Electrical Energy Harvesting Using Thermo Electric Generator for Rural Communities in India

N. Nandan A. M. Nagaraj, L. Sanjeev Kumar

Abstract**—**In the rapidly growing population, the requirement of electrical power is increasing day by day. In order to meet the needs, we need to generate the power using alternate method. In this paper, a presentable approach is developed by analysis and can be implemented by utilizing heat energy, which is generated in numerous ways in some of the rural areas in India. The thermoelectric generator unit will be developed by combing with control circuits and converts, which is used to light the LED lamps. The temperature difference which is available in the kitchens, especially the exhaust pipes/chimneys of wooden fire stoves, where more heat is dissipated into the atmosphere, can be utilized for electrical power generation. Hence, the temperature rise of surroundings atmosphere can be reduced.

Keywords**—**Thermoelectric generator, LED, converts, temperature.

NOMENCLATURE

Io	Load current
Vo	Output voltage
Vi	Input Voltage
Tj	Junction temperature
Po	Power
J	Current Density
I	Current
V	Voltage

I. INTRODUCTION

LARGE amount of power is generated using of hydro power plant, thermal power plant, nuclear power plant, wind and solar power plant. Electricity is generated in the generating station using generators. The rotor is moved with the help of mechanical in turn driven by turbine which cuts the magnetic field, and then the electricity produced [3], [5]. In near future, electricity generation might not always require a machine with rotating parts. Basically, thermoelectric generator (TEG) converts thermal energy or heat to electrical energy [1] based on Seebeck effect and Peltier. TEG is preferred because of its more advantageous like absence of moving parts, less maintenance, less space required, environmentally friendly.

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A. Principle

TEGs work on the temperature difference which is obtained on the either side of metal object. It converts thermal energy into electrical energy, since no moving part is involved and no intermediate mode is used. It is also called as direct mode of conversion. TEG has hot surface and cold surface. The temperatures of hot surface will increase because it is exposed to heat and the cold surface of TEG is maintained at constant temperature. Temperature difference between hot and cold surface will result in flow of energy from lower level to higher level and voltage difference, voltage difference is proportional to the heat this effect is called as Seebeck effect [7]. Current density can be calculated using:

$$J = \sigma(-\nabla V + Eemf) \tag{1}$$

Peltier effect [4], [8] will describe the process of heat dissipation or absorption at the connection of the p & n type materials. If the heat is absorbed by Peltier model, the current will be drawn by the load indicates the electrical power is generated & if the heat is dissipated by Peltier model the current will be drawn by the supply indicates the electrical power is consumed.

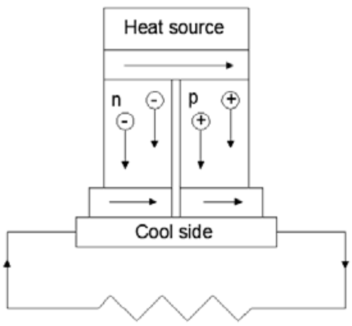

Fig. 1 Peltier model for generation

B. Mechanism

TEGs are made up of solid materials with p-type junction having positive charge of high concentration and n-type junction having negative charge of high concentration. The p-type will be doped to include a high number of positive charge or holes providing Seebeck coefficient of positive [2]. The n-type is doped with in order have high concentration of negative charge or electrons providing Seebeck coefficient of negative. Fig. 1 shows the connection of p type material & n type material for electrical connection in order to collect the current.

II. Methodology

Many different materials are available for making TEG modules. A heat exchanger is been designed to maintain temperature difference between the two faces of the TEG. Aluminum heat exchanger is used because of it has high thermal conductivity. The amount of heat is made to flow on the hot side of TEG is considered as the parameters for the design of heat exchanger.

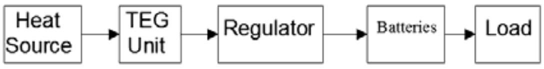

Fig. 2 Model of the power generation Unit

A. Materials

Two TEG Generic Model SP1848-27145 by connecting an electron conducting (n-type) and hole conducting (p-type) material in series, a net voltage is produced that can be driven through a load. Modules surface is flat plane with dimensions 40mmx40mmx3.4 mm.

B. Specifications

TABLE I
Specification of TEG Used

Model	SP1848-27145
Open circuit Voltage (V)	4.8V
Operating Temperature(^{0}C)	0 to 15 ^{0}C
Maximum Temperature(^{0}C)	150 ^{0}C
Wire length (mm)	350
Length(mm)	40
Width (mm)	40
Height (mm)	3.6
Weight (gm)	30

The single TEG with model number SP1848-27145 model is tested with the flow of heated air. With the change in temperature deference of heated air, the voltage and current is observed and tabulated as shown in Table II.

TABLE II
Variation of Voltage & Current with Change in Temperature Difference

Sl. No.	Temperature difference (^{0}C)	Voltage (V)	Current (A)
1	20	0.97	0.225
2	40	1.8	0.368
3	60	2.4	0.469
4	80	3.6	0.559
5	100	4.8	0.669

III. Design

The main aim of this paper is to generate the electricity which can be used for lighting a lamp or charging a battery. The air is being heated by the exhaust pipes/chimneys of wooden fire stoves. Using of single TEG is not possible to generate the power either to light a lamp or charge a battery.

In order to charge a battery of 12V & 2AH, the charge obtained from single TEG with the temperature difference of 80 ^{0}C, the voltage is 3.6V & 0.559A which is not sufficient. Hence, a group of TEG with series [6] and parallel combination is arranged based on the experimental result as shown in Table I, to charge a battery of 12 V, 2 AH, four TEG connected in series (TEG1 to TEG4 as shown in Fig. 3). With 3.6 V of one TEG, 14.4 V will be the voltage after connecting 4 in series. Four number of TEG connected in parallel (TEG1, TEG5, TEG9 & TEG13 as in Fig. 3). With 0.559 A of one TEG, 2.236 A will be the current after connecting 4 in parallel. Basically, it looks like a matrix of 4x4 as shown in Fig. 3.

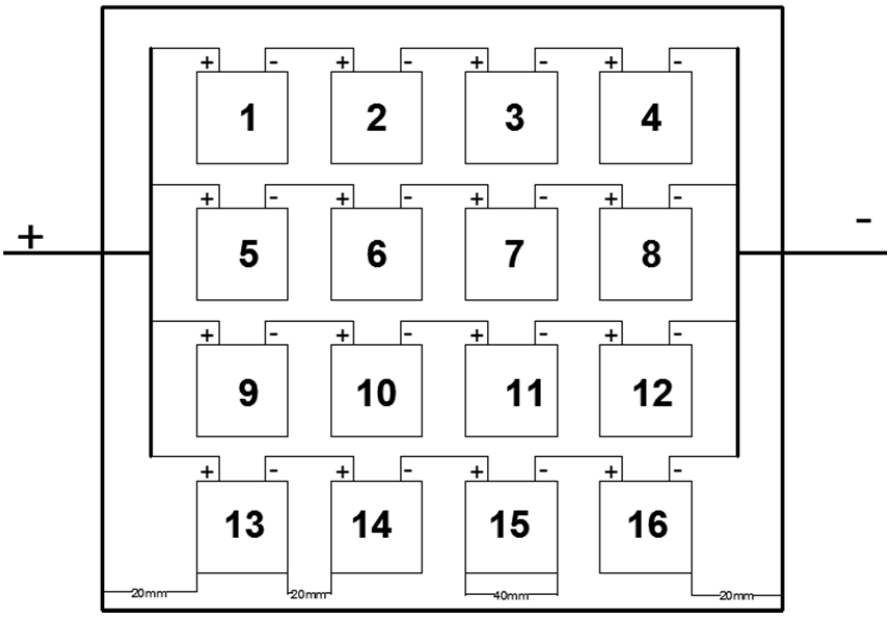

Fig. 3 Arrangement of TEG or TEG unit

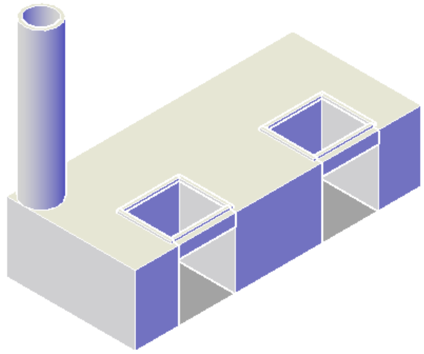

Fig. 4 3D model of stove

The model of wooden lit stove is modeled using AUTOCAD tool, where we can cook the food on both side of the stove, when wood is burnt heat & smoke is produced, smoke which escapes through the chimney/exhaust pipe causing the temperature rise of the chimney/exhaust pipe in-turn heat is also dissipated from the surface of the body to the atmosphere. Instead of heat dissipation to the atmosphere, we keep the group of TEG's which is arranged in series parallel to convert waste heat to useful power. The hot side of TEG unit is installed on to the exhaust pipe/ chimney with aluminum heat exchanger having a dimension of 280 mm x 280 mm with 3 mm thickness, exhaust pipe/chimney length of 1m, inner diameter of 11.5 cm, outer diameter of 12 cm made up of asbestos cement exhaust pipe/chimney. The dimension details for placing of TEG's are as shown in Fig. 3 & the 3-D model of stove is shown in Fig. 4.

IV. Charging Set

The requirement of charger is to charge the battery which is obtained from the TEG unit. Constant voltage, current & auto cutoff are key terminals are to be considered during design of charging unit. Since the electrical parameters or voltage/ current will be varying depending on the temperature difference of TEG unit.

TABLE III
ELECTRICAL CHARACTERISTICS OF LM317

Parameter	Test Condition	Min.	Typical	Max	Unit
Load regulation	I_O = 10 mA to 1500 mA, T_J = 0 °C to 125 °C, $V_O \leq 5$ V		20	70	mV
Line regulation	$V_I - V_O$ = 3 V to 40 V, T_J = 0 °C to 125 °C, VO ≤ 5 V		0.02%	0.07%	V
Thermal regulation			0.03%	0.07%	W
Adjustment pin current	T_J = 25 °C		50	100	µA
Reference voltage	$V_I - V_O$ = 3 V to 40 V, $P_D \leq 20$ W, I_O = 10 mA to 1500 mA	1.2	1.25	1.3	V
Output-voltage temperature stability	T_J = 0 °C to 125 °C		0.7		%Vo
Long-term stability	T_J = 25 °C		0.30%	1%	%/1k Hr
Minimum load current to maintain regulation	$V_I - V_O$ = 40 V		3.5	10	mA

Constant voltage charging of batteries has more advantages for this, and we are using 3- pin voltage regulator of Texas Instrument with IC number LM317 [9] in order to charge the battery. It has a wide range of input voltage from 1.25 V to 37 V and it can handle a current up to 1.5 A. Additional protection is included in this IC, namely thermal protection, output safe-area compensation, internal short- circuit current limiting, and over load protection. The electrical characteristic of IC LM317 is given in Table III.

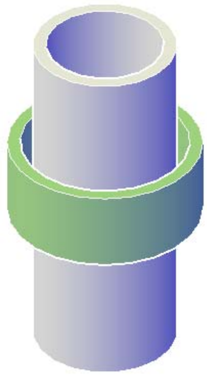

Fig. 5 3D model of TEG unit on chimney/exhaust pipe

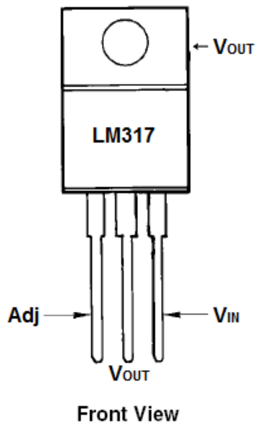

Fig. 6 3 pin voltage regulator

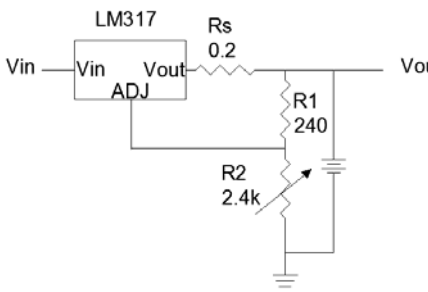

Fig. 7 Typical voltage regulator circuit

The circuit diagram of voltage regulator is as shown in Fig. 7. This regulator produces an output of 14.5 V which is needed to charge a battery of 12 V. Constant voltage can be obtained by varying a 2.4 kΩ pot which is connected across the battery. Characteristics (line regulation & ripple rejection) of LM317 are shown in Figs. 8 and 9.

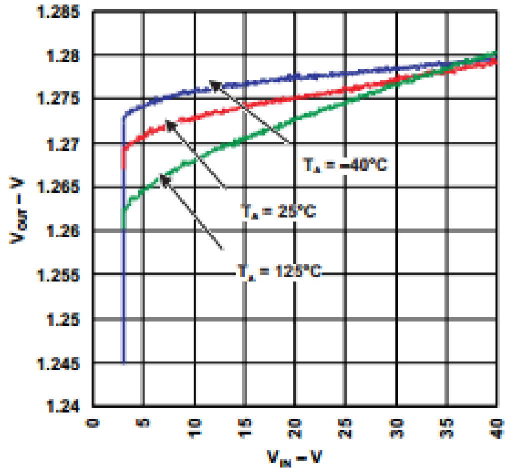

Fig. 8 Line regulation

$$Vout = Vref\left(\frac{R2}{R1+1}\right) \quad (2)$$

$$Iout = \frac{Vref}{Rs} \quad (3)$$

$$Zo/p = Rs\left(\frac{R2}{R1+1}\right) \quad (4)$$

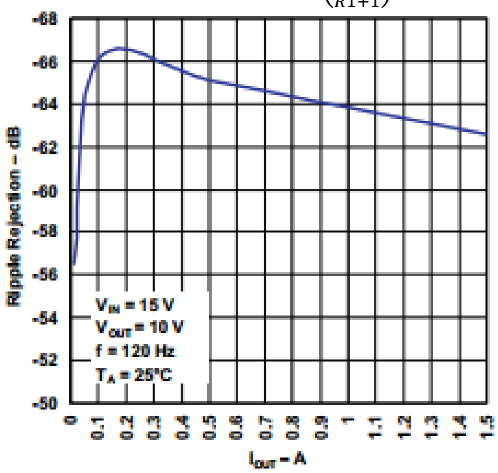

Fig. 9 Ripple rejection

V. Battery

The battery is used of lead acid, the rating of the battery is 12 V, 2.2 AH, Panasonic make sealed rechargeable battery LC-R122R2P [10]. It has extended cycle life, efficient charging under monitored condition, temperature tolerance, long shelf life.

The maintenance cost of lead acid battery is slightly high compared to lithium ion battery & life is up to 3 years with temperature of 25 0C where battery is installed, internal resistance of 70 mΩ of fully charged battery at 25 0C. The charge method which is preferred is constant voltage, repeating use with initial current less than 0.88 A, control voltage of 14.4 V and with discontinuous use initial current less than 0.33 A, control voltage of 13.6 V to 13.8 V per 12 V cell at 25 °C. The characteristics of LC-R122R2P battery at 25 °C are shown in Figs. 10 and 11.

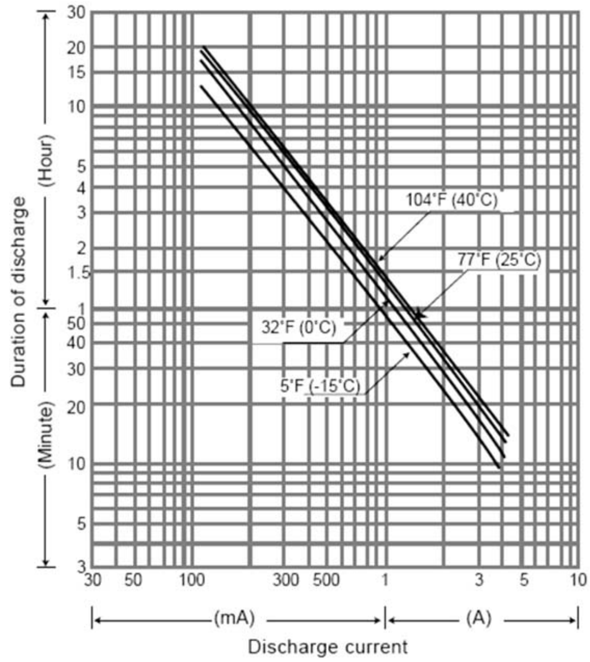

Fig. 10 Duration of discharge v/s discharge current

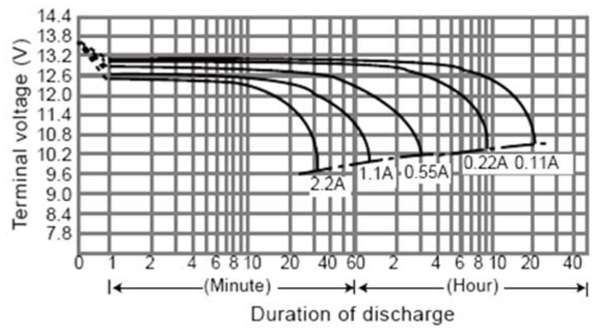

Fig. 11 Discharge characteristics at 25 ^{0}C

VI. Cost Analysis

The cost analysis is carried out based on the cost of the unit and the power generated by a TEG unit in order to charge the battery. The cost analysis is shown in Table IV.

TABLE IV
Cost Analysis

Sl. No.	Description	Cost in Rupees
1	Single TEG unit	600.00
2	wooden fire stoves with chimney	1000.00
3	Battery	600.00
4	Battery charger with controller	800.00
5	Miscellaneous	1000.00

VII. Result

The design of a thermo electric generator is developed for utilization electrical energy which is harvested from air which is heated by the exhaust pipes/chimneys of wooden fire stoves in order to light a lamp or charging a battery. The selection of number of TEG with respect to temperature difference is shown in Tables V and VI, the graphs are shown in Figs. 12 and 13.

TABLE V
CURRENT FOR TEG CONNECTED IN SERIES

		No. of Cells connected in parallel- Current in A				
Series	Temperature (^{0}C)	2	3	4	5	6
1	20	0.45	0.675	0.9	1.125	1.35
2	40	0.736	1.104	1.472	1.84	2.208
3	60	0.938	1.407	1.876	2.345	2.814
4	80	1.118	1.677	2.236	2.795	3.354
5	100	1.338	2.007	2.676	3.345	4.014

TABLE VI
VOLTAGE FOR TEG CONNECTED IN PARALLEL

		No. of Cells connected in series- Voltage in V				
Series	Temperature (^{0}C)	2	3	4	5	6
1	20	1.94	2.91	3.88	4.85	5.82
2	40	3.6	5.4	7.2	9	10.8
3	60	4.8	7.2	9.6	12	14.4
4	80	7.2	10.8	14.4	18	21.6
5	100	9.6	14.4	19.2	24	28.8

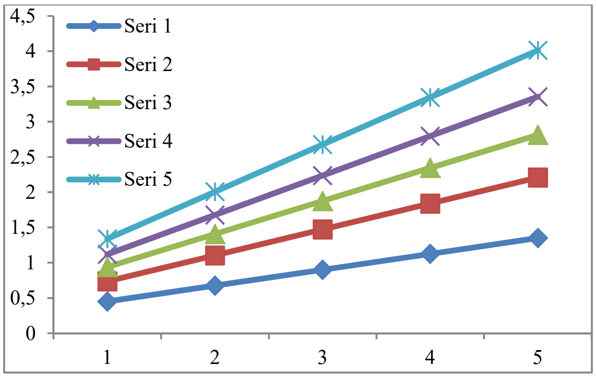

Fig. 12 Plot of current of TEG connected in series v/s change in temperature

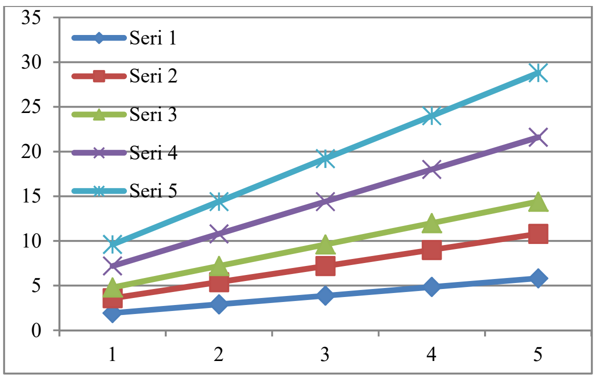

Fig. 13 Plot of voltage of TEG connected in parallel v/s change in temperature

VIII. CONCLUSION

This model is helpful to provide electrification in India, especially rural part where electricity is reach out of their hands. Increasing the number of TEG units in the installation, we may meet power demand in near future. This is one of the alternate methods of generating power by utilizing waste heat.

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