Design and Implementation of Modified P&O Algorithm for Industrial Waste Heat Recovery System Using Thermoelectric Module

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Abstract-This paper proposes a novel Maximum Power Point Tracking (MPPT) control method of thermoelectric power generation for the constant load. This paper reveals the characteristics and the internal resistance of thermoelectric power module (TM). To control the operating point & to extract the maximum power from waste heat using TEG is essential as there is a wastage of heat from Industries, automobiles etc. To fix maximum power point from waste heat, a good number of algorithms has been proposed, one of them is P&O algorithm. Analyzing the thermoelectric power generation system with boost chopper by P&O Method, the output voltage and current of TM are estimated by with only single current sensor. The basic principle of the proposed MPPT control method is discussed, and then confirmed by digital computer simulation using Matlab. Simulation results demonstrate that the output voltage can track the maximum power point voltage by the proposed MPPT control method. The comparative analysis between P&O and modified Perturb & Observe (P&O) algorithm for extracting the power from thermoelectric array TM is analyzed briefly below.

Keywords-*Maximum power point tracking (MPPT); Perturb and Observe(P&O);Thermoelectric module (TM).*

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I. INTRODUCTION

Hence there is a wide scope to utilize the waste heat by its conversion into a electricity with the advent of efficient thermoelectric generators from industrial waste heat recovery system. The thermoelectric generators have been receiving renewed interest in recent years in a wide range of applications like waste heat recovery from different sources like industries, automobiles etc. which is of a great importance in the era of growing energy crisis. In practice, many units require a power conditioner to convert the generator output to a usable voltage. The other remarkable aspect is that the input does not require any production but already available heat and the electrical energy (output) can be recycled to improve the efficiency of the system. Thermoelectric materials to improve efficiency depends upon figure of merit. [1-4]. Thermoelectric systems can be operated with small heat sources and less temperature difference from automotive waste heat recovery into electricity and heat co-generation in homes and businesses. Maximum power point tracking (MPPT) techniques are typically utilized to obtain the maximum available power. The characteristics of scalability, high reliability and free maintenance contribute the out performances of voltage and current in TEG [5-7].

Among the MPPT algorithms implemented in TEG systems, perturb and observe (P&O) and open circuit voltage (OCV) methods are the most widely used . The P&O algorithm falls under the category of a hill climbing algorithm. Hill climbing algorithms are named so due to the algorithm taking steps over sampled data to reach a desired value, in the case of the P&O this takes steps towards the MPP by increasing or decreasing the duty cycle. A boost converter with variable output voltage and a new maximum power point tracking (MPPT) scheme is proposed which improves the efficiency by 10%. [8-10].In this study, a modified P&O algorithm is proposed. Simulations and experiments are conducted to evaluate the tracking efficiency of the proposed system.

II.THEORETICAL BACKGROUND OF TM

Thermoelectric modules having efficient results in power generation and energy recycling systems without any content of toxic or pollutants, this technology is regarding as an alternative Green Technology.

Thermoelectrically materials have a nonzero thermoelectric effect. The N-type and P-type semiconductor of thermoelectric material is connected in series and parallel..For good efficiency, materials with high electrical conductivity, low thermal conductivity and high Seebeck coefficient are needed. Materials such as Bi2Te3 and Bi2Se3 comprise some of the best performing room temperature. Thermoelectric with a temperature-independent figure-of-merit (ZT), between 0.8 and 1.0 . Bi_2Te_3, this compound has been extensively used in the construction of thermoelectric modules [14].

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Let us first discuss the behavior of a material: Bismuth telluride (Bi_2Te_3) is a gray powder, that is a compound of bismuth and tellurium also known as bismuth(III) telluride. It is a semiconductor which is an efficient thermoelectric material for portable power generation. Bismuth telluride was shown to have an improved Seebeck coefficient (voltage per unit temperature difference) of −287 μV/K at 54 °C, high electrical conductivity of 1.1×10^5 S·m/m^2 with its very low lattice thermal conductivity of 1.20 W/(m·K).melting point-580deg c,1076 f,853k.

Table 1 Materials for TM

Material	T_m (K)	$(ZT)_m$
Bi_2Te_3	300	1.2
TAGS	700	2.0
PbTe	650	1.0
Si-Ge	1100	1.0
Bi-Sb	150	0.7

The efficiency of any thermoelectric (TE) material is determined by the figure of merit-ZT, which is defined as,

$$ZT = \frac{\propto^2}{\rho\lambda}(T) \qquad (1)$$

where $\propto$ is Seebeck coefficient, ρ is the electrical conductivity, λ is the thermal conductivity, and T is the absolute temperature.

The heat is transferred from hot side to cold side. By knowing the temperature difference (ΔT) & seebeck coefficient, the open circuit voltage V_{oc} can be estimated as

$$V_{oc} = \propto_{pn} (T_h - T_c) \qquad (2)$$

where $\propto_{pn}$ is the Seebeck coefficient and T_h & T_c are the temperature of the hot side and the cold side, respectively. Seebeck coefficient $\propto_{pn}$ is a property of the material utilized and also varies with temperature.

By knowing the V_{oc} and internal resistance R_{TEG} as shown in fig 1, the current can be determined. Therefore the network becomes short circuited by connecting electrical load. According to ohm's law, the load voltage V_L is expressed as,

$$V_L = V_{oc} - I.R_{TEG} = \propto_{pn} \Delta T - I.R_{TEG} \qquad (3)$$

Therefore the power generated across the short circuit can be calculated as

$$P_{TEG} = (\propto_{pn} \Delta T)^2 . \frac{R_L}{(R_L+R_{TEG})^2} \qquad (4)$$

According to the "maximum power transfer theorem", the power produced by the TEG can be maximized by matching the load resistance RL with the TEG's internal resistance RTEG, and the maximum power available is

$$P_{max} = \frac{(\propto_{pn}\Delta T)^2}{4R_{TEG}} \qquad (5)$$

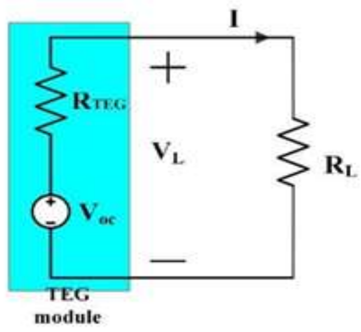

Fig. 1 Equivalent Circuit of a TEG Module

III. THE PROPOSED MODIFIED P&O:

According to maximum power transfer theorem, the output power should be higher than the input. The differences in temperature across TEGs modules are typically time-varying; hence, a MPPT algorithm is required to quickly and precisely adjust the operating condition and maximize the obtained power. For TEG systems, P&O and OCV methods are most commonly applied.

However, in P&O technique; the oscillation around the MPP deriving from perturbation is disadvantage at the steady state. Also, it is hard for P&O technique to promptly respond to the rapidly changing conditions. On the other hand, in the OCV method; the power losses takes place during measurement of V_{OC} since the tracking algorithm must suspend. In spite of the fact, alternative algorithm is employed to increasing the measurements between two methods under rapidly changing conditions & to reduce the power losses.

A. Concept

In this study, a novel MPPT technique is proposed. A novel OCV estimation method which can be utilized during normal operation is first presented. After the estimated ,It moves the output to $V_{OC}/2$ and applies the P&O process using a small perturbation step to bring the output to the real maximum power point. The proposed method features the advantages such as fast tracking time and no energy loss.

From Eq. (2), the value of *VOC* varies with temperature difference is estimated. wherelse the temperature difference remains the same during a very short time interval, the P–V characteristic curve of a TEG shown in fig 2, if the temperature difference changes, the slope of the I–V characteristic curve will also change as shown in fig 3 . Therefore, the value of *VOC* can be estimated by the I–V and P–V characteristic. Therefore, by applying two different voltage command *VX* and *VX'* to the TEG as shown in Fig. 3, two I-V characteristics can be obtained.

$$V_x = V_{oc} - I_x . R_{TEG}$$
$$V_x^{'} = V_{oc} - I_x^{'} . R_{TEG} \qquad (6)$$

From Eq. (6), the equivalent resistance R_{TEG} can then be calculated as

$$R_{TEG} = \frac{(V_x^{'} - V_x)}{(I_x - I_x^{'})} \qquad (7)$$

hence, the relationship between R_{TEG}, V_{OC} and I_x can be obtained by MATLAB simulation,

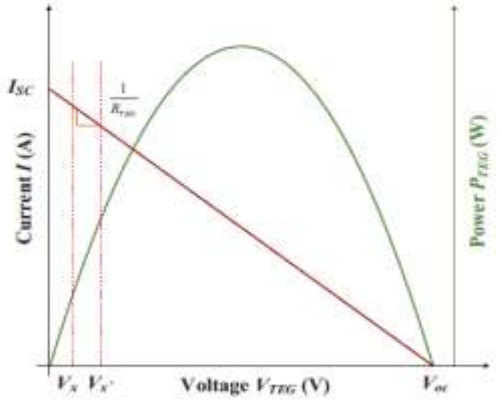

Fig. 2 The designing concept of the proposed OCV Measurement method

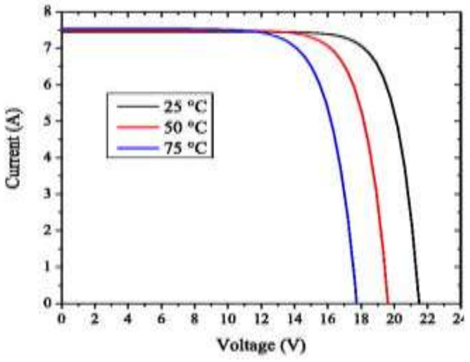

Fig. 3 I-V characteristics of the module at different temperature values

B. Algorithm

P&O is an iterative method. It senses the operating voltage periodically and compares the output power with that of the previous power; the resulting change in power (ΔP_{PV}) is measured. If ΔP_{PV} is positive, the perturbation of the operating voltage should be in the same direction of the increment. However, if it is negative, the system operating point obtained moves away from the MPPT and the operating voltage should be in the opposite direction of the increment, perturbation should be reversed to move back towards the MPPT as shown in fig 4.

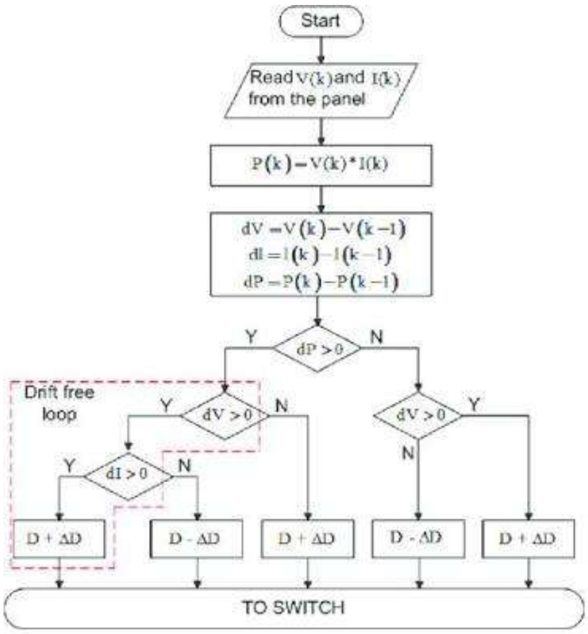

Fig. 4 The Flowchart of the Proposed MPPT method.

IV. SYSTEM DESIGN AND DESCRIPTION

The excess power of the self-powered heating system can be used to charge the other electrical units. A voltage applied between the junctions of the thermocouple creates a temperature difference between them. Depending on the direction of current flow, the junction of the two conductors will either absorb or release heat. As it can convert waste heat to electrical energy .Bismuth telluride-based materials were used. The efficiency of any thermoelectric (TE) material is determined by the figure of merit-ZT

Table 2 Figure of merit for following temperature

Zt ≥ 2	Around 800 °C	More Efficient Than Solar Energy Devices.
Zt ≥ 2	Between 300 To 500 °C	Expected To Be Very Promising F Recovery Of Energy From Low Level Heat.
Bi2Te3 In TM (ZT Peak)	1.2(At Room Temperature)	A Comfortable Ambient Temperature generally taken as about 20°C.

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MPPT is a digital devices which measures the power from TEG and maximizes it. As it links the TE array and battery, it can control the output of TM by comparing the output of battery voltage. It then decides the optimum power output which will most effectively charge the battery. The maximum power point is found at the "knee" of what is called the I-V curve

To implement the P&O algorithm, voltage and current must be known. Voltage and current sensors are placed before the boost converter and must be able to be read by the microcontroller, as explained in the voltage and current sensors section. After the voltage and current measurements are made as described in the ADC section, these values can be used in the algorithm. The power is found by multiplying the voltage and current. An initial value should be set in software for the first iteration, for example the power can equal zero. This new power value will be compared to the last power value. The voltage is then compared to the old voltage value. When an increase in module voltage is required, duty cycle should be increased. When a decrease in module voltage is required, the duty cycle should be decreased. The new voltage, current, and power values should now be saved as old values and the cycle is repeated. The increment at which the duty cycle should be changed should be set in software. If the increment is large, the algorithm will overshoot the actual maximum power point and will continue to overshoot around this point. One advantage of this is that it can find the estimated power point quickly, which is beneficial for fast changing environments, but is less efficient in slow changing environments. By setting the increment small, the algorithm will take much longer to find the maximum power point, but will not overshoot this point as much. This is optimal for slow changing environments.

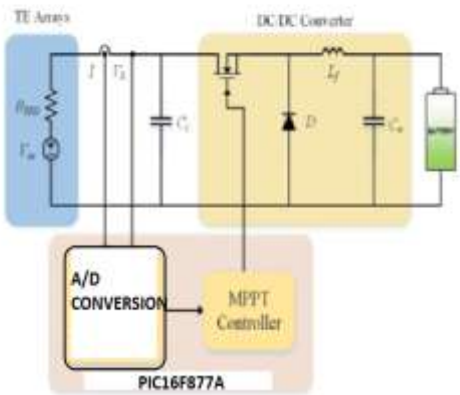


Fig. 5 The proposed MPPT converter

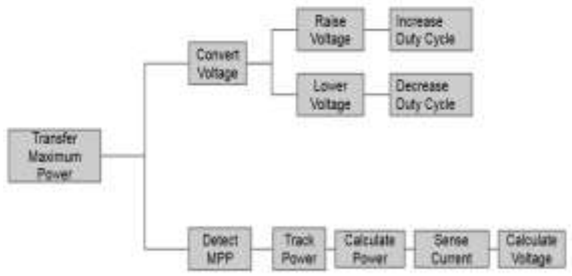


Fig. 6 The Parameters Utilized for TEG module

V. SIMULATION AND RESULTS

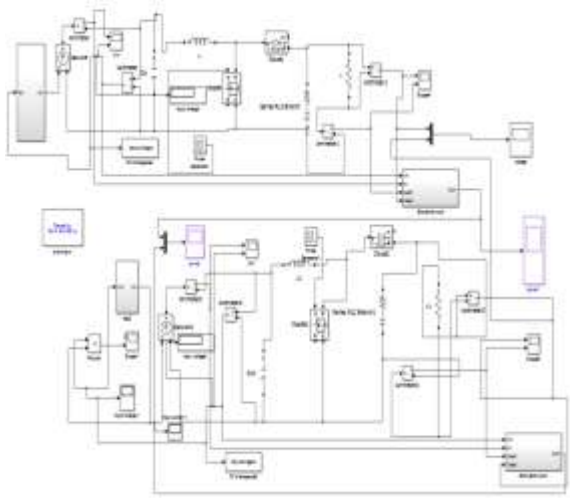
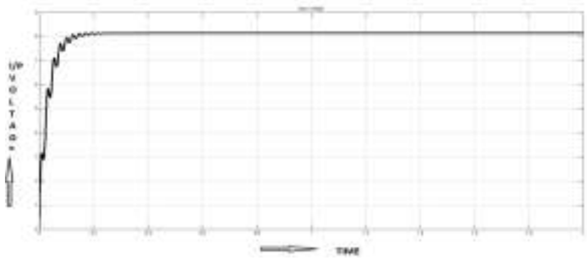
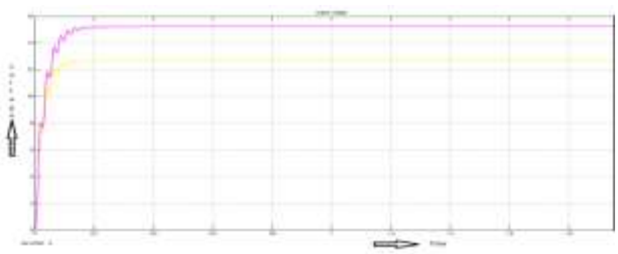


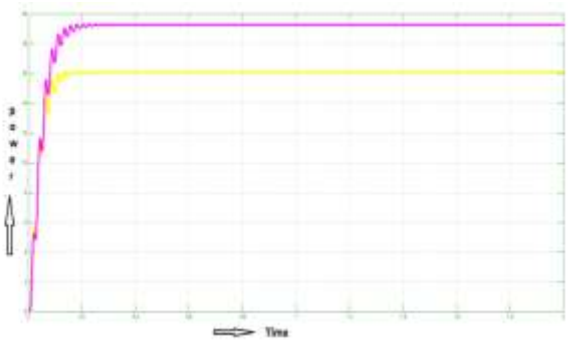
Fig 7 Simulation of Modified P&O Algorithm



(a) input voltage



(b) output voltage



(c) load power with increase in efficiency

Fig. 8 System Parameters (a) Input voltage (b) Output Voltage (c) Load Power

Table 3 Summarized Simulated Performance Of The Compared MPPT Methods

VALUES	EXISTING P&O	PROPOSED P&O
Rise Time	0.02-0.4secs	0.01-0.23 secs
Steady Time	0.4 secs	0.25 secs
voltage	12.68v	15.02v
Power	16.09 watts	19.25 watts
Tracking Efficiency	91.81%	92.88%
	Increase with 1.07%	

VI. CONCLUSION

The implementation of hardware has been designed as a prototype model and it is being in process. From simulation results, Considerable amount of power can be produced from the exhaust heat for constant load with increased efficiency and performance. In this paper, we combined the strength of Open Circuit Voltage & P&O methods of MPPT to extract maximum power from waste heat to run a constant load. The Simulation results proves that the power increase with tracking efficiency of 1.07%.

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