

Comparison of Thermoelectric Generator with Boost Converter and Single-Ended Primary-Inductance Converter



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Abstract Thermoelectric generator (TEG) is a clean and noiseless renewable energy source from heat source, and it can become an alternative way of generating electricity consciously. Building a thermoelectric generator converter can consist of different parts. In this research, we are studying the difference of using boost converter with single-ended primary-inductance converter (SEPIC) with the thermoelectric generator system. The contribution of the study is to determine the performance of TEG using different topology. It is done using a simulation using Matlab Simulink with varying temperature flux and load resistance. Varying the temperatures can give a consistent output, while varying load resistance by increasing can lower the performance of the thermoelectric generator system. It can also be seen that the settling time increases when the load increases. The performance of the boost converter (98.7% efficiency) is better than SEPIC (97.4% efficiency), but it is also according to the designer's desired outcome. The output can also be manipulated by having different settling time by designing the load resistance value.

Keywords TEG · SEPIC · P&O · Boost converter · Matlab/Simulink

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1 Introduction

People are looking for an alternative way of generating electricity without depleting Earth's resources. Thermoelectric generators (TEG) can be the solution for that as it would produce electricity that is clean and noiseless without any moving parts [1]. TEG is a semiconductor device that converts temperature flux between surfaces into electrical energy directly [2]. There are many different parts inside a TEG for it to work efficiently.

With many different parts into a TEG, there can be many different variations that could be made. In this research, we are going to implement the most widely known maximum power point tracking (MPPT) algorithm which is "Perturb & Observe" (P&O). The MPPT is important as it tracks the maximum power point and minimizes impedance imbalance of the DC-DC converter that is being used [2].

The research in this area is commonly focused on using boost converter only. However, the study on the type of converter used for the TEG converter is still new. Since single-ended primary-inductor converter (SEPIC) is good in other application, the performance may improve if the SEPIC converter is used in TEG converter, instead of boost converter. Boost converter is known as a step-up converter with voltage output in excess of the voltage input [3]. SEPIC can be both step-up and step-down converter and instead of the output being inverted such as buck-boost converter, the outcome of this is positive.

This paper analyzed the performance of TEG converter using SEPIC converter. The performance is then compared with the boost converter. In this research, we are going to see which converter is better or if there are even any differences in performances at all. In next section, the methodology of the TEG model and MPPT is shown. Next, the design of both boost and SEPIC converters is discussed. Then, the results of the simulation are illustrated and discussed. The last section is the conclusion.

2 Methodology

Matlab Simulink is used in order to run this research. Only simulation is done and no hardware components are used. For the TEG, the power we want to achieve is not low. As mentioned in future work in [1], it is to run the experiment using a practical sized TEG which is better presented in [2].

In order to get a better understanding of a TEG system and what it consists of, it can be referred to Fig. 1. The block diagram shows the full system and what needs to be realized in order to get the desired outcome. In this research, the manipulated variable would be the temperature of the hot source and load resistance R_L .

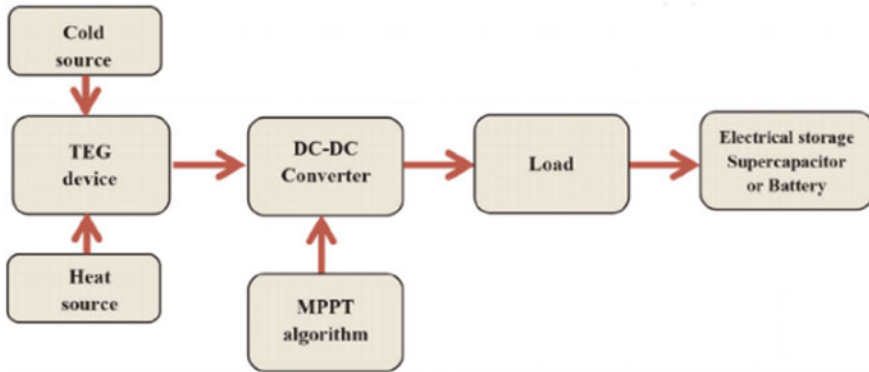


Fig. 1 TEG block diagram [4, Fig. 7]

2.1 Thermoelectric Generator Device

As mentioned earlier, we wanted to have a TEG device that is practical. Having a singular TEG module can only obtain low power [2]. The design of the TEG device has been modified. The modules are arranged in series and parallel so that it could produce a higher power with the total internal resistance, R_{int} , becoming 7Ω . Figure 2 shows the modules in parallel.

From the left side of the figure we can also see the hot surface temperature (T_h), cold surface temperature (T_c), Seebeck coefficient and also module in series. The values for T_h , T_c and Seebeck coefficient are set by TEG properties manufactured by TEG thermoelectric systems as referred in [2].

2.2 P&O MPPT

Discussion of the best MPPT algorithm is still an ongoing research for people in the field of power electronics. The most common one that is being used right now is P&O. This is due to the effectiveness and simplicity of the algorithm. Figure 3 shows the flowchart of the P&O algorithm. It is very helpful in writing the code that is needed.

The P&O MPPT calculates the power of the TEG device by taking the current and voltage value of the current time and also the previous time. From there, it would compute whether the duty cycle needs to increase or decrease, it depends on the graph that can be seen in Fig. 4.

Figures 5 and 6 present the subsystem inside the Simulink that shows where and how the P&O coding is implemented into the TEG system.

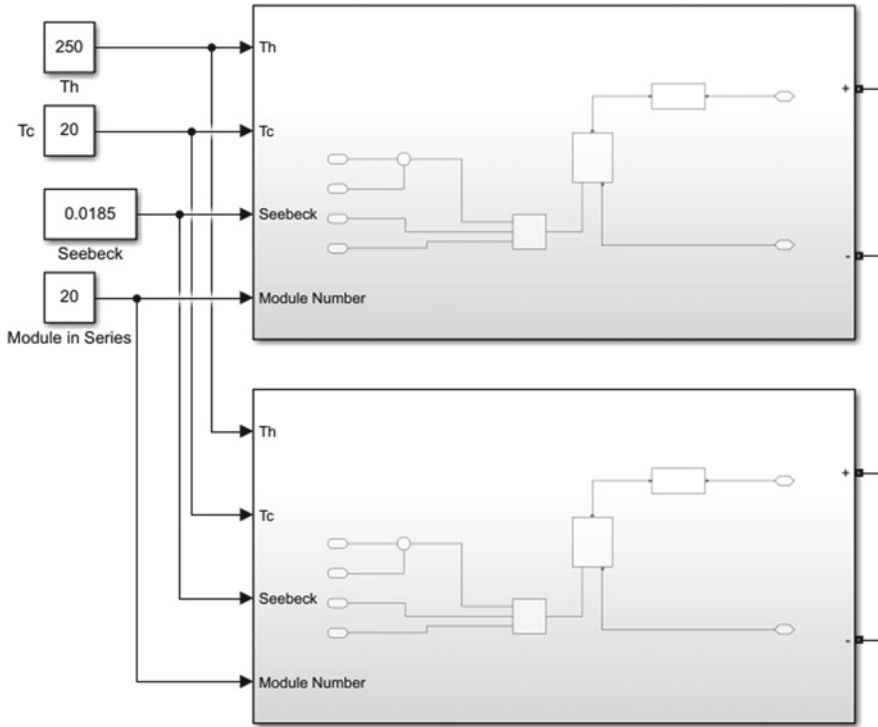


Fig. 2 TEG modules in parallel

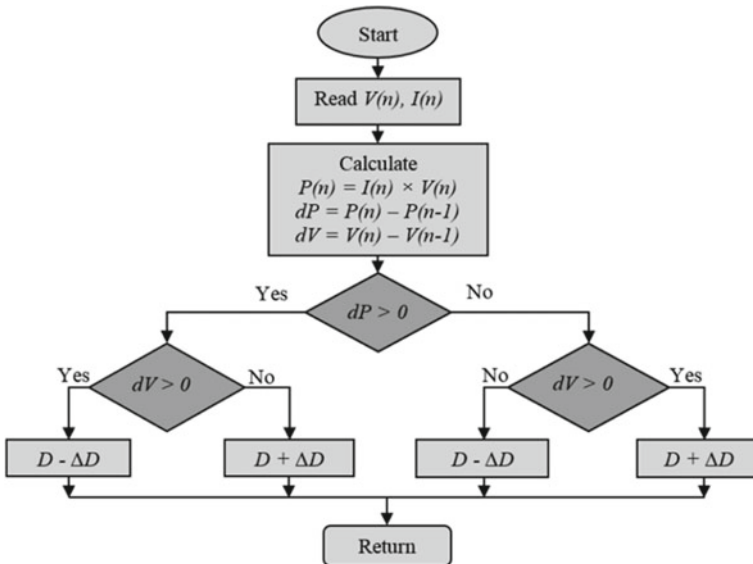


Fig. 3 Flowchart of P&O algorithm [2, Fig. 2b]

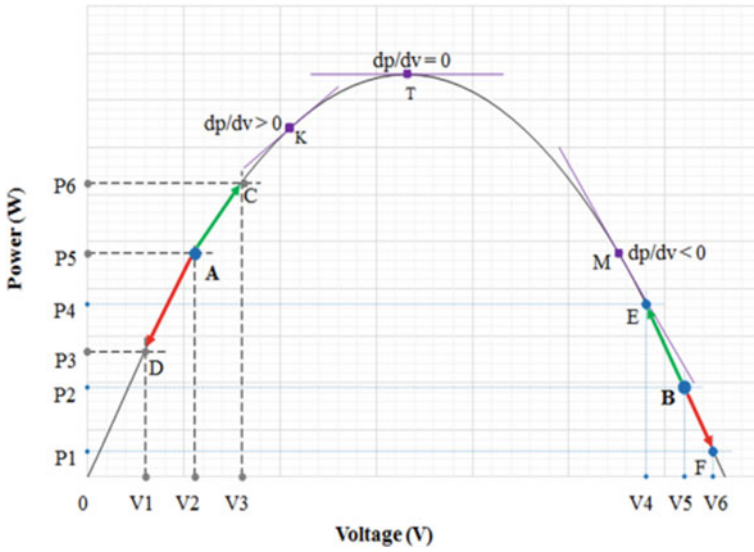


Fig. 4 MPPT graph principle [2, Fig. 2a]

Fig. 5 Subsystem of P&O MPPT

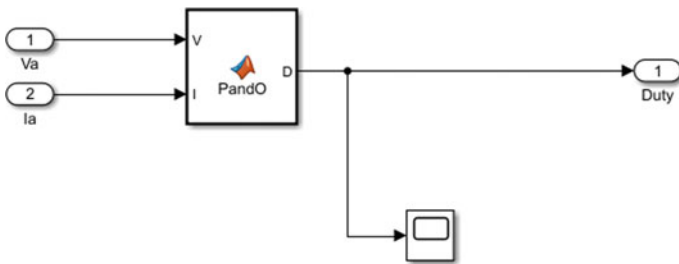


Fig. 6 Inside the subsystem of P&O MPPT

3 DC-DC Converter

There are many different converters that are available to be used inside a TEG system. The two converters that are being used in this research are boost converter and SEPIC converter. Both will go head-to-head by varying the T_h and R_L .

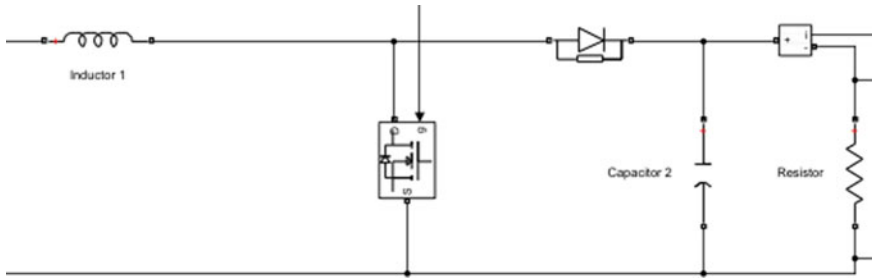


Fig. 7 Boost converter in simulink

3.1 Boost Converter

Boost converters are known to step up the voltage. Using the converter would give an output that is higher than the input voltage. It is ideal for generating a bigger voltage with a small source and easy to control and is efficient [5].

One factor that could decrease the efficiency of the converter is the high input current. An option to reduce ripple current is to make it operate in continuous current mode (CCM), but this would increase the weight and volume of the converter [6].

As we can see from (1), i.e. the ratio for boost converter where we can see what desired outcome we want to achieve. V_{out} is the output voltage, V_{in} is the input voltage and D is the duty cycle. The MPPT manipulates the D of the converter to the maximum power point needed at the moment of time. Therefore, it keeps changing according to the P&O algorithm.

$$V_{out}/V_{in} = 1/(1 - D) \quad (1)$$

Figure 7 shows the Simulink circuit for the boost converter. It consists of an inductor, with a MOSFET as the semiconductor, a diode and also capacitor. The values for each components are $L = 1$ mH, $C = 3000$ μ F and MOSFET with a snubber resistance of $R_s = 1$ M Ω . The MOSFET is connected to the subsystem of P&O MPPT as in Fig. 5. What the P&O MPPT does is, it generates duty cycle in and creates switching signals for converter [7]. Figure 8 shows the whole TEG system with boost converter.

3.2 SEPIC

The single-ended primary-inductor converter is similar to both buck-boost and boost converter. It is identical with buck-boost in terms of output, as it can be both step up and step down. The upside of SEPIC over buck-boost converter is the output is not

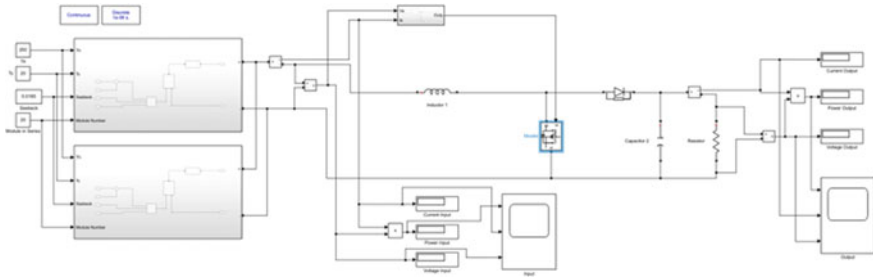


Fig. 8 TEG system with boost converter

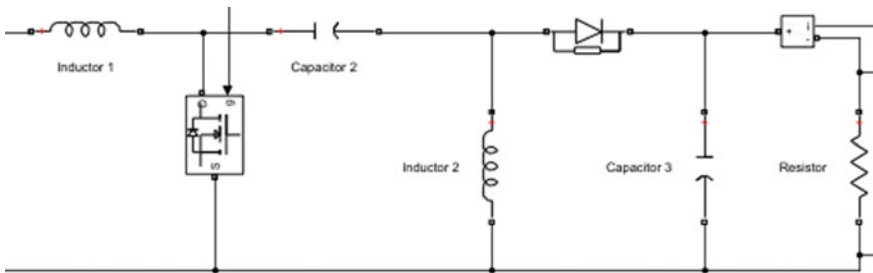


Fig. 9 SEPIC in simulink

inverted. It is akin to a boost converter in its structure, but with adding a buck-boost converter after it.

Figure 9 shows the SEPIC inside the Matlab Simulink. There are a total of two capacitors, two inductors, MOSFET and diode. The values for each components are $L1 = L2 = 5 \text{ mH}$, $C2 = 300 \text{ }\mu\text{F}$, $C3 = 470 \text{ }\mu\text{F}$ and $R_s = 1 \text{ M}\Omega$. Similar to boost converter, MOSFET is connected to the P&O MPPT subsystem as in Fig. 5, small source, easy to control and is efficient [5].

The reason why MOSFET is chosen for both of these converters is because it has low gate threshold voltage that allows better compatibility with microcontrollers and lower power requirements.

SEPIC's duty cycle ratio is known in (2). The principle of it is similar to boost's which is the duty cycle is manipulated using the P&O MPPT algorithm. Figure 10 shows the whole TEG system with boost converter.

$$V_{\text{out}}/V_{\text{in}} = D/(1 - D) \tag{2}$$

The use of SEPIC is also known to have less electrical stress on components that can result in device failure and overheating [8].

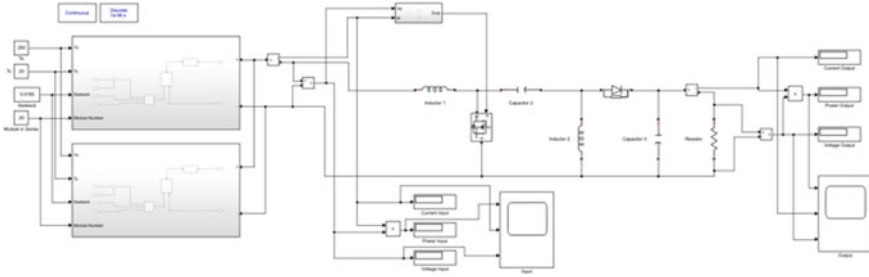


Fig. 10 TEG system with SEPIC

4 Results and Discussion

Since the scope of this research is simulation, the results gotten are also coming from the simulation of Matlab Simulink. Manipulated variable that is mentioned was temperature of T_h and resistance R_L . The experiment done was that when the T_h is differing, the R_L is kept the same and vice versa. The values are $T_h = 30, 80, 100, 150$ and $250\text{ }^\circ\text{C}$ and $R_L = 3, 7, 20, 80$ and $100\ \Omega$.

4.1 TEG with Boost Converter Waveforms

The waveforms that are illustrated have the manipulated variable of $T_h = 250\text{ }^\circ\text{C}$ and $R_L = 7\ \Omega$.

Figures 11 and 12 show the simulation on the Matlab Simulink. From the waveform, we can get the settling time, $T_s = 0.038\text{ s}$ for the power of output. The efficiency of the TEG system for this particular variable is also very good which is 100%. Even though 100% efficiency is not possible, this is fine because we wanted to get the waveform for this section. The different efficiencies will be tabulated in the later section. This may be due to the similar resistance value of internal resistor inside the TEG module and with the R_L .

4.2 TEG with SEPIC Waveforms

The waveform that is illustrated has the manipulated variable of $T_h = 250\text{ }^\circ\text{C}$ and $R_L = 7\ \Omega$.

Figures 13 and 14 show the simulation of SEPIC. From the waveform, we can see that settling time, T_s , is around 0.076 s . The settling time is more than for boost converter. This may be due to the values of the inductors and capacitors, but it is still acceptable and very fast in terms of itself, rendering it useful for the industry. The

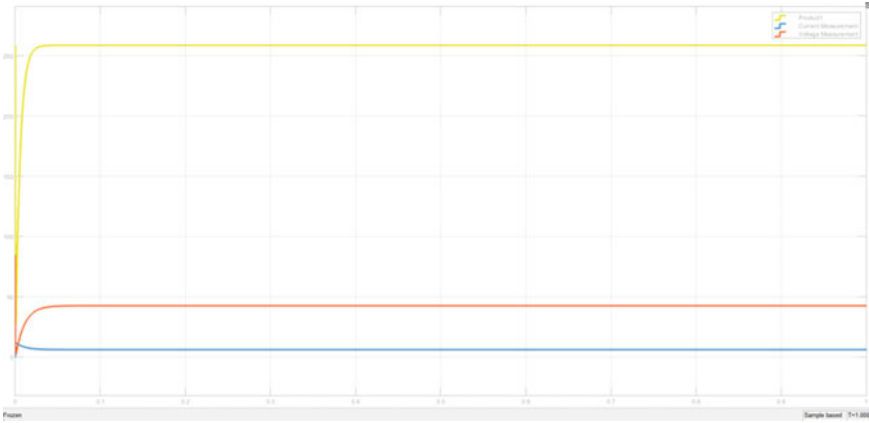


Fig. 11 Input graph simulated for boost converter

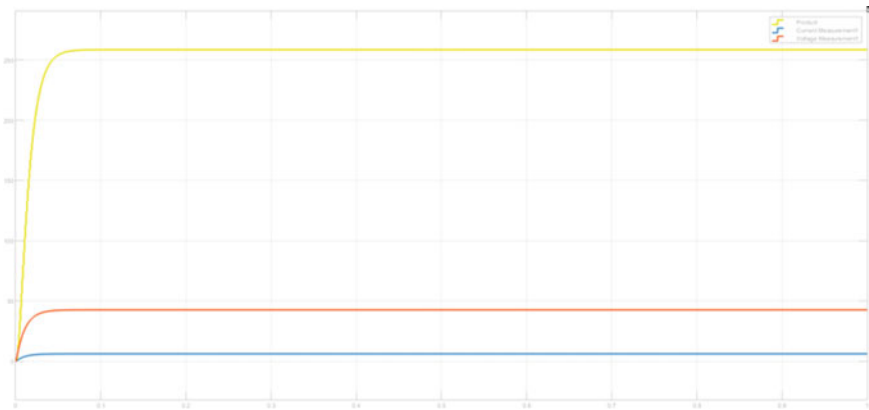


Fig. 12 Output graph simulated for boost converter

efficiency for this particular variable is 97.21% which is quite high and acceptable value. When the output graph is zoomed in, as shown in Fig. 15, we can see the ripple voltage. It sways between $V_{\max} = 260.8 \text{ V}$ and $V_{\min} = 247.1 \text{ V}$.

4.3 Tabulation of Simulation

The simulations were not only tapped into an oscilloscope, but also with the readings. The readings are then tabulated into four different tables which show the efficiency of each converter with different T_h and R_L .

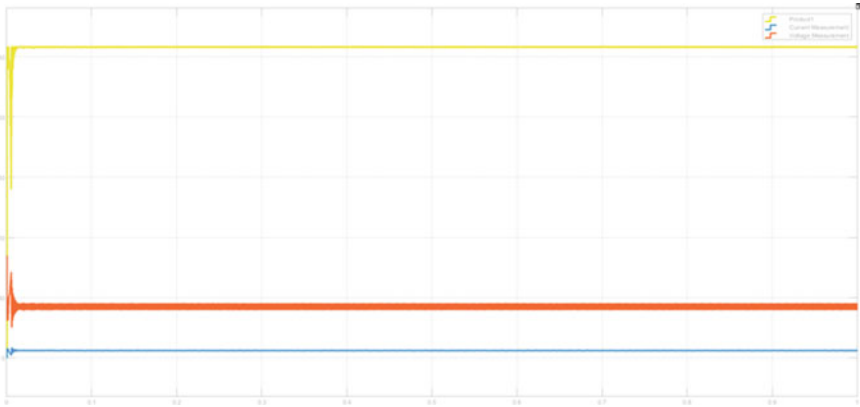


Fig. 13 Input graph simulated for SEPIC

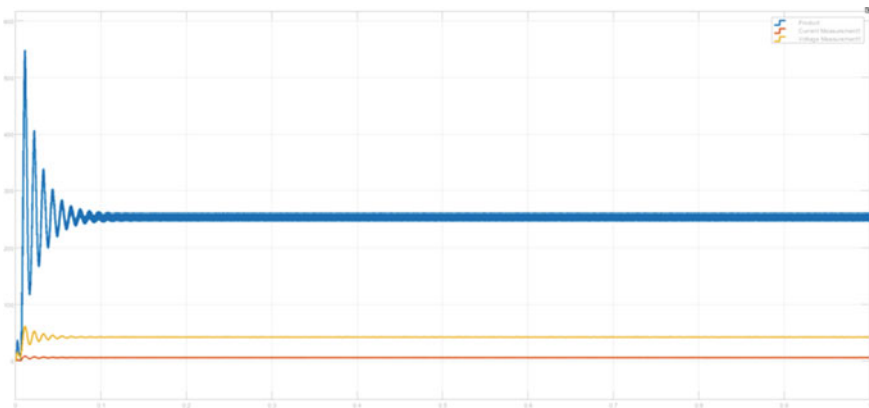


Fig. 14 Output graph simulated for SEPIC

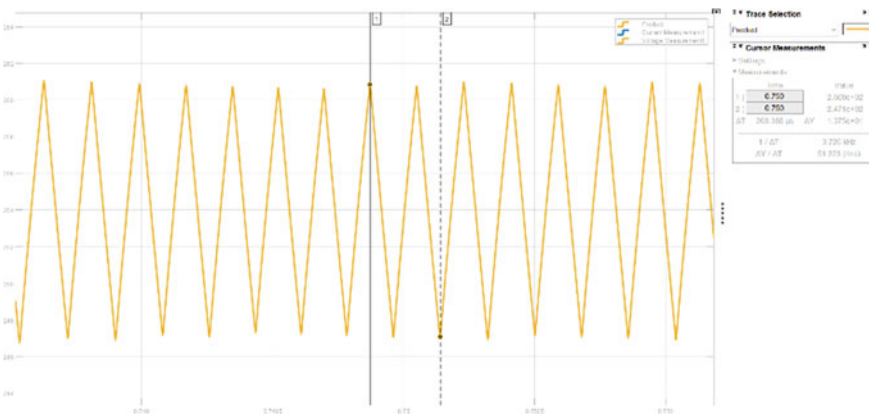
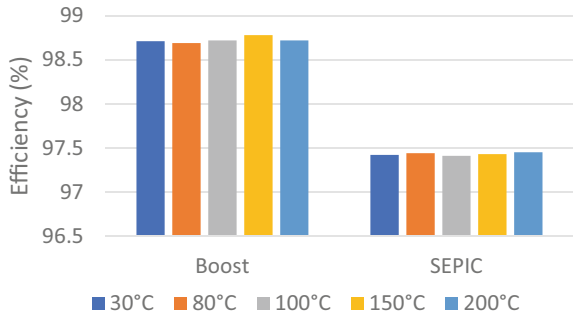


Fig. 15 Output power of SEPIC

Fig. 16 MPPT efficiency of boost and SEPIC converters when the T_h changes



Figures 16 and 17 show the efficiency and performance of each varying temperature and load. It can be seen that the performance for changing T_h is very stable, while increasing the loads will lower the performance. If we would see further, the waveform shows that the settling time of the output is also longer as seen in Fig. 18 comparing with Fig. 12.

Fig. 17 MPPT efficiency of boost and SEPIC converters when the R_L changes

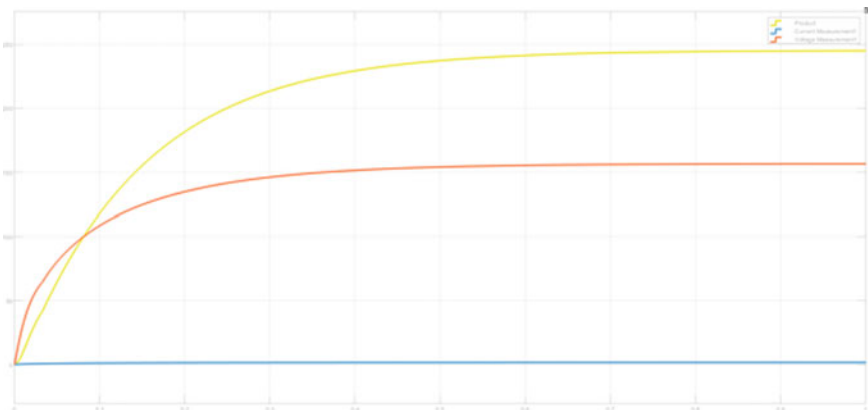
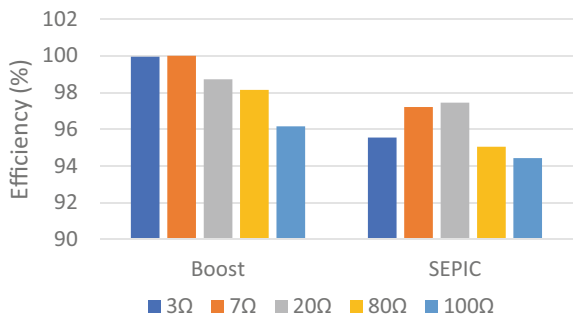


Fig. 18 Output waveform for boost converter $R_L = 100 \Omega$

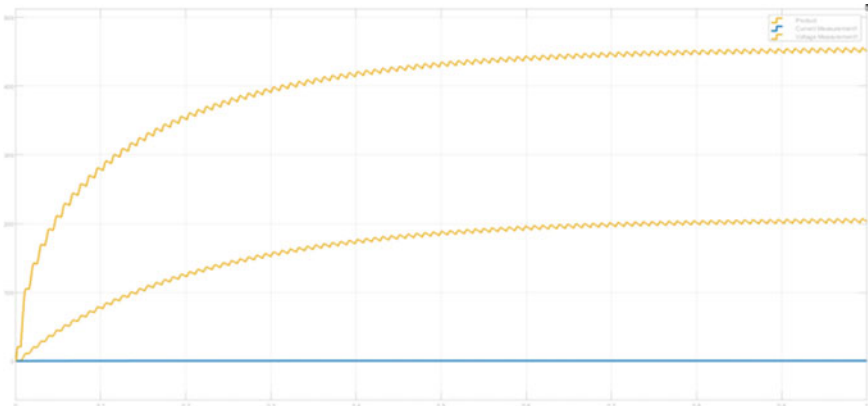


Fig. 19 Output waveform for SEPIC $R_L = 100 \Omega$

Figures 16 and 17 show the result for SEPIC. Here we see the same pattern as boost converter. Varying the temperature of the hot surface makes the performance pretty consistent. Meanwhile, increasing the load affects the performance drastically. The performance decreases except when the load is lower than internal resistor of TEG module which is 3Ω . The power output is higher than the input, which is probably false. This is due to the load being smaller than internal resistance. The same goes with the settling time, which is increasing as the load increases. It can be observed by comparing Fig. 19 which is for 2 s instead of 1 s with Fig. 14.

5 Conclusion

Using different DC-DC converters can give us different results and different shapes of waveform. It all depends on the application and what type of design that is needed inside a system. The boost converter is one that can convert pretty smoothly with less components than in SEPIC. Boost converters only consist of four components, while SEPIC has six components. This can be looked upon during costing of the design. SEPIC is very convenient in having both option of stepping up and stepping down but it might need to have longer settling time. SEPIC will always be a choice of manufacturers to do battery-operated devices. We also have learnt that the value of resistance is important. In getting the desired result, lowering the R_L for SEPIC is the right way. Having the higher resistance also increases the settling time, therefore taking longer time to fulfil the desired output. The efficiency for the boost converter is also on average 1.3% higher compared with the SEPIC converter. Based on the results, it shows that the SEPIC is not a suitable replacement for the TEG application. In the future recommended work, the boost and SEPIC converters need to be designed properly to operate at critical continuous current mode and specified ripple factor. This ensures a fairer comparison.

Acknowledgements The authors would like to thank Universiti Teknologi Malaysia (UTM) and Ministry of High Education Malaysia (MOHE) for funding this research under UTM Encouragement Research (UTMER) Grant (Cost Centre No.: Q.J130000.3851.19J23).

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