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Aggrandizement of Power Conversion Efficiency in Cascaded Buck Boost Converter for Thermo Electric Generator Using Fuzzy Controller

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Abstract: Aims to utilize the waste heat from various sources mainly from boilers, automobile engines and so on. Thermo electric generators are energy conversion devices used for conversion of heat energy into electrical power. Theprinciple used is seebeck effect where temperature gradient can be modulated to produce power. The cascaded buck boost Converter is used in proposed work for TEG and the converter is controlled by fuzzy controller method. The fuzzy rules are framed based on change in variation of input hot side temperature of TEG where the cold side temperature is kept constant. The output from TEG is used to charge the battery and it is used to operate the load as when required. It produces precise and maximum output from the TEG and it also improves the conversion efficiency. It can be used mainly in automobiles, medical server where the TEG source is required to monitor the health parameters of plant operators.

Key words: Thermo Electric Generator · Cascaded buck Boost converter · Fuzzy logic control

INTRODUCTION

Our world current scenario shows that there is a need of an alternative energy for fossil fuels. Energy harvesting has become an important phenomenon due to depletion of fossil fuels. The current sources are facing a great shortage and so the cost is also increasing. Thermo electric generators are new technology which is based on temperature gradient. This can uses the Waste Heat from various sources like exhaust gases from the modern automobiles and boilers [1, 2].Thermo electric technology is used both in electric generation and air conditioning [3]. Thermo electric generators are based on principle seebeck effect [3].

Thermo electric generators have many problems regarding the energy conversion efficiency and internal resistance so as to overcome these problems, the converter design and controllers must be modified to improve the conversion efficiency and reduce the internal resistance. The TEG structure is sandwiched between two thermo electric materials (i.e. two heat exchanger plates) at two ends. One of the heat exchanger has high temperature and it is called hot side of TEG and other heat exchanger which has cold temperature and called as cold side of TEG. There is an electrical insulation layer between the two materials of TEG. The two ends of n and p type materials are electrically connected by a metal. The thermo electric conversion in TEG is based on seebeck effect. It is the conversion of temperature difference directly into electricity. The conductor materials used in this to generate electricity are two metals or semiconductors.

Thermo electric generators have got a high volume of applications. They are specifically useful for precise temperature control applications where accuracy, reliability and compactness are important concerns. Since TEG can harvest waste heat from engines and boilers, it can be used in applications of power generation from cars to space craft [1].

Due to rising in cost of fossil fuels, this waste-heat recovery of TEG will play a main role in future energy source of power generation [4]. This can be used in house hold to large industries. Many industries started to manufacture like ATEG, BSST, KELK and TERMO-GENAB. The world leader in automobile industry, BMW launched its ATEG vision efficient dynamics in March 2009. The company developed a prototype vehicle fitted with a thermoelectric generator, based on Bismuth Telluride materials, for electric power production on board

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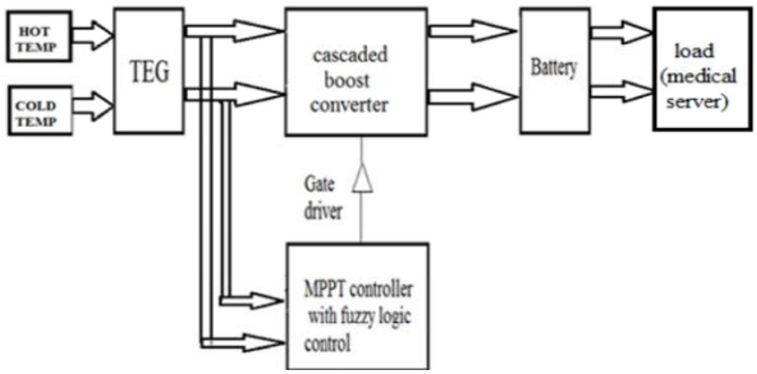

Fig. 1: Block diagram indicating the fundamental structure of the proposed system

[4]. The power production reached levels of 200W during highway driving at 130km/h. Thus TEG has become more prominent in power generation using exhaust heat.

Proposed Work and Other Controllers: In previous models the various converters are controlled by various controller techniques like analog controller [5], digital controller [6, 7] and micro controllers. When micro controllers are used to control the converter, the open circuit voltage method is used [8]. In Analog control circuit, mppt controller algorithm is used. The various mppt algorithms like short circuit method perturb and observe method [9] is used in the previous systems. These are compared to analog, digital controllers are better in terms of speed and efficiency.

In the proposed model, TEG source, cascaded buck boost converter with fuzzy logic control is used and it is represented in Figure1 In the proposed model, fuzzy controller is used which gives precise output, accuracy, easy to implement and very fast [10].

Figure 1 shows the block diagram of the proposed system, where the TEG Array is connected to the input of a modified cascaded Buck boost converter. A fuzzy controller implements mppt fuzzy algorithm controlling the transfer of power from TEGs and driving the MOSFET switches through gate drivers. The output of the modified converter is connected to a battery [11] and then to any small load like medical server.

This buck boost converter is mainly used to improve conversion efficiency and regulation. The converter involves the storage of electrical energy into components, such as capacitors and inductors and the release of energy to the loads. By controlling the time for energy storage and release, average voltage level can thus be either higher or lower than the voltage level of the power source [12].

In the cascaded buck boost converter, the fuzzy logic controllers are implemented in the input side of the boost converter and output side of the buck converter respectively [13]. The output from the thermoelectric generator is given to the fuzzy controller of the boost converter [12]and on the other side output from the buck converter is given to the fuzzy controller from which the switches of buck converter is controlled. The voltage and current are taken from the TEG and given to the mppt where the voltage is added with unit delay and the current is multiplied by voltage, sum with unit time delay and gives power. The power and voltage are obtained from the mppt and it is given to the fuzzy controller.

The output power of the converter is stored in the battery. The battery used is lead acid battery which is simple and reliable besides the cost is also less and it can be used for many applications the stored energy can be used to operate small power load applications.

Mathematical Model of TEG

Principle of TEG: The Thermo electric generator uses phenomenon of thermo electric conversion referred as seebeck effect. It is conversion of temperature difference into electricity. Seebeck coefficient is the measure of magnitude of induced thermo electric voltage in response to the temperature difference. The high conversion efficiency is used to determine performance of TEG materials. Figure of Merit (FOM) is the measure of comparing the potential efficiencies of devices built with different materials.

Mathematical Equation of TEG: The mathematical equation of a thermo electric generator is obtained from the general parameters like hot side temperature, cold side temperature and seebeck coefficient [14].

The open circuit voltage generated by this TE couple is

$$V_{oc} = \int_{Tc}^{Th} \left(Sn(T) - Sp(T) \right) dt \quad (1)$$

Where V_{oc} is open circuit voltage, Th and T_c are hot and cold sides of the temperature, Sn and Sp are seebeck coefficients of n and p type respectively.

If the seebeck coefficients are approximately constant for measured temperature range in TE legs.

$$V_{oc} = (S_n - S_p).(T_h - T_c) \quad (2)$$

Where ΔT is the temperature difference between hot and cold side temperature.

Seebeck coefficient of this material where ΔT is negligible

$$S = \frac{\Delta V}{\Delta T} \quad (3)$$

ΔV is the voltage seen at the terminals

Figure of Merit (FOM) of thermoelectric devices

$$Z=(s^2/R_{kth}) \quad (4)$$

Where R is the electrical resistance and Kth is the low conductivity.

$$Z = \frac{S \times S}{K \times P} \quad (5)$$

- K is the thermal conductivity
- S is the seebeck coefficient
- *P* is the electrical resistivity

Model of TEG Simulation: In the TEG simulation model, the input is hot and cold side temperature.Based on the values of matched voltage and specific DT of thermo electric generator, seebeck coefficient is calculated.

Using the Temperature difference and seebeck co-efficient, open circuit voltage is calculated and using hot and cold side temperature and matched load efficiency, to calculate FOM (Figure of Merit) and internal resistance. FOM is used to measure conversion efficiency and performance of the TEG. The internal resistance value variation shows where the variation of internal resistance is very low for increase in temperature. Resistance is very low such that TEG is more efficient.

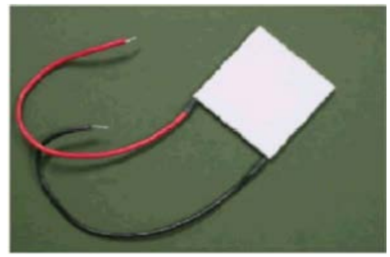

Fig. 2: Hardware model of TEG

The exhaust heat from biomass power plants can be given to the hot side of TEG using pipeline and cold water should be passed through the heat sink to maintain the low temperature at cold side. The Figure 2 shows the TEG model without Heat sink. In this, red and black wire indicates the positive and negative lead of TEG output.

The Figure 3 shows the mathematical model of TEG implemented in mat lab simulation. In this model, the output voltage of TEG is obtained using constant parameters like seebeck coefficient, matched voltage and load efficiency [15, 16]. The variable parameters of the model are hot side temperature and cold side temperature. Mostly the cold side temperature is kept constant near to the room temperature whereas the hot side temperature is varied based on the source.

Electrical Characteristics of TEG: There are certain terminologies which directly changes as there is change in hot side temperature with a constant cold side temperature. The output voltage and internal resistance are changed based on change in hot side temperature. The output electrical characteristics of voltage and current in a PV system is always logarithmic [17, 18] but the electrical characteristics of TEG is linear, this proved in my proposed work.

Figure 5. Variation of TEG internal resistance with respect change in hot side temperature This Figure 4 shows that output voltage induced from TEG varies linearly with respect to the hot side temperature of TEG. This Figure 5 shows that internal resistance varies with change in hot side temperature[18] and it also shows that internal resistance variation is very negligible so that TEG source itself will not act as a load and that internal resistance will draw less power so maximum power can be obtained from TEG.

Cascaded Boost Converter Using Fuzzy Control

Implementation of Boost Converter: The input of the thermo electric generator is hot and cold side temperature.it is then fed to the TEG model where the

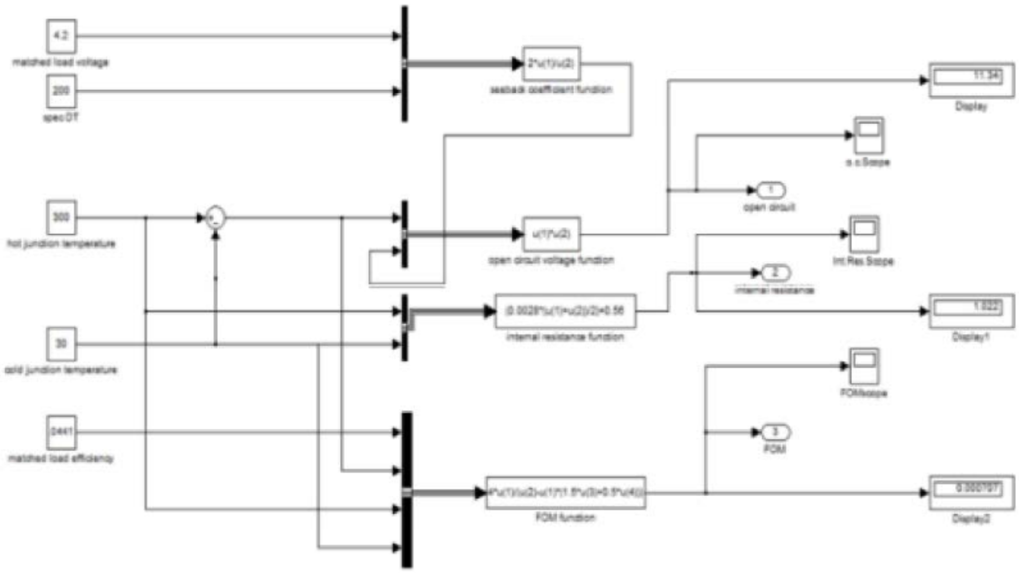

Fig. 3: Simulation model of TEG

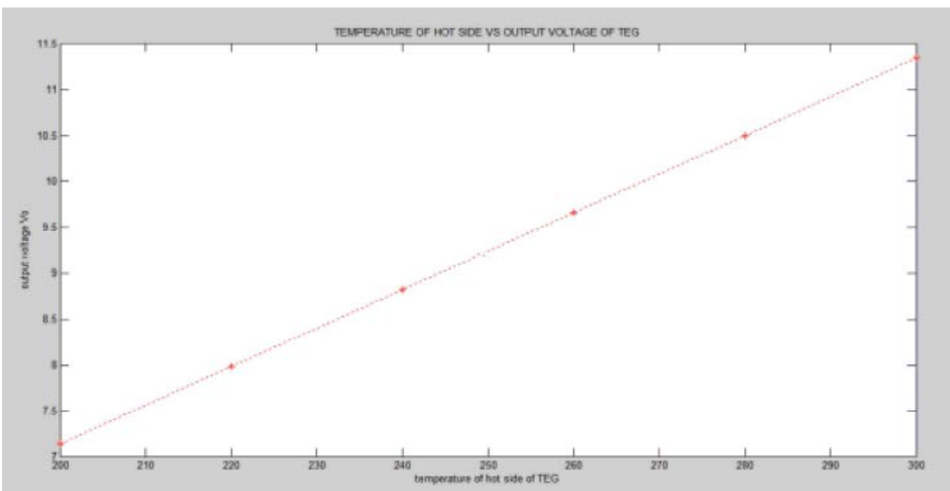

Fig. 4: Variation of TEG output voltage with respect change in hot side temperature

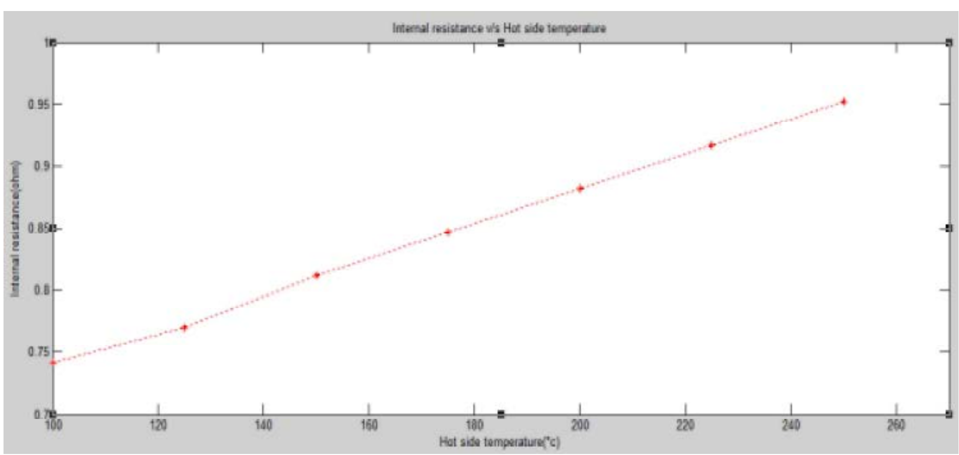

Fig. 5: Variation of TEG internal resistance with respect change in hot side temperature

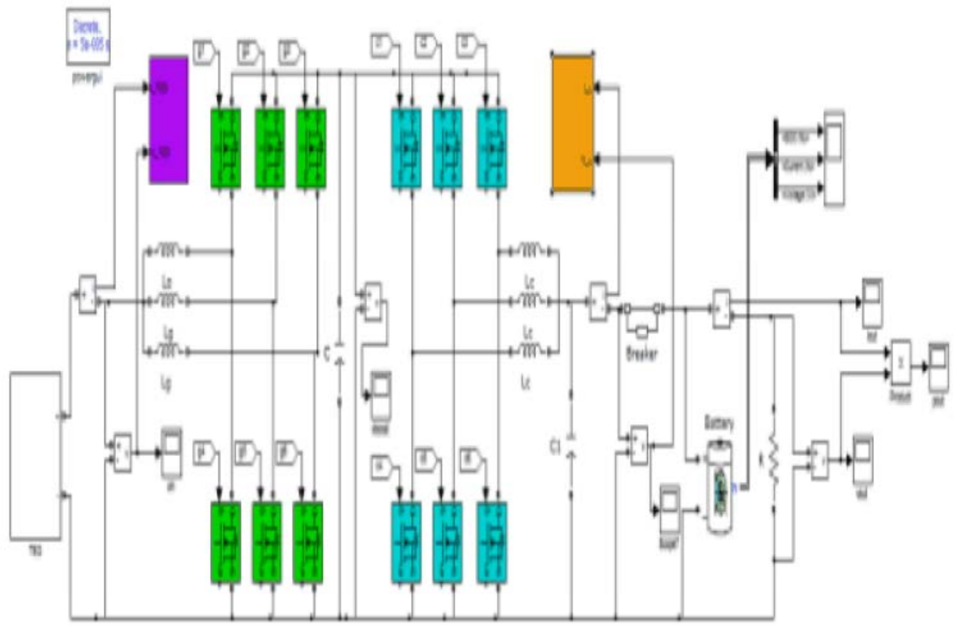

Fig. 6: Simulink Model of MPPT for boost converter using fuzzy logic

temperature difference is made to produce open circuit voltage. The open circuit voltage and current of the TEG are fed to the mppt block where the power and voltage is taken as output. This power and voltage are given to the fuzzy controller by using multiplexer.

From the fuzzy the output signals are given to defuzzified and given to the PWM generator where the signals are generated and it is given to the cascaded boost converter. Hereby the voltage is regulated by fuzzy control. The output from the converter is stored in the battery and it can be used to operate load.

In this proposed work, three level boost converters is used such that 6 mosfet switches are employed; mosfet switches are used because it has high switching frequency. In this modified boost converter, lower leg three mosfet switches used for switching operation during on period and upper leg mosfet switches act as diode because the mosfet is connected from source to drain.

Operation of Cascaded Buck Boost Converter: The output from the TEG is fed to the cascaded buck boost converter that is initially it is given to the boost converter where the switches of the converter are controlled by fuzzy logic control which is given to PWM which generate the pulses to the switches, that is during first cycle the mosfet switches 2,4 and 6 gets turned on.In this lower leg mosfet switches 4 and 6 performs the action of switching such that it allows the current to flow though it,in this process the main current split into two and flows through two switches and it charges the inductor and upper leg mosfet switch 2 perform the action of diode when switches 4 and 6 are turned off during next cycle the stored charge in the inductors are fed to the capacitor and the voltage is measured across the capacitor.

During second cycle the mosfet switches 1, 3 and 5 gets turned on. In this lower leg switch 5 performs the action of switching.it allows the current to flow through and inductor connected across it starts charging.during next cycle when 5th switch is turned off then the stored inductor current flows through the 1 and 3 to the capacitor, this is how capacitor starts charging and it delivers the output to the buck converter here the switches operates same as like boost converter switches and the output obtained from the buck converter is given to the battery, where the energy is stored and from the battery it is used to operate the load.

Fuzzy Controller

Fuzzy Controller Implementation in Both Boosts and Buck Converter: Fuzzy logic is a problem-solving control system methodology that lends itself to implementation in systems ranging from simple, small, embedded micro-controllers, to large, multi-channel pc or workstation –based data acquisition and control systems. It can be implemented in hardware, software, or combination of both [17]. Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a

CHANGE IN ERROR(CE)

ERROR(E)	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NS	ZE
NS	NB	NB	NS	ZE	PS
ZE	NB	NS	ZE	PS	PB
PS	NS	ZE	PS	PB	PB
PB	ZE	PS	PB	PB	PB

Fig. 7: Fuzzy rules for boost converter

CHANGE IN ERROR(CE)

ERROR(E)	NB	NS	ZE	PS	PB
NB	NS	ZE	PS	PB	PS
NS	ZE	PS	PB	PS	ZE
ZE	PS	PB	PS	ZE	NS
PS	PB	PS	ZE	NS	NB
PB	PS	ZE	NS	NB	NS

Fig. 8: Fuzzy Rules for Buck Converter

basis from which decisions can be made or patterns discerned. Fuzzy inference system (FIS) has been successfully applied in fields such as automatic control, data classification, decision analysis, expert Systems and computer vision. The process of inference involves Membership functions, Logical Operations and If-Then rules [17].

Table 1:Variation of output values

Input voltage (v)	Hot side temperature (°C)	Output voltage (v)	Output power (w)
7.14	200	17	28
7.98	220	18.5	35
8.82	240	21	43
9.66	260	23	52
10.5	280	25	60
11.34	300	27	70

Figure 7 and 8 shows Fuzzy rules for boost and buck converter. The output voltage and current of the TEG are converted to power and current and it is given as input to the fuzzy controller.

The fuzzy rules are framed based on the electrical characteristic of the TEG. The output from the fuzzy is given to the PWM generator.The PWM Signal generator generate the signals for operating the switches,in this PWM generator 3 arm bridge (6pulses) is chosen such that output signal can be demux and it can generate pulse signals for 6 mosfet switches. These output signals can be connected to the scope so the pulse signals to six switches can be observed from it.

The simulation results of voltage, current and power of the cascaded buck-boost converter are shown below in the Figure 9, Figure 10 and Figure 11 respectively.

The Figure 10 and 11 shows the output current and output power of the cascaded buck boost converter. The output current and power also increases linearly as the change in the input voltage.

This Table 1 shows the variation of output voltage, current and power with respect to change in input voltage that is change in hot side temperature.

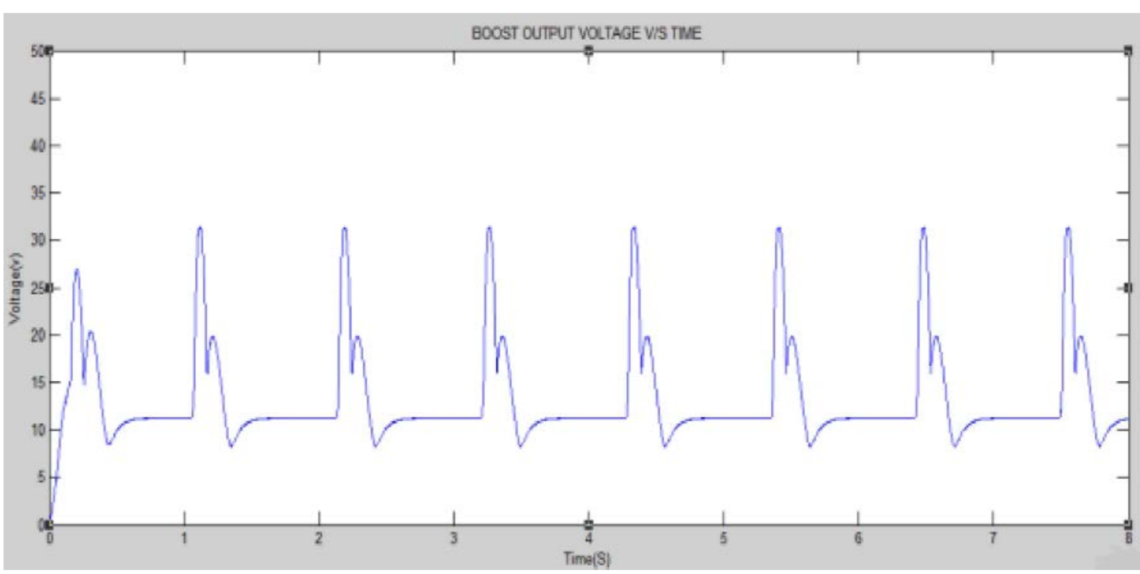

Fig. 9: Variation of output voltage with respect to time

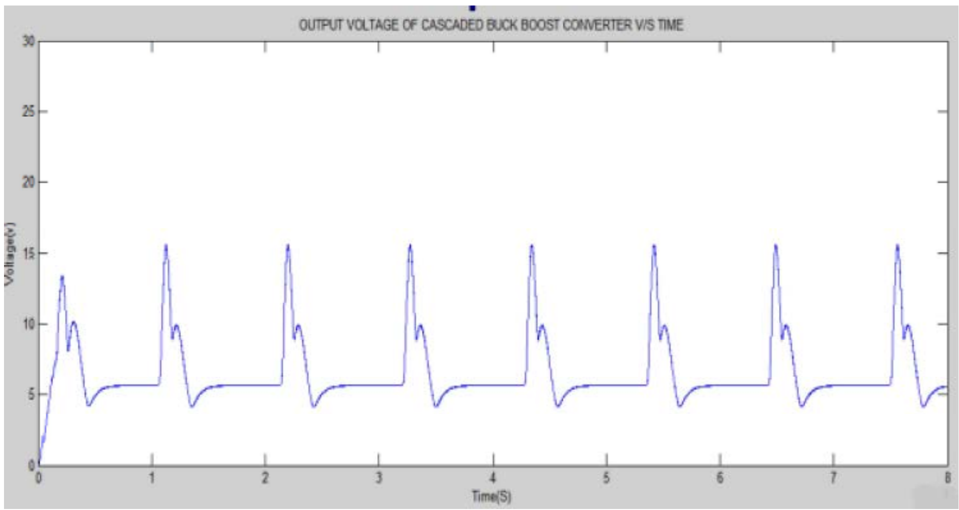

Fig. 10: Variation of output current with respect to time

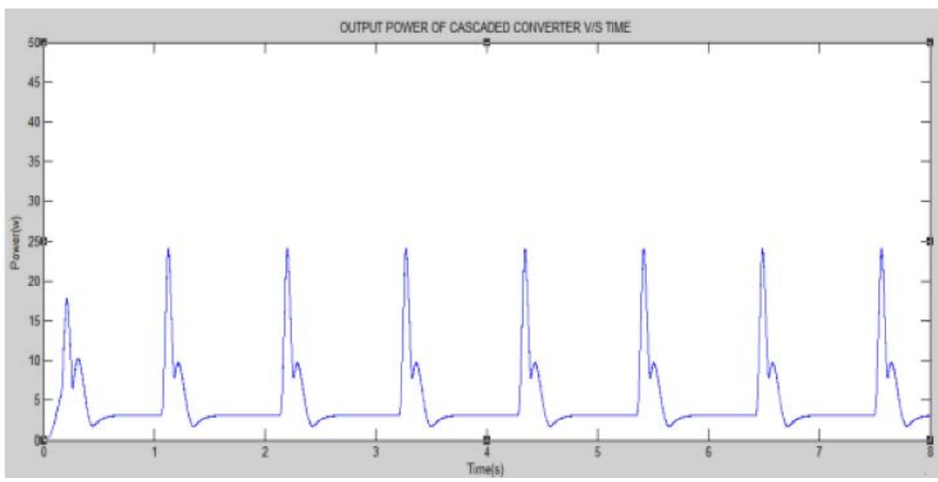

Fig. 11: Variation of output power with respect to time

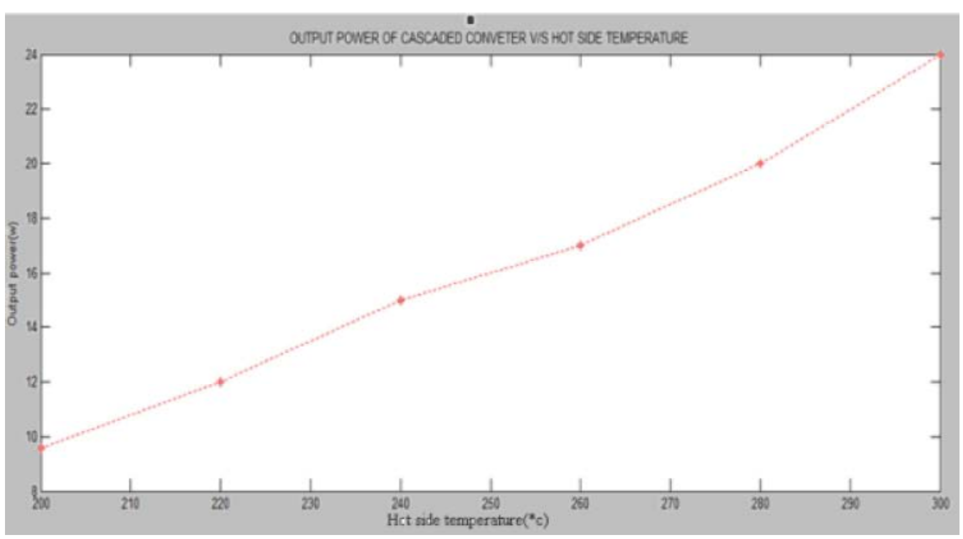

Fig. 12: Variation of the output power with respect to the change in hot side temperature

The Figure 12 shows that variation of the output power with respect to the change in hot side temperature and also this variation is linear. It is observed that with fuzzy logic control, the output power obtained is high and conversion efficiency also improved [18].

CONCLUSION

The waste heat recovery (WHR) technique is a significant factor in the thermo electric generator based power generation. In recent years this thermo electric generator can be of greater use in industries and in automobiles where the boiler heat and engine heat are wasted. In general the efficiencies of TEG are low. This project using cascaded buck boost converter increases the power conversion efficiency upto 80 % and output power is also increased.

This proposed work produces the output voltage of 27v and power of 70w for cascaded buck boost converter. When the TEG modules are connected in series then it can also produce up to 200W to 500w output power. It can be easily implemented in cars and the power generated can be either stored in battery or it can be used for operating any load in industries/power plants.

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