can efficiently utilize the waste heat energy from automobile exhausts and convert it into electrical energy. This technique is more effective when the distance travelled by the automobile is longer. The Peltier device (TEC1-12706) can work more efficiently below 150 °C beyond which the power output starts to degrade. The scope of the proposed work can be extended to convert waste heat generated in air conditioner outdoor unit and laptops.

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