Open Circuit Voltage Based MPPT Tracing For Thermoelectric Generator Fed Non-Inverting Synchronous Buck-Boost Derived Converter – Part II (Hardware Studies)

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ABSTRACT

Thermoelectric generator [TEG] devices are advantageous technique to extract the waste heat. This works based on the principle of See-beck effect, where an electromotive force will be generated when the junction of two dissimilar metals are experience a temperature difference. The overall efficiency of these modules are low, but advantages of being small, lightweight and this is easy to maintenance free, make it an attractive addition to applications where energy per unit weight or size is a primary factor. Among the key problems is obtaining a consistent voltage to power devices which depend on a consistent voltage more than maximum power. The open circuit voltage (Voc) based on MPPT algorithm is proposed here and this is well suitable for the linear electrical characteristic of the TEGs model. This experiment goal is to evaluate the thermoelectric (TEG) modules performance when connected to a non-inverting synchronizes buck-boost convertor, taking into account of this: input and output voltage, current and power, as well as convertor efficiency against various temperature differences. The experimental trial rig is using TEG module connected in series to a 0.4-5V to 5V buck-boost convertor. The hot side of the TEG module are heated via a heating blocks while the cold side are cooled by using water cooling blocks respectively. The experimental Testing is showed that at a temperature difference of 72˚c, the input voltage and current of 1.78V and 0.79A are increased and reduced respectively to 4.16V and 0.16A. At a temperature variance of 145˚c, the input voltage and current of 3.09V and 0.79A are raised and reduced respectively to 5.15V and 0.67A. From this test is also noted that the overall efficiency of the proposed converter increases along with temperature variance, ranging from 64% at 72˚c to 98% at 145˚c. The conversion procedure is also more efficient in case of the input voltage is near to the preferred output voltage.

Keywords—Thermo electric generator (TEG), MPPT, Open-Circuit Voltage, DC-DC, Buck-Boost Converter

1. INTRODUCTION

Thermoelectric generator (TEG) [1] is a solid-state energy device which is converts waste thermal into electricity. Generally it contains of an arrangement of 2N pellets from p and n type semiconductor substantial that sort up N thermoelectric couples. [2] These models are combined thermally in parallel and electrically in series respectively. The Thermoelectric models can be used for cooling, heating, and power generation. As a thermoelectric cooler (TEC), the TEM has found applications in thermal management and control of microelectronic devices such as diode lasers and CPUs. As a thermoelectric generator (TEG), the TEM could be used to produce the electric energy in isolated places when temperature grades are available.
Due to moderately high price and less efficiency the use of thermoelectric generator have been prohibited in the areas of such as in medical, telecommunication, army, remote control, and space applications [3]. But in current centuries, due to the increasing ecological problems and power price is encouraged examination into alternate commercial techniques of producing the electrical energy. TEG can be applied in different applications. Often, the thermoelectric generators are used in low power remote applications or where huger but extra effective thermal engines that is vehicle engines is not be probable. Unlike thermal engines, a solid state of electrical modules characteristically used to achieve heat into electric power, this are not consist of any moving parts. Fundamentally have more reliability of this devices, it marks the TEGs good suitable for equipment with less to ambiguous energy wants in isolated unoccupied or unreachable localities that as vacuum of space. One of the effective solutions is to convert waste thermal into electrical energy with TEG [4].

The magnitude of the TEG’s open-circuit voltage [5] is directly proportional to the temperature difference, as detailed in principle effect of see-beck effect. TEG’s model can be connected either in series or parallel in order to achieve the preferred levels of voltage and current respectively. In order to connect TEG to the power electronic converters,[6] such as buck, boost or buck-boost converters are commonly used. The choice of converter topology is be influenced by on the voltage of input and outputs; for illustration, for connection to dc micro grids a high step-up gain converter is used, while for connection to a 12-V car battery a Buck or Buck–Boost type can be used. In this paper we are using a non-inverting synchronous Buck-Boost converter [7], [10] to guarantee a extensive input voltage range and subsequently harvest the energy from the TEGs over a various range of operative temperatures respectively.

2. PRINCIPLE OPERATION OF THERMOELECTRIC GENERATOR

Thermoelectric generators (TEG) are devices which are able to convert thermal (temperature variation’s) into electrical energy, by using a principle is called the Seebeck effect (a form of thermoelectric effect). There are mainly five important physical methods take place in a TEM [3] model that are heat convection, Seebeck energy generation, peltier cooling and Thompson effect respectively. A thermoelectric produces electrical power from thermal flow across a temperature gradient. As the heat flows from hot to cold, free charge carriers (electrons or holes) in the material are also focused towards the cold end as shown in fig. 1. The causing voltage (V) is directly proportional to the temperature variance (ΔT) through the Seebeck quantity, α, (V = αΔT). As shown in fig.1, every voltage adds up as in connection serially and whenever a load is joined to the TEG’s terminals, current moves from hot to cold side respectively. The flowing of this current harvests thermal by Joule heating and drives extra thermal from hot to the cold side it’s happened because of the Peltier influence, this is an effective technique in power generation. A large load current magnifies the effect of Peltier, which is rises the clear heat conductivity of the model which in turns reductions the temperature variance ΔT.

![Fig. 1 Schematic Representation Of TEG Model](image_url)
3. MPPT METHOD

In this paper, we focused on the maximum power point technique by using open circuit voltage algorithm. Normally TEG has less efficiency so need to boost the efficiency by implementing this technique. It is observed of Electrical features of TEG; the maximum power can be obtained at half of the open circuit voltage. So maintain the every time that half of the open circuit voltage then gets maximum power from the TEG it is a challenging task for maintaining that voltage. For that reason we design a DC-DC synchronize buck-boost converter and DCD snubber circuit. By using this circuit we can maintain every time half of the open circuit voltage. The open- circuit voltage of TEG’s set at a load half of the open-circuit voltage. In this method the converter can be disconnected from the TEG and generally requires an input capacitor. The input capacitor of converter has to be charged up to open-circuit voltage during that time output power is null collected. The input capacitor is chosen in the order of tens of microfarads, so as to maintain the RMS current which means the output capacitor may need hundreds of microseconds charged up to reach the open-circuit voltage and this one depends on the internal resistance (Rint). Sometimes disconnect the TEGs from the converter; an extra series switch is needed. This series switch needs to be in continuous conduction period for longer time, for this required high side gate drive circuit. Additional losses are presented in switch with ON time. And switch ON time is interrupting the normal operation of converter. The measurement is taken in every time of switch ON.

3.1 MPPT Converter

This section presents non-inverting synchronous Buck-Boost DC-DC converter which is shown in schematic diagram of the complete system in fig 2.where TEG is represented by a voltage source $V_{OC}$ an internal resistance $R_{int}$ and a parasitic inductance $L_p$.the proposed innovative DCD snubber is connected across the input of the synchronous Buck-Boost converter to supress the overvoltage transients The converter supplies a power to the battery and electronic load. A microcontroller measured the input and output voltages, to calculate the MPPT algorithm and controls the gate drives of the converter’s MOSFETs.

3.2 Operation Principle Of The Converter

The circuit diagram of proposed synchronous buck-boost converter are shown in fig 3.
This is consisting of three switches, two diodes, two capacitors and single inductor. Here the converter takes place four various operations at each period of cycle. The gate pulses of switches can be calculated by sequence of switching in circuit which is shown in below.

![Diagram of Switching Sequence in Single Switching Time](image1)

**Fig. 4** Switching Sequence in Single Switching Time

### 4. HARDWARE EXPERIMENT

The hardware diagrams of proposed model are shown in below diagram

![Block Diagram Of Hardware Model](image2)

**Fig. 4** Block Diagram Of Hardware Model

Where TEG model are connected across the MPPT boost converter which are run by driver circuit. For driving this converter we are supplying DC power to the MPPT controller followed by driver circuit respectively. The temperature monitor control regulates the various range of temperatures obtained from the thermoelectric generator. Variations on supply heat to TEG produced the different range of temperature this are simultaneously displayed on liquid crystal display (LCD). The PIC microcontroller controls the buck-boost converter with respect to driver circuit. Once the experimental operation is get over the obtained output voltage is stored in battery.

![Input Side Warm Supplying To The TEG](image3)

**Fig. 5** Input Side Warm Supplying To The TEG
Fig. 6 Water Cooling Setup To Make The TEG Device Is Cool

Fig. 7 MPPT Converter, Driver Circuit Setup

4.1 Experimental Results

The obtained result from different temperatures are shown in below table 1.

<table>
<thead>
<tr>
<th>T-Hot side</th>
<th>T-cold side</th>
<th>$V_{in}$ (v)</th>
<th>$I_{in}$ (a)</th>
<th>$P_{in}$ (w)</th>
<th>$V_{out}$ (v)</th>
<th>$I_{out}$ (a)</th>
<th>$P_{out}$ (w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>135.3</td>
<td>38.1</td>
<td>4.09</td>
<td>0.79</td>
<td>3.21</td>
<td>5.14</td>
<td>0.62</td>
<td>3.18</td>
</tr>
<tr>
<td>118.6</td>
<td>36.20</td>
<td>3.51</td>
<td>0.65</td>
<td>2.28</td>
<td>4.8</td>
<td>0.52</td>
<td>2.49</td>
</tr>
<tr>
<td>102.4</td>
<td>31.5</td>
<td>2.85</td>
<td>0.59</td>
<td>1.68</td>
<td>4.53</td>
<td>0.42</td>
<td>1.90</td>
</tr>
<tr>
<td>83.2</td>
<td>29.01</td>
<td>2.81</td>
<td>0.51</td>
<td>1.41</td>
<td>4.24</td>
<td>0.26</td>
<td>1.10</td>
</tr>
<tr>
<td>71.7</td>
<td>26.6</td>
<td>1.7</td>
<td>0.46</td>
<td>0.78</td>
<td>3.9</td>
<td>0.21</td>
<td>0.81</td>
</tr>
</tbody>
</table>

Fig. 8 The Input Side Obtained Voltage With Respect To Temperature
Output side obtained voltage are shown in below snapshot

![Figure 9](image_url1)

**Fig. 9** The output Side Obtained Voltage With Respect To Temperature

![Figure 10](image_url2)

**Fig. 10** The Buck-Boost Output Switching Waveform

### 5. CONCLUSION

This paper presents an effective way to harvest the waste heats which are ejected from engines and numerous other sources in day to day life. The MPPT algorithm is programmed to a low-price PIC microcontroller and for this does not required costly sensors. A DC–DC non-inverting synchronous Buck-Boost converter is proposed here, this converters can able to operate in either Boost mode, Buck-Boost or Buck mode respectively from this we can harvest the energy over a extensive range of temperature alterations across the thermoelectric generator. The presented MPPT system was tested both under steady state and transient conditions with real TEGs, demonstrating its ability to set the optimum electrical operating point quickly and very accurately. It is able to harvest close to 100% of the MP that can be produced by the TEG in the steady state and 98.7% during thermal transients. Therefore in Future work will focus on comparing the proposed MPPT method to other MPPT algorithms for TEG devices.

### REFERENCES