

Design and Implementation of Energy Harvesting from the Domestic Chimney

Suma Umesh¹, Rakesh S², Sanjay N S³, Ranjith B Thampan⁴ and Neeraja Anand⁵

¹⁻⁵BMS Institute of Technology and Management, Bangalore, India

Email: sumaumesh@bmsit.in

Abstract—Power generation using domestic chimneys involves capturing the energy generated by the exhaust gases from cooking appliances, such as stoves and ovens. This energy can be converted into electrical power using a thermoelectric generator (TEG) which works on the principle of Seebeck effect. The TEG works by utilizing the temperature difference between two surfaces to generate an electric current. Power generation using domestic chimneys has the potential to provide a sustainable source of energy for households, reducing reliance on the grid and decreasing carbon emissions. This work presents the simulation model for the proposed work with thermoelectric generator using Simulink modelling along with the hardware implementation of the prototype. The results reveal that relation between temperature gradient and power output is linear, making TEG a suitable method to harvest energy from the domestic chimney.

Index Terms— Energy harvesting, thermoelectric generator, Seebeck effect.

I. INTRODUCTION

Power generation using kitchen chimneys can help to improve energy access and reduce reliance on traditional fuels by providing a clean and sustainable source of energy. The power generation using domestic chimneys has the potential to provide households with a sustainable and renewable source of energy. It harnesses the heat energy generated by cooking appliances and converts it into electricity using thermoelectric generators. This innovative technology can help reduce reliance on non-renewable energy sources and the carbon footprint associated with energy consumption, especially in areas where the grid is unreliable or non-existent. Moreover, it can improve the health and well-being of people living in these areas by providing a clean and sustainable source of energy. By utilizing waste heat that would otherwise be lost to the environment, power generation using domestic chimneys can be a cost-effective and efficient method of producing electricity for small-scale applications. It is especially useful in areas where demand for electricity is low or only required for a short period of time. The motivation for using domestic chimneys to generate power is to find sustainable and clean sources of energy that can help to improve energy access, reduce reliance on fossil fuels, and improve the health and well-being of people living in areas without reliable access to electricity.

Many techniques have been developed over the years for optimizing the energy harvested from various sources. The wind energy is harvested from piezoelectric materials using stacked buck converter topology [1]. This topology allows for sourcing from multiple inputs. A novel method is developed for harvesting wind energy from moving train is demonstrated using canonical shaped ducted turbines, installed over the roof of the train

and coupled to a generating unit. CFD simulated results are used to investigate the design profile [2]. A smart turbine energy harvest (STEH) system based on aerodynamics of vortex-induced vibration from a home-chimney external cap pin wheels [3]. The ducted wind turbine design implementation, its economic analysis has been carried out in detail [4]. This system uses horizontal three blade turbine. Further, various configurations of generators are employed with wind turbines to generate electricity such as squirrel cage induction generator, doubly fed induction generator, permanent magnet synchronous generator and switched reluctance generator [5]. In the present work, the heat energy from domestic chimney is harvested into electricity using thermoelectric generators (TEG) which works on Seebeck effect.

II. DESIGN AND SIMULATION

Thermoelectric generators are solid state devices made up of two dissimilar materials typically a p-type and an n-type materials connected in series. When the hot gas from the source heats one end of the TEG, a temperature gradient is created and as shown in Fig.1[6]. This causes electrons to flow from hot end to cold end, resulting in an electric current.

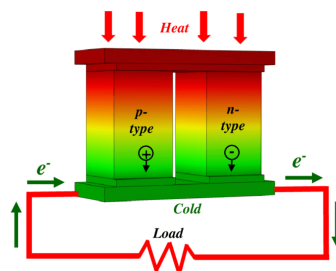


Fig. 1. Schematic diagram of Thermoelectric generator [6]

The block diagram of the proposed scheme of generating electricity from domestic chimney using thermoelectric generator is as shown in Fig. 2. The hot air from the chimney enters the hot side of the thermoelectric generator. The TEG system consists of four main components: the heat source, thermoelectric modules, heat sink (cold source), power electronics (DC-DC converter etc), and monitoring and control system. The heat source provides the temperature gradient necessary to generate electricity through the *Seebeck* effect. The thermoelectric modules convert the temperature gradient into electrical power. The heat sink is responsible for dissipating the waste heat from the cold side of the TEG and maintaining the temperature gradient across the device. The power electronics convert the low-voltage, low-current output of the TEG into a usable form of regulated electrical power. Finally, the monitoring and control system ensures optimal performance and safety by monitoring temperature and current and regulating the temperature gradient and power output.

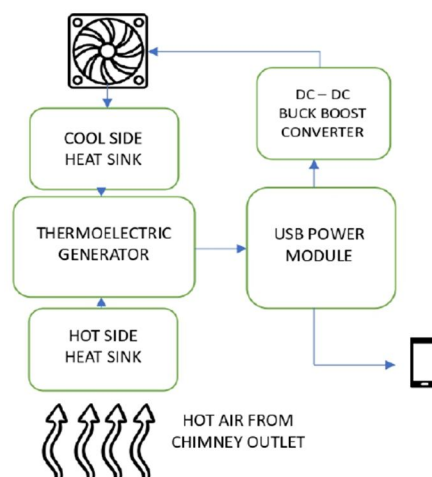


Fig.2 Block diagram of power generation scheme from domestic chimney

The energy harvesting model using thermoelectric generator is carried out using Simulink module from MATLAB. The schematic generated from Simulink is as shown in Fig. 3.

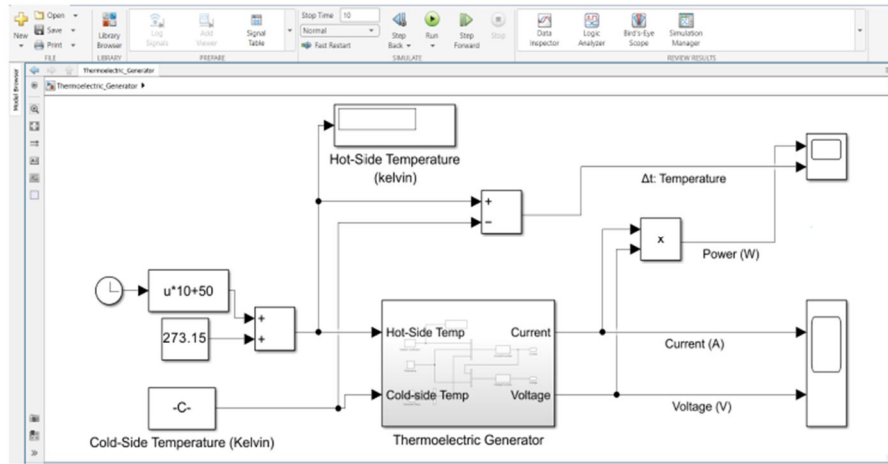


Fig. 3. Schematic of the energy harvesting from domestic chimney using thermoelectric generator

The Simulink model includes the heat source, thermoelectric modules, heat sink, power electronics, and monitoring and control system components built using appropriate blocks in Simulink. The temperature gradient, heat flux, and other input parameters are provided to run the simulation. The output in terms of electrical power and temperature gradient are recorded and used for performance analysis. Simulating a TEG in Simulink can provide valuable insights into the performance of the system and help optimize its design for maximum energy conversion efficiency. The thermoelectric generator block is modelled as shown in Fig.4 and the data for the same is taken from the data sheet of *HZ-20HV*, a commercially available thermoelectric generator.

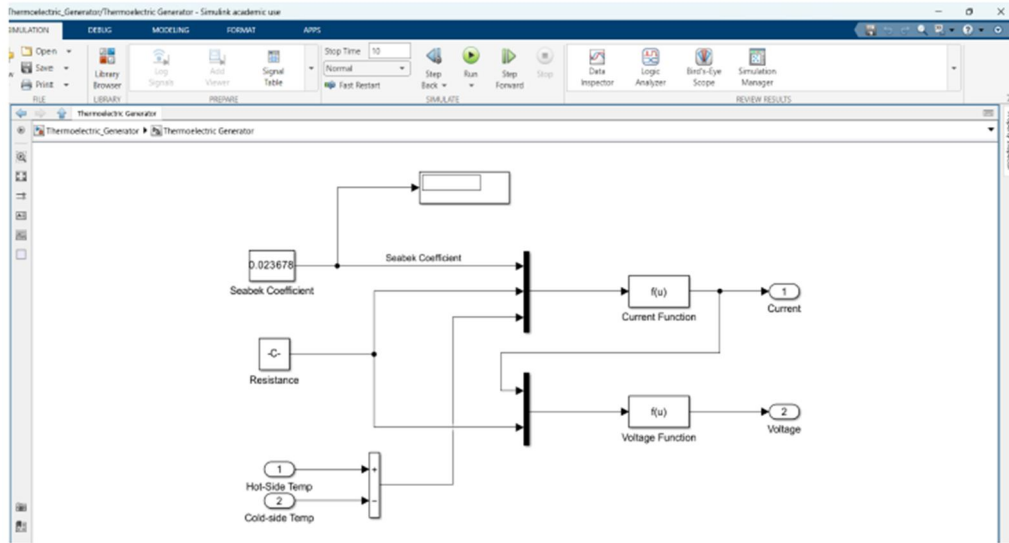


Fig. 4 Thermoelectric Generator model using Simulink

The hot side temperature, T_h is taken as 250°C and cold side temperature T_c is taken as 50°C. The temperature difference between hot side and the cold side, ΔT is represented by

$$\Delta T = T_h - T_c$$

The matched voltage V_m and matched power W_m are taken as 5.6 V and 25.5 W respectively. The internal resistance is denoted as R and R_L is the load resistance. Generally, the resistances are matched and $R = R_L$, where R_L is expressed as

$$R_L = \frac{V_m^2}{W_m}$$

The *Seebeck* coefficient is given by:

$$\alpha = \frac{2V_m}{\Delta T}$$

The electric current is given by

$$I_e = \frac{\alpha \times \Delta T}{(1 + m)R}$$

where $m=1$, when $R = R_L$

the matched load current, I_m is given by

$$I_m = \frac{\alpha \times \Delta T}{2R}$$

The short circuit current with $V_L=0$ is given by

$$I_{sc} = \frac{2V_m}{W_m}$$

The output voltage V is given by

$$V = R \times (I_e - I_{sc})$$

The modelling of the thermoelectric generator and the energy harvesting using Simulink helps to understand the system better and provides opportunity to optimize the design parameters before going for hardware realization of the circuit.

III. SIMULATION RESULTS

By simulating the system, it becomes possible to evaluate the power output, efficiency, and other important parameters under different operating conditions. The Simulink model facilitates optimization and sensitivity analyses, enabling the exploration of design choices, component sizing, and control strategies to maximize power generation and overall system efficiency. The fig. 5 shows the temperature vs time and power output in watts vs time plot.

It is clear from the graphs that, the relation between temperature gradient and power output is linear. Therefore, thermoelectric generator can be employed for harvesting energy from domestic chimney.

This plot also provides insights into the maximum power output that can be achieved for a given temperature gradient and the optimal temperature gradient that can be sustained without causing thermal damage to the modules.

Through Simulink simulations, potential improvements can be identified and assessed before implementing the physical system. This reduces the cost and time associated with iterative physical prototyping and allows for a more informed decision-making process. Overall, the Simulink model of power generation using a domestic chimney provides a powerful tool for understanding, optimizing, and validating the system design, leading to more efficient and effective utilization of waste heat for power generation.

IV. EXPERIMENTAL WORK

A thermoelectric generator (TEG) is a device that converts heat energy directly into electrical energy through the phenomenon known as the thermoelectric effect. The thermoelectric effect is the generation of a voltage difference when a temperature gradient is applied across a junction of two dissimilar conductive materials. TEGs typically consist of multiple pairs of thermoelectric materials, often semiconductor materials such as bismuth telluride or lead telluride. These pairs, known as thermocouples, are arranged in series and connected electrically to form modules as depicted in fig 6. When there is a temperature difference across the thermocouples, the heat flows from the hot side to the cold side. Due to the difference in *Seebeck* coefficients of the thermoelectric materials, an electric potential is generated, resulting in the flow of electric current through an external load connected to the TEG. However, TEGs typically have low conversion efficiencies compared to other power generation technologies. Efforts are being made to enhance their performance through material advancements, device optimization, and system integration.

A heat sink is an integral component used in thermoelectric generators (TEGs) to enhance heat transfer and optimize the performance of the system. Its primary function is to absorb and dissipate excess heat from the hot

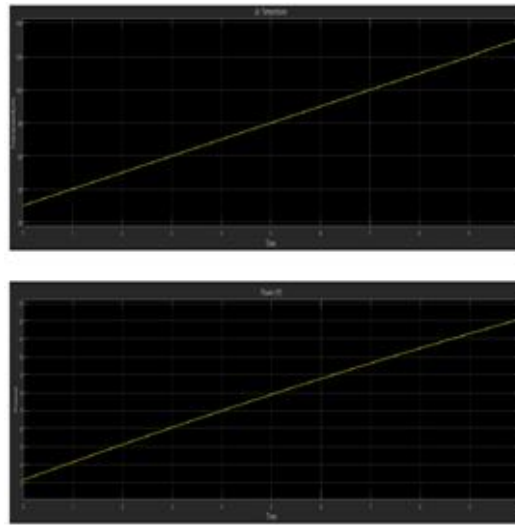


Fig. 5 (a)Temperature vs time plot, (b) Power output vs time plot

side of the TEG, maintaining a relatively lower temperature on that side. Heat sinks are typically made from materials with high thermal conductivity, such as aluminium or copper. These materials efficiently conduct heat away from the TEG, allowing for effective heat dissipation. They often have fins or other extended surfaces to increase the surface area for better heat dissipation. The shape and arrangement of the fins can be optimized to promote convective heat transfer. They often have fins or other extended surfaces to increase the surface area for better heat dissipation. The shape and arrangement of the fins can be optimized to promote convective heat transfer.

A cooling fan can be used in a thermoelectric generator (TEG) system to enhance heat dissipation and improve overall system performance. It increases the airflow and facilitate convective heat transfer. It helps in dissipating heat from the hot side of the TEG, preventing overheating and maintaining a lower temperature on that side.

A DC-DC step-up boost converter is a commonly used along with thermoelectric generator (TEG) systems to efficiently increase the low voltage output from the TEG modules to a higher voltage level. The boost converter operates using switching components, typically a transistor (MOSFET) and a diode. The transistor switches on and off, allowing current to flow through the inductor during the on-state and storing energy in the inductor's magnetic field. The diode prevents reverse current flow during the off-state, directing the energy to the output capacitor and load. The boost converter consists of an inductor and a capacitor. The inductor stores energy during the on-state and releases it during the off-state, while the capacitor smoothens out the voltage ripple and provides a steady output voltage.

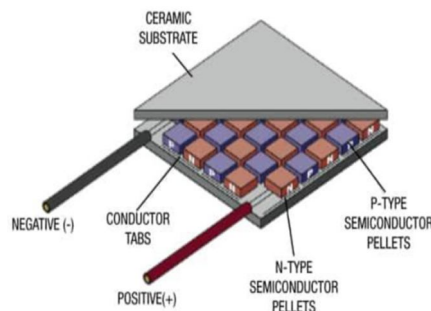


Fig. 6 Schematic of a thermoelectric generator

The boost converter often includes a control circuit that adjusts the duty cycle of the switching transistor to regulate the output voltage. It utilizes pulse-width modulation (PWM) techniques to maintain a stable output voltage despite changes in load or input voltage conditions.

A power bank module can be integrated into a thermoelectric generator (TEG) system to enable the charging of electronic devices. It serves as a portable energy storage device, allowing the TEG system to accumulate and store electrical energy generated from the TEG modules.

The power bank module includes charging circuitry that allows it to receive electrical energy from the TEG system and store it in its internal rechargeable batteries. It also typically incorporates voltage regulation circuitry to stabilize the output voltage and ensure compatibility with various electronic devices or loads. This regulation ensures that the output voltage remains within the desired range to safely charge connected devices.

By integrating a power bank module into a TEG system, the electrical energy generated by the TEG can be efficiently stored and used to charge electronic devices. This enables the TEG system to serve as a portable and sustainable power source, providing convenient charging capabilities for devices even in remote locations or during power outages.

The hardware implementation for power generation using a domestic chimney by a TEG offers the potential to utilize waste heat and convert it into usable electricity, contributing to energy efficiency and sustainability. It allows for the generation of electricity without relying solely on traditional energy sources. However, it is important to consider safety measures, proper installation, and adherence to building codes and regulations when implementing such a system to ensure safe and efficient operation. A prototype is implemented as proof of concept in this work as shown in Fig. 7.

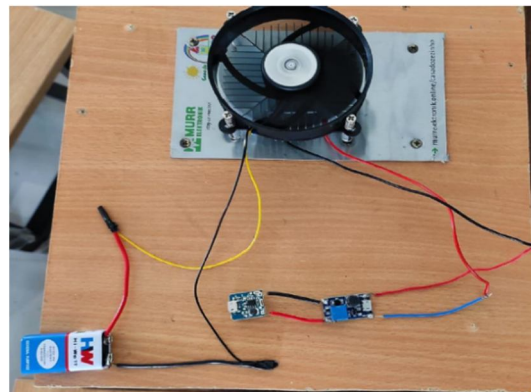


Fig. 7. Prototype implementation of energy harvesting using thermoelectric generator

V. RESULTS AND DISCUSSIONS

In a typical setup, a TEG module is integrated into the chimney system, where the hot flue gas flows across the module's hot side, while the cool ambient air is on the module's cold side. The temperature difference between the hot and cold sides creates a voltage across the module, generating electrical power. The performance of a TEG using chimney flue gas depends on several factors, including the temperature gradient, material properties, and design considerations. Higher temperature gradients generally result in increased power generation. The choice of TEG materials is crucial to achieve optimal performance, as different materials have varying Seebeck coefficients and electrical conductivities. Researchers have been exploring advanced materials and engineering techniques to enhance TEG efficiency.

As a proof of concept, we have implemented thermoelectric generation using the set up as shown below and temperature gradient is created using a heat source and the output of the TEG is recorded as presented in the Fig. 8.



Fig. 8. Output volage generated from thermoelectric generator

VI. CONCLUSIONS

The simulation of a thermoelectric generator (TEG) in Simulink can provide valuable insights into the performance of the system and help optimize its design for maximum energy conversion efficiency. One key result that can be obtained from a TEG simulation is the power output as a function of the temperature gradient across the thermoelectric modules. This plot can provide insights into the maximum power output that can be achieved for a given temperature gradient and the optimal temperature gradient that can be sustained without causing thermal damage to the modules.

Once the TEG system has been optimized, the simulation results can be compared with experimental data to verify the accuracy of the Simulink model. This step is important to ensure that the simulation results accurately represent the real-world behaviour of the TEG system.

In conclusion, power generation using thermoelectric generators (TEGs) in domestic chimneys is technically feasible. It is possible to harness some energy from the heat produced by domestic chimneys, it is unlikely to be a significant or highly efficient method of power generation. Other renewable energy sources and technologies, such as solar, wind, and geothermal, offer more viable and scalable solutions for meeting energy needs in residential settings. The domestic chimney can be a source for small power generation.

ACKNOWLEDGMENT

The authors thank the Management of BMSIT&M and BMS Educational Trust for providing the necessary resources and creating conducive environment to carry out the work.

REFERENCES

- [1] Taufik Taufik, Jameson Thornton, Mohammad Taufik, "Small-scale wind energy harvesting using piezoelectric converter" 2012 International Conference on Power Engineering and Renewable Energy (ICPERE) , <https://ieeexplore.ieee.org/document/6287249>
- [2] B. Sindhuja, "A proposal for implementation of wind energy harvesting system in trains" Proceedings of The 2014 International Conference on Control, Instrumentation, Energy and Communication (CIEC) , <https://ieeexplore.ieee.org/document/6959180>
- [3] Ajibike Eunice Akin-Ponnle, Felisberto Sequeira Pereira, Nuno Borges Carvalho, "Aerodynamics of Home-Chimney Pinwheels as Smart Turbine Energy Harvester (STEH) for Smart City IoT" 2022 Wireless Power Week (WPW), <https://ieeexplore.ieee.org/document/9854030>
- [4] Javad Taghinezhad, Esmail Mahmoodi, Mehran Masdari; Reza Alimardani, "Spectral Analyses of an Optimized Ducted Wind Turbine using Hot-Wire Anemometry" 7th Iran Wind Energy Conference (IWEC2021), <https://ieeexplore.ieee.org/document/9467033R>. Nicole, "Title of paper with only first word capitalized," J. Name Stand. Abbrev., in press.
- [5] Apar Chitransh, Sarbjeet Kaur, Rehana Parveen, "Comparative Analysis of Different Configuration of Generators for Extraction of Wind Energy" 2021 Fifth International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud) (I-SMAC), <https://ieeexplore.ieee.org/document/9640627>
- [6] Abedlhafid, Mohammed & Izman, S. & Noor, Alias & Basheer, Uday & Rajoo, Srithar (2017). A review of thermoelectric p-type $\text{Ca}_3\text{Co}_4\text{O}_9$ nanostructured ceramics for exhaust energy recovery.
- [7] Alexey V. Babich; Dmitry V. Pepelyaev, "Thermoelectric and Thermal Properties of the Materials for the Flexible Thermoelectric Generator Application", Published in 2021 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (ElConRus). <https://ieeexplore.ieee.org/document/9396220>
- [8] A. Bansal, D.A. Howey; A.S. Holmes, "CM-scale air turbine and generator for energy harvesting from low-speed flows" TRANSDUCERS 2009 - 2009 International Solid-State Sensors, Actuators and Microsystems Conference, <https://ieeexplore.ieee.org/document/5285378>
- [9] Wei Du, Qirong Yang, Jisheng Song, "A Study of the Ventilation Performance of a Two-Segment Chimney Integrated with A Residence" 2010 Asia-Pacific Power and Energy Engineering Conference, <https://ieeexplore.ieee.org/document/5449017>
- [10] Michael S. Davis, A. Jafarian, F Ferdowsi, Mohammad R. Madani, "Wind Energy Harvesting Capability of a Novel Cascaded Dual-Rotor Horizontal-Axis Wind Turbine" 2021 International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME), <https://ieeexplore.ieee.org/document/9590963>.