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# Design and Analysis of Thermoelectric Dc boost converter

Anish Kumar*[1], Praveen Kumar choudhary[2]
[1*]Department of Mechanical engineering, BIT, Sindri
[2]Reseach Scholar, Department of Mechanical engineering, BIT, Sindri

***Abstract -***
*In today's consumer-oriented market, researchers are increasingly focusing on harvesting energy from ambient and renewable sources to enable sustainable power generation and reduce dependency on conventional energy resources such as batteries and fossil-fuel-based electricity. The rapid growth of portable electronics, wireless sensor networks, and Internet of Things (IoT) devices has created a significant demand for low-power, long-life, and maintenance-free energy solutions. In many practical situations, frequent battery replacement is difficult, costly, and environmentally harmful. Therefore, energy harvesting has emerged as an effective alternative to power such low-energy devices by utilizing naturally available energy in the surrounding environment.*

*Energy harvesting methods offer enormous opportunities to derive power from sources such as mechanical vibrations, human motion, thermal gradients, airflow, and other forms of wasted or unused energy. In general, energy harvesters operate like transducers, where the available ambient energy is extracted and converted into usable electrical power. Among different techniques, triboelectric and thermoelectric harvesting are considered highly promising due to their simplicity, compactness, and suitability for small-scale applications.*

*This research aims to demonstrate the practical implementation and performance validation of Thermoelectric Energy Harvesting (THEH) through developed hardware prototypes and experimental setups. A usable amount of electrical energy is extracted from both harvesters under real-world operating conditions. The generated output is measured, analysed, and further validated using the developed hardware model to ensure feasibility for real-time applications. The results indicate that ambient energy harvesting using triboelectric and thermoelectric principles can provide an effective solution for powering low-power electronics and self-sustained sensing systems in future smart applications.*

*Keywords:*

# 1.Introduction

A well-designed electrical circuit can contribute significantly in enhancing the power management of energy available from a conventional and non-conventional input source. A continuous development in energy harvesting circuits has helped scientists to generate energy from renewable energy resources. A parallel advancement to circuits alongside power efficient generators has seen an upward surge with time [1-5]. These electrical circuits are capable to convert the available energy in environment into usable electrical power. An extensive research has been done to prove the practicability of thermal to electrical energy conversion using thermoelectric energy generators. This electrical energy has been presented as an alternate solution to operate ultra-low power sensors and devices which are currently dependant on batteries with limited shelf life in previous chapter [6-10]. Thermocouple materials based thermoelectric generators works as an active device for scavenging ambient and waste thermal energy into usable electrical power. Due to a simple non-moving design assembly, endurance, low-cost maintenance and absenteeism of any chemical scientists worldwide are interested in TEGs and the supporting circuits for highly efficient power generation [11-15]. Already available commercial TEGs still have limited usability because to lower output voltage of the order of few millivolts from them. To enhance their serviceability and electrical output parameters they are often clustered together in series or parallel combinations which increases the output voltage to appreciable level [16-20]. The problem with such topologies is the rise in the size of the system making it bulky. Additionally, the heating and cooling source mechanism for such systems proportionally increases. A possible combination of electrical circuits with these modules provides a much-improved solution for generating desirable output voltage and power [1-4]. These circuits which can take in millivolt level input voltage and gives amplified output voltage in volts are termed as boost converters. We have considered here a DC-DC boost converter as the obtained output voltage from thermoelectric harvester is a DC signal. These boost converters work on energy storage elements and inductors are a general choice for designing them. An inductor-based boost circuits rely highly on efficient switching mechanism for transferring power to load side with minimum losses. This further helps to increase the output power levels. The switching is required to switch ON/OFF the MOSFET deployed as a switch in the circuit [21-25]. To harvest the available low thermal energy from TEGs, a feedback control method for continuous or discontinuous flow of inductor current through an ON/OFF MOSFET switch can be implemented. The switching rate and duty cycle of the switching input for MOSFET operation are critical to the amount of amplification obtained [5-8]. This necessitates a carefully designed circuit for optimum duty cycle ratio selection for optimum switching of the selected MOSFET switch [26-30].

The study presented here is based on PWM switching, square wave switching and simple gate switching of an inductor-based boost converters designed to amplify the output voltage from a TEG. Three inductor-based boost converter configurations with different switching architectures were investigated. The value of open circuit output voltages in all the three cases was recorded for comparison. TEC1-12706, a commercially available thermoelectric generator module with a thermal source, was used as an input source for DC-DC boost converter circuit [31-33].

## 1.1. System design

A boost converter circuit for DC-DC voltage conversion was designed to increase the output voltage generated from a commercially procured thermoelectric generator module TEC1-12706. This thermoelectric module comprises of many series connected thermocouples working on Seebeck effect to convert the temperature gradient into electrical output power as discussed briefly. These thermocouples are connected in parallel and series electrically to increase the output power. A requisite temperature gradient to the junction of these pairs results in generation of equally proportional output voltage. Any further change in either of the temperature junction will result in corresponding change in output electrical voltage. The actual generated voltage can be calculated using equation 1.1 below [9]:

$$Vout = \alpha \,.\Delta T \tag{1.1}$$

Where, $\alpha$ = seebeck coefficient

$\Delta T$ = temperature gradient

The Seebeck coefficient for a thermoelectric module is the intrinsic property of the material used for fabrication. It is difficult to change this parameter and requires separate study of compositional and structural properties. On the other hand, temperature gradient can be varied to achieve a requisite output voltage. As given by the equation above as the temperature gap between hot and cold side increases, output voltage also increases proportionally. This implies achieving high voltage output by simply changing the junction temperature. But for a simpler design structure this parameter cannot be varied infinitely as increase in hot side temperature may affect the cooling of other side thereby reaching a constant temperature gradient at certain point. For larger temperature gaps other modules with better quality semiconductor materials are available but are usually very costly. This limitation motivated the investigations for possibility of using a boost converter with such thermoelectric energy generation devices. DC boost converter is the electrical circuit which can amplify/step-up a lower DC voltage level to higher DC value. Along with amplified output voltage, it also regulates the DC voltage to give a regulated power supply. Fig. 1 shows a simple switch-based conventional boost circuit for DC-DC power conversion.

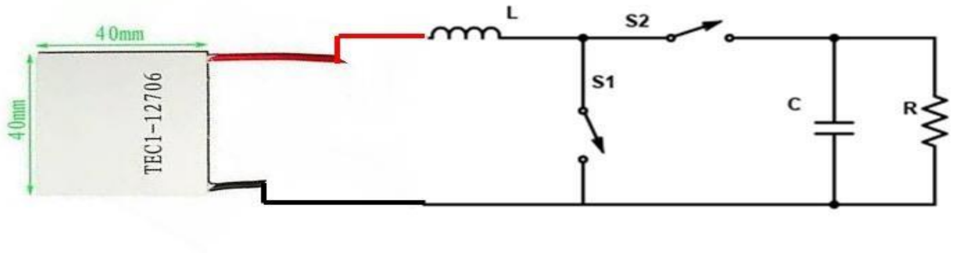


**Fig. 1:** Basic Boost Converter

An inductor, two switches and a capacitor along with output load forms the basic components. The amount of power conversion in this circuit is governed by repetitive closing and opening of the two switches S1 and S2. The switches involved here are semiconductor switches like diode, BJT, IGBT or MOSFET. The continuous process of alternate switching of S1 and S2 forwards the power from inductor to charge the capacitor. At initial cycle, first S1 is closed while S2 remains open and inductor current begins to increase resulting in energy storage in inductor. This increase in current will expand the magnetic field of the inductor. This implies that the inductor is now storing the energy being a passive device. With reversal operation S1 is opened and S2 is closed there is a decrease in current through inductor. This will decrease the magnetic field around the inductor. This in turn releases the energy deposited in the inductor. Finally, the inductor current is transferred to the load resistance thereby charging the capacitor in the process. CCM (Continuous Conduction Mode) and DCM (Discontinuous Conduction Mode) are the two operating modes for DC-DC boost converters (275). S2 should open if conductor current approaches zero to achieve maximum efficiency in boost converters. S1 and S2 switching in CCM is not based on inductor current. As shown in Fig. 2 at lower load resistances, a reverse current starts to flow from the output towards input, reducing the efficiency of the circuit. In DCM mode, on the other hand, the inductor current approaches zero when S2 is open. This obviously improves the circuit's voltage boosting efficiency by preventing the output current from flowing towards the input side. As discussed, duty cycle variation can affect output voltage, and maximum output voltage can be generated with an optimal duty cycle value [10-12]. There are various sources that can be used to control the switches and thus change the duty cycle. In this work different switching sources for generating maximum output power from a boost converter circuit are investigated. Three sources namely: simple gating pulses, square wave, and PWM input were employed to control the alternate ON/OFF switching of MOSFET switch for enhancing the output voltage from load side.

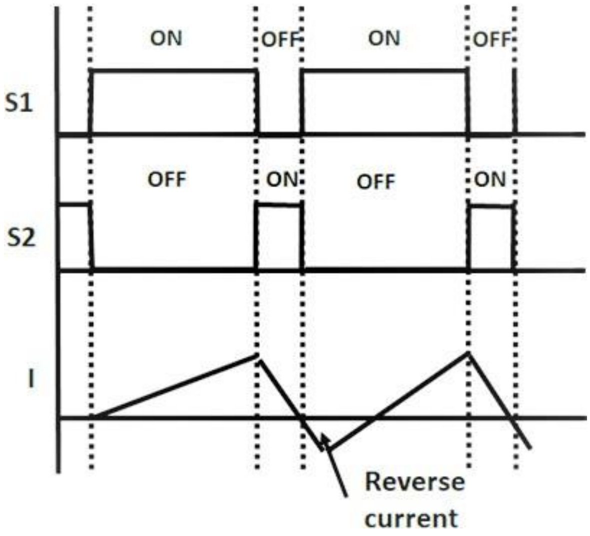


**Fig. 2:** Inductor current in CCM

The schematic block diagram for all the three tested circuits is shown in Fig. 3 (a,b,c).

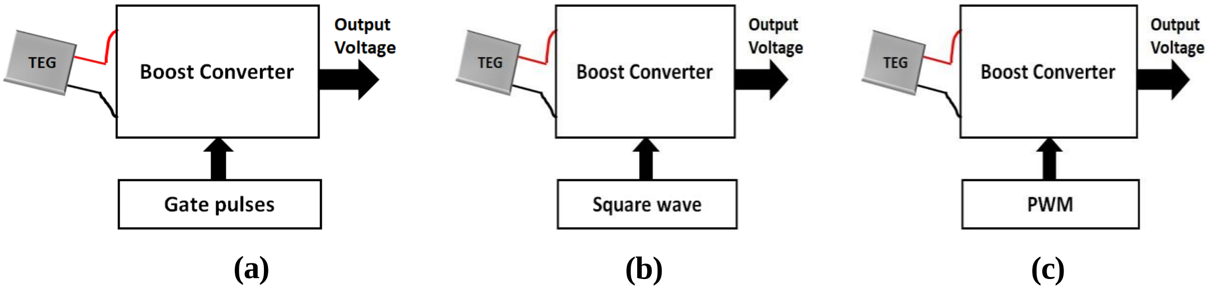
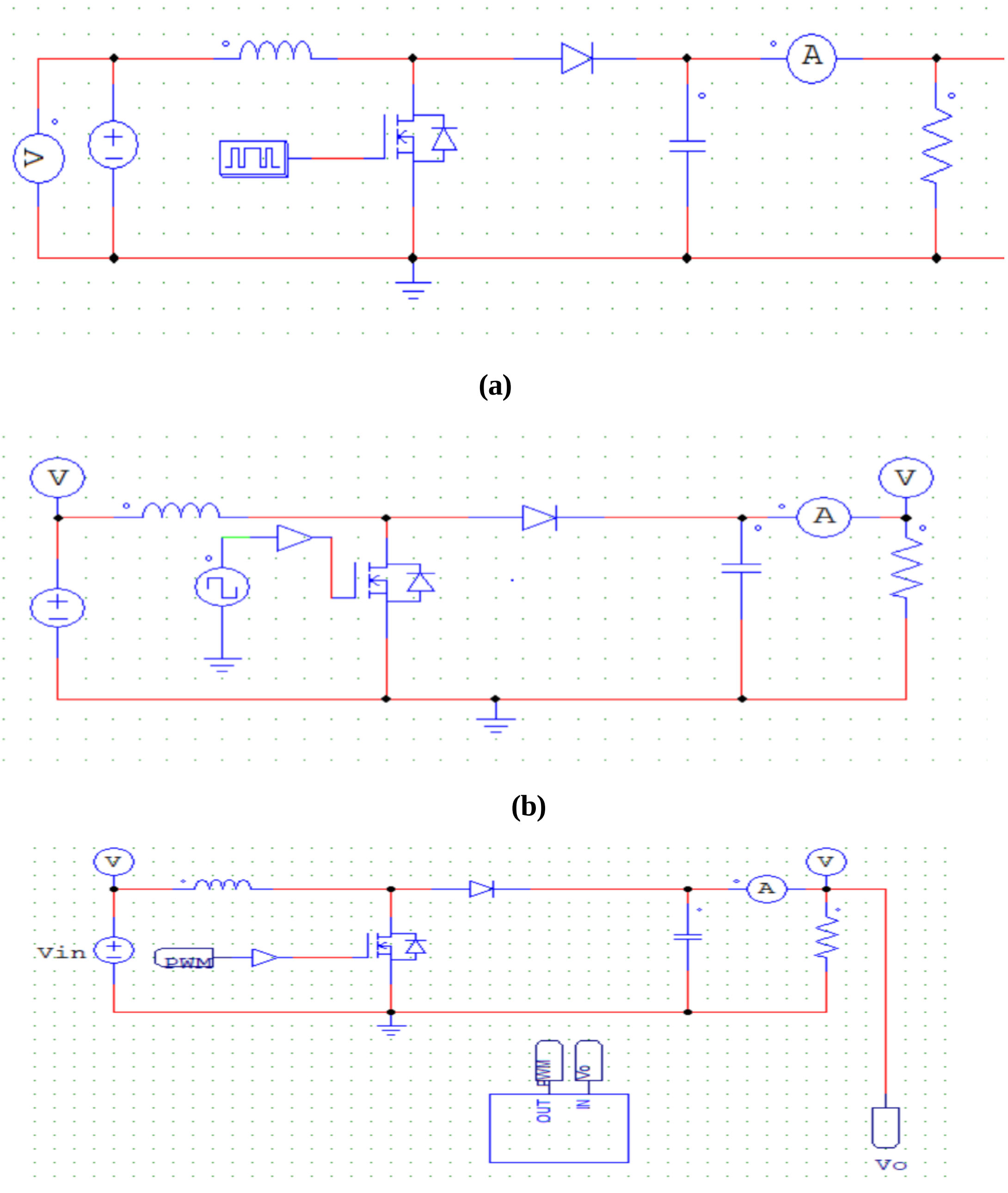


**Fig. 3:** Block diagram of boost circuit with different switching sources (a) Gate switching (b) Square wave switching (c) PWM switching

A software simulation was carried out for all the above listed switching sources. The desired output electrical parameters like output voltage (open circuit), current and measured output power are recorded and compared for maximum power generation for all the three configurations.

## 2. Results and discussion

The above mentioned three DC-DC boost circuit configurations were designed and simulated in PSIM. Fig. 4 (a,b,c) shows the PSIM circuit for gate pulse, square wane and PWM controlled boost circuit.



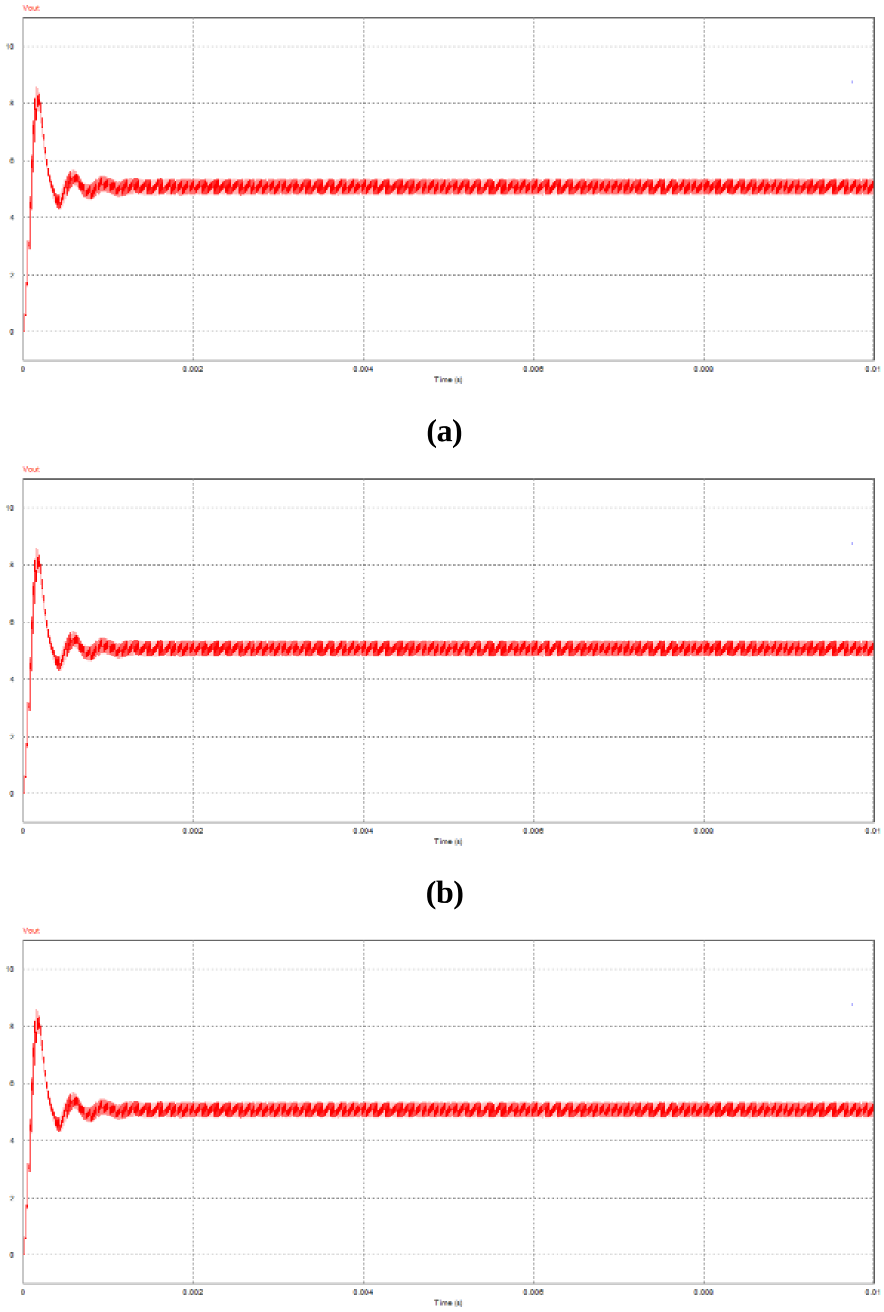
(a)

(b)

(c)

**Fig. 4:** PSIM models of boost converter (a) Gate pulse control (b) Square wave control (c) PWM control boost circuit

when subjected to the appropriate temperature difference, the commercially available TEC1-12706 module produces 0.2 V output voltage. In PSIM software, a constant DC source of 0.2 V is used to approximate the TEG module's symbol representation.



**(a)**

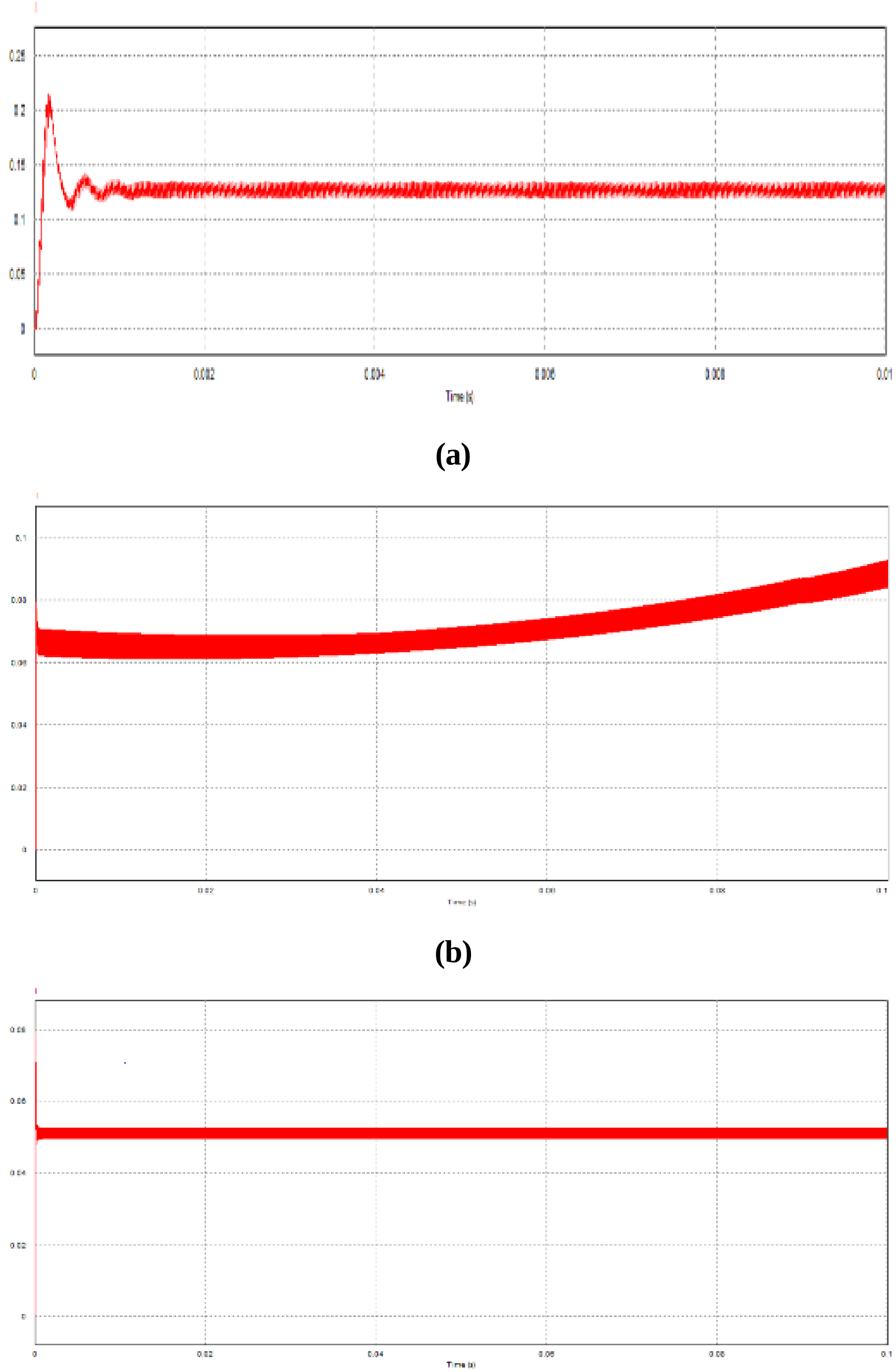
**(b)**

**(c)**

**Fig. 5:** Output voltage for switching modes (a) Gate pulse (b) Square wave (c) PWM input

Three different boost converters were designed in PSIM with three different switching sources (fig 5 a,b,c).

The output open-circuit voltage and corresponding load current were obtained using an output display scope in PSIM. According to the generated results, the gate-controlled configuration generated the highest amount of output voltage for the above-designed boost circuit.



**(a)**

**(b)**

**(c)**

**Fig. 6:** Output current for switching modes (a) Gate pulse (b) Square wave (c) PWM input

Such configurations can amplify a small amount of input voltage available from TEG for further usage. A 0.2 V input voltage is amplified to an appreciable 5.26 V output voltage. The measured output current is also 131 mA. Although the square wave and PWM controlled boost circuits could amplify the input voltage, they could only do so to 3.5 V and 1.98 V, with 87 mA and 51 mA current respectively. The output voltage graphs obtained using PSIM simulations for all the three switching configurations are shown in Fig. 6. As evident from Fig. 6 (a) switching the boost converter using gated pulses generated maximum output voltage for the designed boost converter. Fig. 6 (b) reveals that an enhanced output voltage is generated with square wave input switching. Although, a larger voltage was achieved but it was still less as compared to gated pulsed switching. As a general view, PWM control gives comparatively easier control for duty cycle variations it increases the complexity of the circuit. Also, it failed to enhance the output voltage level as efficiently as other two configurations could achieve. The maximum output voltage of 1.98 V is achieved for given designed specifications. Fig. 6 (c) gives the output current graph for all the three switching configurations.

## 3. Conclusions

1. A low-cost robust triboelectric pair material-based sensor was fabricated and tested for harvesting triboelectricity. When frictional contact was applied to a sensor strip made of thin sheets of PTFE and aluminium, an output voltage was generated. A generic counting system for counting the occurrences of certain events can be developed using triboelectric such material-based sensor. This low-cost triboelectric sensor strip doesn’t require any input power and is efficient for long term use due to its robustness.
2. An experimental investigation to analyze to the output performance of a thermoelectric generator was done. To maximize the heat absorption for generating thermoelectricity thermally conducting materials like Al, Fe and matte finish metal paint can be applied to a thermoelectric module. This thermoelectric generator (TEG) assembly can be used for generating output voltage using heat absorbed by different heat absorbing materials. A comparative study for various materials shows the best available material for better heat absorption. A series of three thermoelectric modules can generate adequate amount of energy to power up low and ultra-low power systems and sensor nodes.
3. A triboelectric sensor for a traffic monitoring system was developed to calculate the

speed of a moving vehicle and estimate its weight. This system has numerous advantages, including low cost, quick response, automated measurements, ease of deployment and maintenance, and so on. A robust low-cost triboelectric sensor was fabricated and tested which can be used for accurate speed measurement and corresponding weight estimation of passenger vehicles in motion. A number of road tests conducted on this system reveals more than 95% accuracy potential for such systems with 3% mean absolute percentage error.

4. A candle-soot-coated thermoelectric module for harnessing thermal energy from sunlight, is a promising technique to generate significant amount of output voltage. A substantial temperature gradient, when created across two dissimilar surfaces of thermoelectric module by concentrating sunlight and flowing water, can generate appreciable amount of energy. Soot coating with different thickness obtained by direct exposure to candle flame, delivered 1.5V of maximum open-circuit voltage with 14 mA peak current.
5. A carbon soot coated thermoelectric module (TEC1-12706) when exposed to direct sunlight can utilize solar heat for thermoelectric energy harvesting. The TEG module was coated with different thicknesses of candle soot using a candle flame and the crystal morphology was examined using Raman spectroscopy. When coated with the fourth consecutive CS layer, a maximum of 1.46 V of open-circuit voltage and 14.2 mA of peak current are obtained. Further, if solar radiations and continuous water flow can maintain the required temperature difference, the output voltage can be further elevated using an electrical circuit like dc–dc boost converter. Such arrangement can charge a rechargeable battery (for eg., 2.1V VARTA NI-MH used here).
6. Different DC-DC boost converter circuit configurations can generate different amount of output voltages. In the present work, three such arrangements were designed and simulations were carried out. It was observed that a Gate pulsed switching in boost converter generated highest amount of output voltage. Apart from efficient energy harvesters improvement in DC-DC boost converters and other related electrical circuits can further enhance the output voltage.

## 4. Future scope of present research

The presented work demonstrates the energy generation mechanisms using triboelectricity and thermoelectricity. Although, the energy generated from the designed systems were able to demonstrate the potential of using these technologies for efficient power generation, there exists some areas which can be explored for further improvements. To assist researchers for future work, following topics are suggested for further investigations:

1. The integration of two or more independent renewable sources for developing a multi-input source system can be investigated for enhancing the resources utilization. In our generators we have used single ambient source for primary energy generating. Integrated system can guarantee energy generation from atleast one source in absence of other source. This can increase the usability and reliability of the system to a great extent.
2. The electrical circuits used for voltage amplification can be investigated further. We have focussed our research on boost converter circuits only. Other such topologies like charge-pumps and other such circuits for voltage enhancement can be designed and tested for maximum power optimization.
3. The effect of Maximum power point tracking (MPPT) system on the designed energy harvesters can be investigated for possible performance enhancement.

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