International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-4, February 2020

Cuk Converter for Waste Heat Recovery from Automobile Engine using Thermoelectric Generator with Air as Coolant

D. Poornima, S. Sangeetha

Abstract- The growing concern on energy conservation and reduction of carbon footprint has led to a lot of inventions and innovations in terms of energy-efficient technologies in all the energy consuming applications. The automobile sector is a crucial zone where these technologies have a major role to play due to the sheer abundance of the number of automobiles.Many small refinements, alterations and innovations are happening in this field which has led to furthermore energy economic automobiles than before.But even in an advanced internal combustion engine, about two-thirds of fuel consumed by an automobile is discharged into the surroundings as waste heat. The effect of this is the increase in the surrounding air temperature which in turn contributes significantly to global warming. This paper proposes amethod to reduce the emission of heat from automobiles by designing and implementinga waste heat recovery system for internal combustion (IC) engines. The key aim is to reduce the amount of heat released into the environment and to convert it into useful energy. A thermoelectric generator (TEG) assembly is used to directly convert the wasted heat energy from the automobile into electrical energy. This electrical energy is conditioned using a Cukconverter and maximum power point tracking (MPPT) algorithm is embedded in the converter for impedance matching and maximum power transfer from TEG to the converter. The conditioned output is used to charge the battery of the vehicle. This methodologyalso increases the energy efficiency of the vehicle as a higher capacity battery can be employed.The proposed system can work well under varying temperature conditions to give a constant output. It can be implemented in any mechanical/ electrical systems were there is wastage of heat energy like gas pipelines, wearable electronics, space probes, cookstoves, boilers, thermal vision, etc. One of the thrust areas where this technology can be effectively utilized in today's world is in electric vehicles where the energy efficiency is the most important factor.

Keywords- Thermoelectric Generator, Waste Heat Recovery,Electric Vehicles, Maximum Power Point Tracking, Cuk converter

I. INTRODUCTION

The automobile industry is one of the worlds' most important economic sectors but unfortunately, it is one of the major causes of carbon emission and an increase in temperature of our earth. The reason for this is that automobiles use IC engines, which have a huge amount of energy loss in the form of heat almost up to 70%.

Revised Manuscript Received on February 28, 2020.
* Correspondence Author
D. Poornima*, Assistant Professor, Dept of Electrical and Electronics Engineering, Sri Ramakrishna Institute of Technology, Coimbatore, Tamil Nadu. India E-mail : poornima.eee@srit.org
S. Sangeetha, Assistant Professor, Dept of Electrical and Electronics Engineering, Sri Ramakrishna Institute of Technology, Coimbatore, Tamil Nadu. E-mail :sangeetha.eee@srit.org

Only one-third of the energy in the fuel of an IC engine is being converted into mechanical power, the rest is wasted as heat. This heat is discharged into the surroundingwhich adds to the global warming scene[1].In recenttimes, greater research is done by large companies like BMW, Honda for the reduction of CO_2 emission to the environment seeking better use ofthe waste heat [2].This paper concentrates on the usage of the heat wasted from automobiles to generate electricity using a device called a thermoelectric generator (TEG). It is a device which converts heat energy directly into electrical energy. Already many researches are done for waste heat recovery from chimneys and cookstoves [10].Research is being taken to extract maximum energy from the wasted heat energy of automobiles contained in the exhaust [3].The temperature of the surface of the exhaust pipe is detected to be high and is around 200°C to 500°C. A suitable TEG is selected to withstand the temperature of the exhaust pipe and is properly mounted on the pipe along with the heat sink. A converter is also designed to boost up the voltage obtained from the TEG to get the vehicle battery voltage.[4].In this set up a Cuk dc-dc converter is connected to the TEG module for power conditioning [5].MPPT algorithm is used in the converter control circuit to maximize the power obtained from the TEG. The conditioned output of the converter is fed to the battery through current feedback [6, 7, 8]. The long term goal of the proposed methodis to offer significant fuel economy improvements and savings in fuel consumption by applying it to conventional and hybrid vehicles [9].This also focuses on reducing the heat emission to the environment. Furthermore, advancement could be brought in this technology by increasing the efficiency of the TEG through experimentation with new materials.

II. WORKING PRINCIPLE

A. Thermoelectric Generator

The basic principle underlying the thermoelectric generating operation isthe Seebeck effect. It detects the temperature differences between both sides and converts it directly into electrical voltage. This is also known as the Seebeck generator. TypicallyTEGs are expensive and less efficient but have no moving part,are compact, and are silent in operation. Large scale industries also use thermoelectric generator modules to transform waste heat into electrical power. When used in automobiles they are considered asautomotive thermoelectric generators (ATGs). ATGs help to enhancethe fuel efficiency of the vehicle and reduce heat discharged into the surrounding atmosphere.

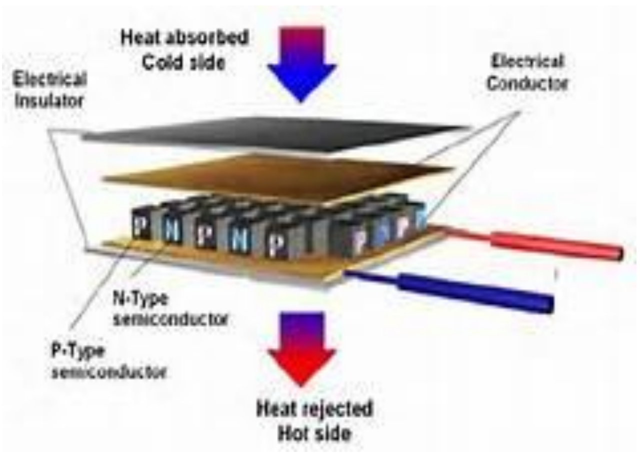

Fig.1. Thermoelectric material

A thermoelectric module is composed of two different thermoelectric materials, one being an n-type semiconductor andanother being a p-type semiconductor, attached at their endsas given in Fig 1.An electric current flows in the circuit when there is a temperature difference between the two materials i.e. between the two sides of the thermoelectric generator. The current magnitude isdirectly proportional to the difference in temperature between the two sides if the load is constant. Thermoelectric generators usually produce a very low voltage, maximum in the range of millivolts. Many TEGs can be connected in series and parallel for increasing the deliverable voltage and current. In this setup, the TEG SP1848-27145 model is used for waste heat recovery. It is manufactured using N-type and P-type Bismuth Telluride $Bi2Te3$ material and can give up to 4.8V for a temperature of 100° C.

B. Seebeck effect

A thermoelectric generator module with its heat sink and cooling feature is given in Fig2. The principle behind the operation of this device is the Seebeck effect. It is the phenomenon by which the difference in temperature between two dissimilar semiconductor materials is converted into a potential difference. It consequently runs an electric current if a load is used to complete the circuit.

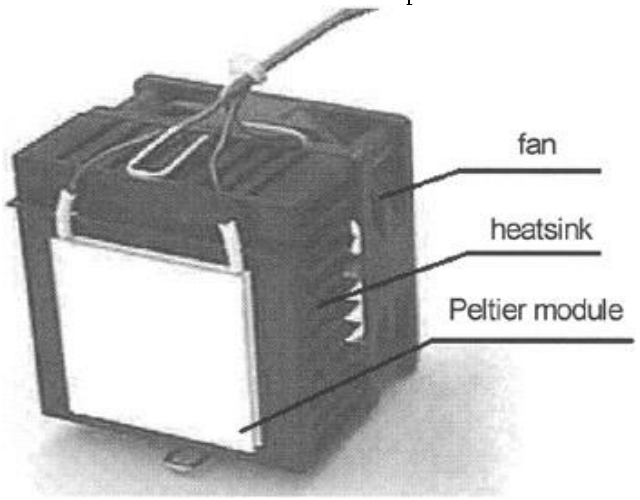

Fig 2. Thermoelectric generator module

Based on ohms law, thecurrent density is given by,

$$J=\sigma\ (-\Delta V+E_{emf})$$

Where ΔV is the voltage, σ is the material conductivity. Eemf=-S*Δ TWhere S is the Seebeck coefficient and ΔT denotes the difference in temperature.

III. PROPOSED SYSTEM

The overall flow diagram of the proposed system is given in Fig.3. The heat energy is wasted in the automobile mainly in the exhaust gas pipe. The TEG assembly is mounted on the pipe via a copper plate heat exchanger. There are 6 TEGs connected in series. The output of this assembly is given to a cuk converter. The output terminals of the converter are connected to the battery for the vehicle operation. The converter is embedded with the MPPT algorithm which keeps the power output at its maximum.

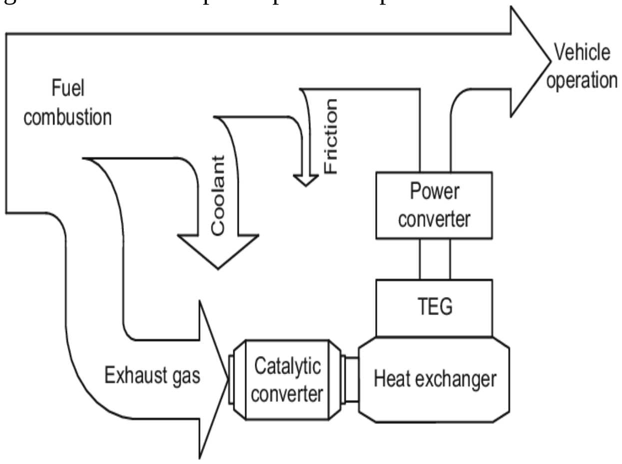

Fig 3. Flow diagram of the proposed system

Fig 4 shows the cuk converter circuitwhich is employed to boost up the voltage obtained from TEG. This is essential because the voltage obtained from the TEG may not be sufficient to operate or charge the battery/load since the TEG is of low efficiency. There are several types of boost converters. The boost converter used in this set up is a Cuk converter.

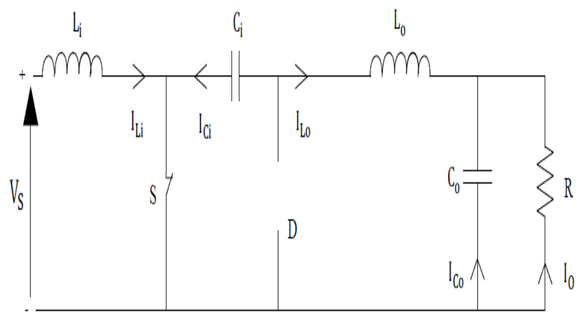

Fig 4. Circuit diagram of cuk converter

Cukconverter is an inverted output buck-boost converter that is used in the boost mode in this method as shown in Fig 4. The capacitor C_1acts as the storage element and transfers power from the input circuit to the output circuit. One of the reasons for choosing a Cukconverter is its input current and output currentis continuous, which helps in regulating the input current while using MPPT.

Thevoltage of the converter iscontrolled by varying the duty ratio with the help of the MPPT algorithm. The amplitude of ripple is reduced to zero as the input and output inductors are wound on the same core. This reduces the need for additional power capacitors for filtering or the high rated switches.This makes the cukconverter economical too.

C. Maximum Power Point Tracking

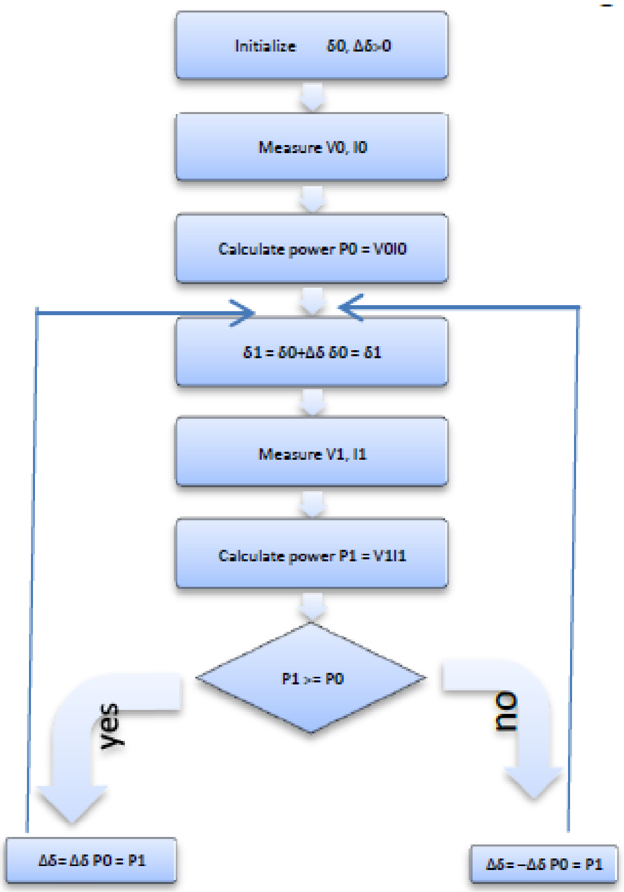

Fig 5. Flow chart of MPPT Algorithm

MPPT algorithm has been extensively used in photovoltaic module controllers and its effect on the output poweris well proved. This is an algorithm that is embedded in charge controllers to keep the module working consistently at maximum powerpoint. This is a new method being implemented in TEGs. Perturb and Observe method is used in this proposed system. This is the most efficient method during normal operating conditions. This method depends on the open-circuit voltage and short circuit current of the thermoelectric generator for finding the maximum power operating point. The open circuit voltage of the TEG is given a small perturbation and the output of that particular cycle is compared with that of the previous cycle. If the power of the present cycle is more than that of the previous cycle, the perturbation is continued in the same direction, otherwise it is followed in the opposite trend.The flow chart for the proposed algorithm is given in Fig 5.

IV. PROPOSED SYSTEM OPERATION

The automobile is started and accelerated. This produces exhaust gas which contains a high amount of heat energy. Due to this high heat, the temperature of the exhaust gas pipe will also be veryhigh. This liberation of heat to the atmosphere contains a large amount of CO_2 gases, heat and other rare gases. This heat liberated to the atmosphere acts as a source of heatfrone side of the thermoelectricgenerator. The atmospheric air acts as the coolant for another side. Since the setup is a stable model, an aluminium heat sink is also used through which the air circulates. Air is used as a coolant in this experiment. The heat is passed to the thermoelectricmodule through the copper plate. The copper plate ensures uniform heating of the teg module.The voltage generated at the terminals of the thermoelectric generator module is given to the input of the converter section which boosts the voltage to 12 V and helps to charge the battery. The MPPT module tracks the voltage to give high efficiency.Fig.6 shows the laboratory set up for the proposed system.

Fig 6. Proposed System

V. RESULT AND DISCUSSION

The results obtained from the thermoelectric generator due to temperature differences and the output voltage generated is tabulated as below.

TABLE I:Temperature difference vs Voltage output

Sl.No.	Hot side Temperature	Cold side Temperature	Temperature difference	Output of TEG module(volts)	Converter Output (Volts)
1.	46.2	30.1	16.1	0.01	0
2.	96.4	30.1	66.3	0.27	0
3.	113.9	31.2	82.7	1.6	3
4.	134.6	31.3	103.3	3.6	11.9
5.	147.5	31.2	116.3	5.2	12
6.	190.9	31.3	159.6	6.3	12.3

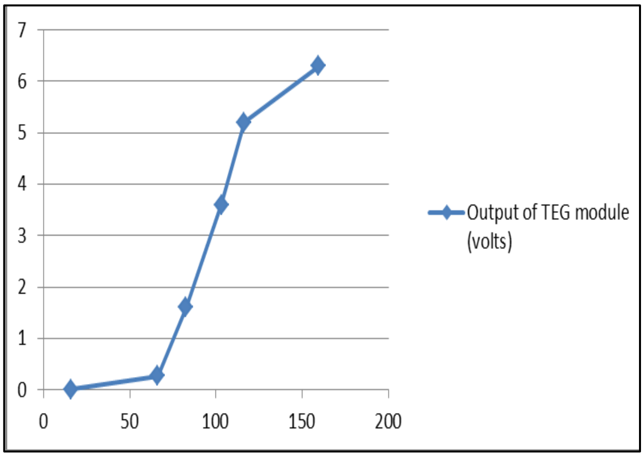

Fig.7 The variation of TEG output with temperature difference.

It is observed from table 1 that the potential difference available at the TEG is directly proportional to the difference in temperature between the two sides of the thermoelectric generator. As one of the sides of the TEG gets heated up, the temperature difference increases further and the voltage output from the TEG assembly also builds up. The output voltage from the TEG is stabilized at the battery voltage using the cuk converter which is connected to the battery. The variation of the output voltage with the temperature difference between the sides of the TEG is shown in Fig.7

VI. CONCLUSION

The proposed system was aimed at decreasing the overall heat that is released into the atmosphere by an automobile engine and to increase the energy efficiency of the system by converting the wasted heat into electricity. Such a heat recovery system has been designed and experimented by the use of thermoelectric generator. The results show that the heat produced by the exhaust pipe of the automobile has been converted into useful electrical energy at the voltage of the vehicle battery. It is also seen that as the temperature difference between the sides of the TEG increases, the voltage developed is also increased. This output is stabilized with the help of a Cuk converter using MPPT algorithm. The newly incorporated components have no effect on the internal parts of the automobile since only the heat has been extracted and used. The energy produced from the system is stored in the battery and made used for other parts of the automobile.

ACKNOWLEDGEMENT

The work described in this paper was supported by a grant from Sri Ramakrishna Institute of Technology, Coimbatore under SRIT Research Promotion Scheme.

REFERENCES

1. Stabler F. "Automotive applications of high-efficiency thermoelectrics". DARPA/ ONR/DOE high-efficiency thermoelectric workshop; 2002. p. 1–26.
2. João Paulo Carmo, Luis Miguel Gonçalves, José Higino Correia," Thermoelectric Microconverter For Energy Harvesting Systems" IEEE Transactions On Industrial Electronics, Vol. 57, No. 3,Pp 861-867 March 2010
3. Chuang Yu *, K.T. Chau, "Thermoelectric automotive waste heat energy recovery using maximum power point tracking"Elsevier Energy Conversion and Management 50 (2009) 1506–1512
4. Jan Hedrick Hermann Carstens Berlin,"Control and optimisation of a DC-DC converter for thermoelectric generators". Proceedings of the FISITA 2012 World Automotive Congress, vol 32016
5. Cuk S, Middlebrook RD."A new optimum topology switching dc-to-dc converter". In: IEEE power electronics specialists conference; 1977. p. 1–20.
6. Eakburanawat J, Boonyaroonate I. "Development of a thermoelectric batterycharger with microcontroller-based maximum power point tracking technique". Appl Energy 2006; 83(7):687–704.
7. Yu C, Chau KT, Chan CC. "Thermoelectric Waste heat Recovery for Hybrid electrical Vehicles". Paper no. 21. In: International electric vehicle symposium and exposition; 2007
8. Hyunbin Park,Minseob Sim,Shiho Kim," Achieving Maximum Power from Thermoelectric Generators with Maximum-Power-Point-Tracking Circuits Composedof a Boost-Cascaded-with-Buck Converter", The Minerals, Metals & Materials Society, 2015
9. T.Yany.Potential applications of thermoelectric waste heat recovery in the automotive industry, Materials and processes laboratory, GM R&D center.,2009
10. D.Poornima and S.Sangeetha, "Design of a biomass cookstove with cogeneration using thermoelectric generators", International Journal of Applied Engineering Research.,vol.13, pp11009-11012, June 2018
11. Andrea Montecucco, Andrew R. Knox,"Maximum Power Point Tracking Converter Based on the Open-Circuit Voltage Method for Thermoelectric Generators" IEEE Transactions On Power Electronics, pp 0885-8993 2013.

AUTHORS PROFILE

Ms. D. Poornima has obtained her B.Tech degree in Electrical and Electronics Engineering from National Institute of Technology, Calicut, Kerala in 2004. She received her ME in Power Electronics and Drives from Muthayammal Engineering College, Tamilnadu in 2012. . At present she is working as an Assistant Professor in Department of EEE at Sri Ramakrishna Institute of Technology, Coimbatore. She is pursuing her Ph.D in the field of power electronics.

Ms. S. Sangeetha has obtained her BE degree in Electrical and Electronics Engineering from Bharath Institute of Science and Technology, Tamilnadu in 2001. She received her ME in Power Systems Engineering from Sona College of Technology, Tamilnadu in 2006. At present she is working as an Assistant Professor in Department of EEE at Sri Ramakrishna Institute of Technology, Coimbatore. She is pursuing her Ph.D in the field of renewable energy.