Thermoelectric Generator power supply

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Abstract:

The main motivation for this project is the growing awareness for necessity of alternative energy sources that will take advantage of natural processes, the reasons for searching this alternatives lies in the fact that concentration of fuel sources such as oil, gas and coal (which are the main energy source's in the last 100 years) running out in nature, and there is a great awareness of the pollution generated in there extraction.

Our project focused on electrical energy extracted from Thermo electric elements. The main goal was to design and construct a DC-DC converter for Thermoelectric cell when the main characteristics are input voltage around 0.5[V] and the ability to provide a current of up to 5[A].

First we conducted a broad research for solutions that have been tried in the field of low voltage converters, and our conclusion was that is not yet found a serious solution for working with such ultra low input voltage.

Our converter is based on the Push-Pull topology, when the main goal is to convert the input voltage generated by the generator to a voltage of around 24[V], when it is known that this voltage level is relevant for a large number of applications.

The main emphasis was on building a small, cheap, and efficient converter. Where The main challenge was to maintain high efficiency, when it is well known to be hard in this range of input voltages.
Final topology:

![Figure 1: Final scheme of the converter](image)

As we can see the output consists of two capacitors connected in series, each half period only one is charged, and the output voltage is the sum of both capacitors voltages, this configuration allows us to reduce twice the windings ratio between primary to secondary in the transformer and thereby allows us to use smaller Magnetic body, the values of capacitors are selected emphasis on maintaining a low output voltage ripple.

Coils: $L_{ikg}$ $L_m$ are parasitic parameters of the transformer which we tried to control in the design process. Another advantage of this circuit is the absence of an output coil, that as we know taking up large space.

while switching we get high voltage changes on the capacitors at the exit and as a result we risk in high current, the $L_{kg}$ inductance of the transformer at the exit is designed so that it will absorb the high voltages and will allow a smooth transfer of energy to the output.

In this topology there is no reference to the problem of $L_{ikg}$ inductance (this inductance represents the total flux that is not shared between primary and secondary coils and is represented by serial inductance, when the values of these coils reach high values it is impossible to ignore them and their presence can dramatically impair circuit operation, the problem occurs in the “dead” time between switching, every half period one of the coils gaining energy, when one of the transistors is turning off a resonance circuit formed between the coil and capacity of the switch and large voltages picks can be appear on the drain side, this phenomenon can destroy the switch, as well as reduce the overall efficiency of the converter.) we tried to address the problem by creating a physical short route as possible between the transformer terminals and switches.
<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>input voltage</td>
<td>0.2-0.8[V]</td>
</tr>
<tr>
<td>input current</td>
<td>0.5-5[A]</td>
</tr>
<tr>
<td>Maximum input power</td>
<td>2.5[Watt]</td>
</tr>
<tr>
<td>Efficiency</td>
<td>75%-90%</td>
</tr>
<tr>
<td>Output voltage ripple</td>
<td>50[mV]</td>
</tr>
<tr>
<td>Maximum output voltage</td>
<td>40[V]</td>
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<tr>
<td>Maximum output current</td>
<td>0.1[A]</td>
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<tr>
<td>Working frequency</td>
<td>50[KHz]</td>
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<tr>
<td>Duty_Cycle</td>
<td>48%</td>
</tr>
</tbody>
</table>

Table 1 Technical Specifications

Figure 2 the converter that was build
Figure 3: Output voltage and input current for different loads

Figure 4: Efficiency and output power for different loads
Analysis of the results:

- **Efficiency and Power**: from the graphs above we can see that for loads of the order of 0.4 to 1.4 [KΩ] the efficiency was 80%-90%, the problem with these loads is that we don’t use the full capacity the generator can supply 2 to 2.5 [Watt]. (large values of loads force low entry currents, so for the same input voltages we get various output power). We can see that for a load of about 0.2 [KΩ] the input current got up to 5 [A], and for the input voltage of 0.5V the power transferred to the load was almost 2 [Watt]. The efficiency for this load was lower than the rest because the total power increased significantly and higher current flowed into the system, but despite the decrease in efficiency the total power transferred was significantly higher, and therefore the decision about optimal load should consider the amount of current the generator can provide, and the maximum current the circuit can handle with.

- **Output**: The initial conversion ratio we requested was from 0.5 to 24 [V] did not succeeded, but it was expected, because the demand didn’t take into account not ideal elements, but still the conversion ratios are very good, and for input of 600 [mV] for most loads output voltage stabilized at around 24 [V]

**Figure 5** input current: Simulation results with practical results
Measurements with the TEG:

we connected a thermo electric generator (TB-32-2.8-1.5, KRYOTHERM) to our converter and made measurements, the generator was operated by connecting one side to panel with large power resistors which heated by high current, and the other side cooled by a fan to make a significant temperatures difference. measurements were carried out for different loads to check for which input resistance values the power supplied to the output was maximal, the measurements made in the laboratory showed that the serial resistance of the generator is about 0.2 [Ω]. As expected the maximal power delivered when the input resistance (Rin) was equal to the generator’s internal resistance (Rt).

![Diagram of TEG setup](image)

**Figure 6** input and output power as function of Rin

As we can see that maximum power delivered to converter entrance achieved for Rin= 0.2 [Ω], however the maximum output power was for input resistance of 0.25 to 0.28 [Ω] the reason for these result is that high voltage and low current are increasing the total efficiency of the system.
Power losses distribution

- $P_c = R_{E	ext{CR}} I_{\text{rms}}^2$, ESR of the capacitor losses.
- $P_D = V_d I_o + R_{on} I_o^2$, losses as result of the voltage drop on the diodes.
- $P_{fet} = R_{d(on)} I_{mos}^2$, $R_{ds(on)}$ losses.
- $P_{R11} = R_{11} I_{\text{rms}}^2$, losses as result of primary windings resistance.
- $P_{R12} = R_{12} I_{\text{rms}}^2$, losses as result of secondary windings resistance.
- $P_{ikg} = \frac{I_{\text{pk}} I_{\text{max}}^2}{2} f_s$, losses as result of leakage inductance.
- $P_v = 1.5 \times 10^{-6} f^{1.3} (\Delta B)^{2.5} 10^{-6} A_e L_e$ iron losses.

![Figure 7 power losses distribution for 0.590[V] input and $R_{load}=530\,\Omega$](image)

<table>
<thead>
<tr>
<th>$P_{cin}$</th>
<th>3.4[mW]</th>
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<tbody>
<tr>
<td>$P_D$</td>
<td>47[mW]</td>
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<tr>
<td>$P_{fet}$</td>
<td>6.7[mW]</td>
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<tr>
<td>$P_{R11}$</td>
<td>15.1[mW]</td>
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<tr>
<td>$P_{R12}$</td>
<td>2.7[mW]</td>
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<tr>
<td>$P_{izg}$</td>
<td>32[mW]</td>
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<tr>
<td>$P_v$</td>
<td>17.4[mW]</td>
</tr>
<tr>
<td>$P_{co}$</td>
<td>0.2[mW]</td>
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