ENERGY GENERATION FROM WASTE HEAT AND CHARGING THE BATTERY

Dr.Infant Vinoth C[1], Dr.Sundar G[2], Joshua S D[3], Bharath Kumar V[4], Kamaleshwaran J[5], Ari Krishna B[6]
Department of Electrical and Elecrtonics Engineering
Sri Shakthi Institute of Engineering and Technology,Coimbatore-641062

Abstract
A large amount of energy produced in automobiles, industries, and electronic systems is lost to the surroundings in the form of waste heat. Recovering and utilizing this wasted thermal energy can significantly improve overall system efficiency and contribute to sustainable energy generation. The project titled "Energy Generation from Waste Heat and Charging the Battery Using Thermoelectric Generator (TEG)" focuses on converting waste heat into useful electrical energy through thermoelectric technology.

The proposed system employs Thermoelectric Generator (TEG) modules, which operate on the principle of the Seebeck Effect. When a temperature difference exists between the hot side and cold side of a TEG module, a voltage is generated. In this project, waste heat from sources such as vehicle exhaust systems, industrial machinery, engines, or other high-temperature equipment is utilized as the heat source. The cold side of the TEG is maintained at a lower temperature using heat sinks and cooling arrangements to maximize the temperature gradient and improve power generation efficiency.

The electrical energy generated by the TEG modules is initially low and varies depending on the temperature difference. Therefore, a DC-DC boost converter and voltage regulation circuit are incorporated to stabilize and increase the generated voltage to a suitable level for battery charging. The regulated power is then stored in a rechargeable battery, enabling the harvested energy to be utilized for powering auxiliary devices, sensors, lighting systems, and other low-power electronic applications.

This project demonstrates a practical and sustainable approach to waste heat recovery using thermoelectric generators. The implementation of TEG-based energy harvesting systems can contribute to reduced fuel consumption, lower operational costs, improved energy management, and decreased environmental impact. The results highlight the feasibility of using thermoelectric technology for battery charging applications and showcase its potential for future deployment in automotive, industrial, and renewable energy sectors.

Keywords:
TEG, Waste Heat Recovery, Seebeck Effect, Battery Charging, Energy Harvesting, DC-DC Converter, Power Generation, Renewable Energy.

I. INTRODUCTION

In recent years, the increasing demand for energy and the depletion of conventional energy resources have encouraged the development of sustainable and energy-efficient technologies. A significant amount of energy generated in automobiles, industries, and power systems is lost as waste heat to the environment. Recovering this wasted thermal energy and converting it into useful electrical power has become an important area of research in modern energy systems.
The proposed project, "Energy Generation from Waste Heat and Charging the Battery Using Thermoelectric Generator (TEG)," focuses on utilizing waste heat as a renewable source of energy. The system employs Thermoelectric Generator (TEG) modules that operate on the Seebeck Effect, where a temperature difference between two surfaces produces an electrical voltage. Waste heat from sources such as vehicle exhausts, industrial machinery, or electronic equipment is used as the heat source, while heat sinks are utilized to maintain a temperature difference across the TEG modules.
The generated electrical energy is conditioned through a DC-DC boost converter and voltage regulation circuit to obtain a stable output suitable for battery charging. The stored energy can then be used to power low-power electronic devices and auxiliary systems. The integration of rechargeable battery storage ensures continuous energy availability and improves the overall efficiency of the system.

II. LITERATURE SURVEY

Several researchers have explored the use of Thermoelectric Generators (TEGs) for converting waste heat into electrical energy. Studies have shown that TEGs are capable of generating power from temperature differences present in automobile exhaust systems, industrial furnaces, and other heat-emitting equipment. Researchers have investigated various thermoelectric materials and module configurations to improve conversion efficiency and power output. The findings indicate that TEG-based energy harvesting systems can effectively utilize waste heat that would otherwise be lost to the environment, thereby improving overall energy efficiency and reducing dependence on conventional power sources.

Recent developments have focused on integrating TEG modules with energy storage systems and power conditioning circuits for practical applications. Various research works have demonstrated the use of DC-DC converters to regulate the fluctuating output voltage of TEGs and enable efficient battery charging. Studies also highlight the advantages of TEG systems, such as the absence of moving parts, low maintenance requirements, silent operation, and long operational life. These characteristics make TEG technology a promising solution for sustainable energy generation in automotive, industrial, and renewable energy sectors, encouraging further research and development in waste heat recovery applications.

III. GLOBAL OBSERVATION (INTERNATIONAL STATICS)

The efficient utilization of energy has become a major concern worldwide due to the increasing demand for power and the depletion of conventional energy resources. According to international energy reports, a significant portion of the energy produced in industries, automobiles, and power plants is lost as waste heat. It is estimated that more than half of the primary energy consumed globally is released into the environment as unused thermal energy. Recovering even a small percentage of this wasted heat can contribute substantially to global energy conservation efforts.

Many developed countries, including the United States, Germany, Japan, China, and South Korea, have actively invested in waste heat recovery technologies to improve energy efficiency and reduce greenhouse gas emissions. Thermoelectric Generator (TEG) technology has emerged as one of the promising solutions because it can directly convert heat into electricity without requiring moving mechanical components. Research institutions and industries across the world are focusing on developing advanced thermoelectric materials and high-performance TEG systems for automotive, industrial, and renewable energy applications.

The global market for thermoelectric generators is experiencing steady growth due to increasing awareness of sustainable energy technologies and stricter environmental regulations. TEG systems are being deployed in vehicle exhaust heat recovery, industrial furnaces, power generation units, and remote monitoring systems. Continuous advancements in thermoelectric materials, power conditioning circuits, and energy storage technologies are enhancing the efficiency and practicality of TEG-based systems. These developments demonstrate the growing importance of waste heat recovery in achieving global energy efficiency, reducing carbon emissions, and supporting a sustainable future.

IV. INDIAN STATICS

India is one of the world's largest energy consumers, with rapid industrialization and increasing transportation demands contributing to high energy usage. Studies indicate that a significant amount of energy in industries such as steel, cement, power generation, and manufacturing is lost as waste heat. Recovering this energy can help improve efficiency, reduce fuel consumption, and support the nation's energy conservation goals.

To promote sustainable development, India has introduced various initiatives focusing on energy efficiency and renewable energy technologies. Research institutions and industries are actively exploring Thermoelectric Generator (TEG) systems for waste heat recovery in automobiles and industrial applications. The adoption of such technologies can contribute to reduced carbon emissions, lower operating costs, and enhanced utilization of available energy resources.

V. METHODOLOGY

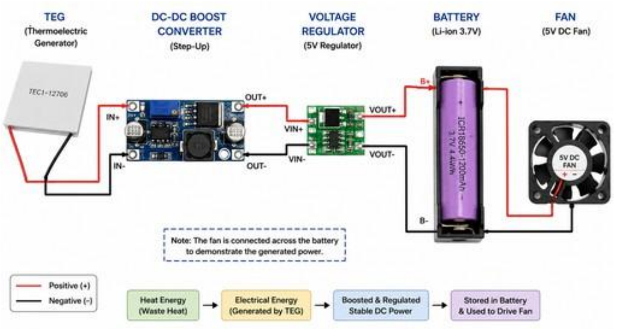

Fig.1 circuit diagram

In recent years, the Government of India has emphasized energy conservation through programs led by organizations such as the Bureau of Energy Efficiency and the Ministry of New and Renewable Energy. These initiatives encourage industries to adopt innovative technologies that improve energy utilization and reduce environmental impact. Waste heat recovery systems are increasingly being recognized as an effective solution for enhancing industrial productivity while supporting national sustainability objectives.

The growing automotive sector in India also presents significant opportunities for the implementation of Thermoelectric Generator (TEG) technology. Vehicles generate a considerable amount of heat through engine operation and exhaust gases, much of which remains unused. By integrating TEG-based energy harvesting systems, this waste heat can be converted into electrical energy for battery charging and auxiliary power applications. Such advancements can contribute to improved fuel efficiency, reduced emissions, and the development of cleaner transportation technologies in the country.

VI. UNVEILING THE INNER WORKINGS

The proposed system is designed to harvest waste thermal energy and convert it into useful electrical power through the use of Thermoelectric Generator (TEG) modules. In many industrial machines, automobile engines, exhaust systems, and electronic equipment, a large amount of energy is dissipated as heat into the surrounding environment. Instead of allowing this thermal energy to go unused, the system captures it and utilizes it as a source for power generation. The core component of the system is the TEG module, which operates based on the Seebeck Effect. According to this principle, when a temperature difference exists between two sides of a thermoelectric material, an electrical voltage is generated. One side of the TEG module is placed in contact with the heat source, while the opposite side is connected to a heat sink to maintain a lower temperature. This temperature gradient enables the direct conversion of thermal energy into electrical energy.

The voltage generated by a single TEG module is generally low and depends on the magnitude of the temperature difference. To improve power generation capability, multiple TEG modules can be connected in series or parallel configurations. The raw electrical output obtained from the TEG modules may fluctuate due to variations in the heat source and environmental conditions. Therefore, the generated power is supplied to a DC-DC boost converter, which increases the voltage to a required level and provides a stable output. Voltage regulation circuits are also incorporated to ensure safe and efficient operation of the system. These power conditioning stages are essential for maximizing energy utilization and preventing damage to connected components due to voltage fluctuations.

Once the electrical output is properly regulated, it is directed to a rechargeable battery charging circuit. The charging circuit controls the flow of current and ensures that the battery is charged safely and efficiently. The stored energy can later be used to power various low-power electronic devices, sensors, monitoring systems, communication modules, and auxiliary loads. The inclusion of a battery storage unit allows the generated energy to be utilized even when the heat source is unavailable or when the temperature difference decreases. This feature enhances the reliability and practicality of the overall system for real-world applications.

An important advantage of the proposed system is that it contains no moving mechanical parts. As a result, it operates silently, requires very little maintenance, and offers a long operational lifespan compared to conventional energy generation systems. Furthermore, the system does not consume additional fuel or produce harmful emissions during operation, making it an environmentally friendly solution. By converting waste heat into useful electrical energy, the system improves overall energy efficiency, reduces energy losses, and contributes to sustainable energy management practices.

The proposed TEG-based waste heat recovery system can be implemented in a wide range of applications, including automobiles, industrial plants, power generation facilities, and renewable energy systems. As research in thermoelectric materials and power electronics continues to advance, the efficiency and performance of TEG systems are expected to improve further. This makes thermoelectric energy harvesting a promising technology for future energy conservation efforts. The project successfully demonstrates how waste heat, which is typically considered a by-product, can be transformed into a valuable source of electrical energy for battery charging and other practical applications.

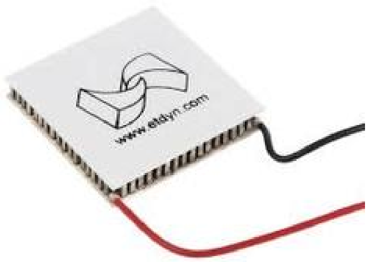

Fig.2 TEG Module

The Thermoelectric Generator (TEG) module is the primary component of the proposed waste heat recovery system and plays a crucial role in converting thermal energy into electrical energy. A TEG module operates based on the Seebeck Effect, a phenomenon in which an electrical voltage is generated when there is a temperature difference between two dissimilar semiconductor materials. The module consists of multiple pairs of P-type and N-type semiconductor elements electrically connected in series and thermally connected in parallel. When one side of the module is exposed to a heat source and the other side is maintained at a lower temperature, charge carriers move from the hot side to the cold side, producing a direct current (DC) voltage. The amount of voltage generated depends on the temperature difference across the module, making effective heat transfer and cooling essential for maximizing power output.

The primary purpose of a TEG module is to recover energy that would otherwise be wasted as heat and convert it into useful electrical power. Unlike conventional power generation systems, TEG modules do not require moving parts, turbines, or complex mechanical arrangements. This results in silent operation, high reliability, low maintenance requirements, and long service life. TEG modules are compact, lightweight, environmentally friendly, and capable of operating continuously as long as a temperature gradient exists. Due to these advantages, they are widely used in waste heat recovery systems, automotive exhaust energy harvesting, industrial applications, aerospace systems, remote power supplies, and renewable energy projects.

Fig.3 IR Sensor

The DC Boost Converter Module is an essential component in the proposed Energy Generation from Waste Heat and Charging the Battery Using TEG system. The electrical output generated by a Thermoelectric Generator (TEG) is typically low and varies depending on the temperature difference across the module. In many cases, the voltage produced by the TEG is insufficient for directly charging a battery or powering electronic devices. Therefore, a DC Boost Converter is used to increase the low input voltage from the TEG to a higher and more stable output voltage suitable for battery charging and other applications.

A DC Boost Converter is a type of DC-DC power electronic converter that steps up the input voltage while maintaining efficient power transfer. It consists of key components such as an inductor, switching transistor, diode, capacitor, and control circuitry. During operation, the converter stores energy in the inductor and then releases it at a higher voltage level through rapid switching action. This process enables the converter to transform a low and fluctuating voltage into a regulated output voltage. Modern boost converters offer high conversion efficiency, compact size, low power loss, and reliable performance, making them suitable for energy harvesting applications.

In this project, the DC Boost Converter plays a vital role in ensuring that the electrical energy generated by the TEG can be effectively utilized. Since the TEG output changes with variations in heat source temperature, the boost converter stabilizes the voltage and provides a consistent output for the battery charging circuit. Without the converter, the generated voltage may be too low or unstable to charge the battery efficiently. By increasing the voltage to the required level, the DC Boost Converter maximizes the usability of the harvested energy and improves the overall performance of the system.

The inclusion of a DC Boost Converter significantly enhances the effectiveness of the waste heat recovery system. It enables efficient energy transfer from the TEG module to the battery, minimizes energy losses, and ensures reliable charging under varying operating conditions. Thus, the DC Boost Converter acts as a critical interface between the energy generation stage and the energy storage stage, contributing to the successful implementation of the project.

Fig.4 ESP8266 WiFi Module

The 5V DC Fan is used in this project as a demonstration load to show the practical utilization of the electrical energy generated by the Thermoelectric Generator (TEG). When waste heat is applied to the TEG module, it converts thermal energy into electrical energy through the Seebeck Effect. The generated electricity can then be used to operate low-power devices such as a DC fan, providing a clear demonstration of successful energy conversion.

The fan operates on a 5V DC supply and requires relatively low power, making it suitable for testing and demonstration purposes. When the TEG generates sufficient voltage and the output is boosted using the DC Boost Converter, the fan starts rotating, visually indicating that electrical power is being produced from waste heat. This helps verify the effectiveness of the energy harvesting system and allows easy observation of the generated output.

In this project, the 5V DC fan serves as an output device that demonstrates the capability of the system to convert waste heat into usable electrical energy. Its operation confirms that the generated power can be utilized for practical applications and highlights the potential of TEG technology for powering small electronic devices and charging batteries using recovered waste heat energy.

Fig.5 Thermal Paste

Thermal paste is an important material used in the proposed Thermoelectric Generator (TEG) system to improve heat transfer between the contact surfaces. It is a thermally conductive compound applied between the heat source and the hot side of the TEG module, as well as between the cold side of the TEG and the heat sink. Since the surfaces of these components are not perfectly smooth, tiny air gaps can exist between them.

Air is a poor conductor of heat, which can reduce the efficiency of heat transfer. Thermal paste fills these microscopic gaps and provides a better thermal path for heat flow.

The primary purpose of thermal paste is to maximize the temperature difference across the TEG module, which is essential for efficient power generation. By improving thermal conductivity between the contacting surfaces, more heat reaches the hot side of the TEG while heat is effectively removed from the cold side through the heat sink. This enhanced heat transfer increases the voltage and power output generated by the TEG module.

In this project, thermal paste plays a crucial role in improving the overall performance of the waste heat recovery system. Without thermal paste, heat transfer losses may occur, reducing the effectiveness of the TEG module and lowering electrical power generation. Therefore, the use of thermal paste helps achieve better energy conversion efficiency, improved system reliability, and more effective battery charging from the recovered waste heat energy.

VII. HARMONIZING TRADITION

The food processing and culinary industries consume significant amounts of energy during cooking, baking, boiling, and heating operations. A large portion of this energy is released into the environment as waste heat. Traditional cooking methods have long relied on thermal energy for food preparation, while modern technological advancements focus on improving efficiency and sustainability. The integration of Thermoelectric Generator (TEG) technology provides an innovative approach to utilizing this otherwise wasted thermal energy.

By incorporating TEG modules into cooking and food-processing environments, waste heat generated from ovens, stoves, furnaces, and industrial cooking equipment can be converted into useful electrical energy. This recovered energy can be used for charging batteries, powering sensors, operating monitoring systems, or supporting other low-power electronic devices within the facility. Such integration enhances energy utilization while reducing overall power consumption.

The combination of traditional heat-based processes with modern energy harvesting technology demonstrates how innovation can improve sustainability without altering existing operational methods. This approach promotes energy conservation, reduces environmental impact, and supports the development of smart and efficient systems. The project highlights the potential of TEG technology to bridge conventional thermal applications with modern energy management solutions, creating a pathway toward more sustainable industrial and commercial practices.

TECHNOLOGY IN CULINARY INNOVATION

Technology has transformed the culinary industry by improving food preparation, processing, storage, and overall operational efficiency. Modern kitchens and food processing facilities increasingly utilize advanced equipment, automation systems, sensors, and energy-efficient technologies to enhance productivity and maintain food quality. These innovations help reduce manual effort, improve consistency, ensure food safety, and optimize resource utilization.

One of the major areas of technological innovation in the culinary sector is energy management. Cooking equipment such as ovens, stoves, boilers, and industrial food processing machines generate significant amounts of heat during operation. Advanced technologies now focus on recovering and utilizing this waste heat instead of allowing it to be lost to the environment. Thermoelectric Generator (TEG) technology is one such innovation that can convert waste thermal energy into useful electrical energy, improving overall energy efficiency and reducing operating costs.

The integration of modern technology with culinary practices supports sustainability, energy conservation, and environmental protection. Smart monitoring systems, automated controls, and energy recovery solutions enable more efficient operation while maintaining high standards of food production. As technological advancements continue to evolve, the culinary industry is expected to become increasingly intelligent, sustainable, and resource-efficient, benefiting both businesses and consumers.

IX. CONNECTING CULINARY WORLDS

The culinary industry has evolved significantly through the exchange of ideas, techniques, and technologies across different cultures and regions. Traditional cooking methods developed over centuries are now being combined with modern innovations to improve efficiency, sustainability, and food quality. This connection between diverse culinary practices has enabled the adoption of advanced technologies that support better resource utilization and environmentally responsible operations.

In modern food processing and cooking environments, large amounts of heat are generated and often lost as waste. By integrating technologies such as Thermoelectric Generators (TEGs), this waste heat can be converted into useful electrical energy. The recovered energy can be utilized for powering monitoring systems, charging batteries, or supporting low-power electronic devices within food preparation and processing facilities. Such applications demonstrate how technological advancements can enhance traditional thermal processes without affecting their core functionality.

The concept of connecting culinary worlds extends beyond cultural exchange and includes the integration of sustainability with innovation. By combining established cooking practices with energy-efficient technologies, industries can reduce energy wastage, lower operational costs, and minimize environmental impact. This approach supports the development of smarter and more sustainable food systems while preserving the value of traditional culinary methods.

VIII. INNOVATION

Innovation plays a vital role in addressing modern energy challenges by developing efficient and sustainable solutions for power generation. The proposed project introduces an innovative approach to energy harvesting by utilizing waste heat, a commonly overlooked energy source, and converting it into useful electrical energy through Thermoelectric Generator (TEG) technology. Instead of allowing thermal energy to dissipate into the environment, the system captures and transforms it into electricity that can be stored and utilized for practical applications.

The project combines multiple technologies, including thermoelectric energy conversion, voltage boosting, battery charging, and energy storage, into a single integrated system. The use of TEG modules enables direct conversion of heat into electricity without moving parts, resulting in a reliable, silent, and low-maintenance solution. The incorporation of a DC boost converter further enhances system performance by regulating and increasing the generated voltage to a level suitable for charging batteries and powering small electronic devices.

This innovation contributes to improved energy efficiency, reduced energy wastage, and environmental sustainability. By demonstrating the practical use of waste heat recovery for electrical power generation, the project highlights the potential of thermoelectric technology in future automotive, industrial, and renewable energy applications. The system serves as an example of how innovative engineering solutions can transform unused energy resources into valuable sources of power.

X. NAVIGATING ADOPTION CHALLENGES AND SHAPING LANDSCAPES

Despite the advantages of Thermoelectric Generator (TEG) technology, several challenges must be addressed for its widespread adoption. One of the primary limitations is the relatively low energy conversion efficiency of current thermoelectric materials. The electrical output generated by TEG modules depends heavily on the temperature difference across the module, which may vary under different operating conditions. In addition, the initial cost of high-quality thermoelectric materials and associated power conditioning circuits can affect large-scale implementation.

Another challenge involves maintaining an effective temperature gradient between the hot and cold sides of the TEG module. Efficient cooling systems and proper thermal management techniques are required to maximize power generation. Variations in heat availability, environmental conditions, and system design can also influence the overall performance of the energy harvesting system. Continuous research is therefore necessary to improve material properties, increase efficiency, and reduce manufacturing costs.

Despite these challenges, the future outlook for TEG technology remains highly promising. Advancements in thermoelectric materials, power electronics, and energy storage systems are expected to enhance performance and expand application areas. As industries and governments increasingly focus on energy conservation and sustainable development, waste heat recovery systems are likely to become more widely adopted. The proposed project demonstrates the potential of TEG-based energy harvesting and contributes to the growing movement toward efficient, eco-friendly, and innovative energy solutions for the future.

XI. DECODING THE TECHNOLOGICAL FRAMEWORK

The proposed Energy Generation from Waste Heat and Charging the Battery Using Thermoelectric Generator (TEG) system is designed using a combination of thermal energy harvesting, power conditioning, and energy storage technologies. The core component of the system is the Thermoelectric Generator (TEG) module, which converts waste heat into electrical energy through the Seebeck Effect.

A temperature difference is maintained across the TEG module by exposing one side to a heat source while keeping the other side cool using a heat sink and cooling arrangement. This temperature gradient enables the generation of electrical power without the use of moving mechanical parts.

The electrical output produced by the TEG module is generally low and varies with changes in temperature. To overcome this limitation, a DC Boost Converter is incorporated into the system. The converter increases and regulates the generated voltage to a suitable level for battery charging and other applications. Thermal paste is applied between the contact surfaces to improve heat transfer efficiency, while a heat sink and cooling fan help maintain an effective temperature difference across the TEG module. These supporting components work together to maximize energy conversion efficiency and system performance.

The regulated electrical energy is then supplied to a rechargeable battery charging circuit, where the generated power is stored for future use. A 5V DC fan is also used as a demonstration load to visually indicate successful power generation from waste heat. The integration of energy harvesting, voltage regulation, cooling mechanisms, and battery storage creates a complete and efficient technological framework. This framework demonstrates how waste thermal energy can be transformed into useful electrical energy, contributing to energy conservation and sustainable power generation.

XII. CONCLUSION

In conclusion, the integration of modern technology into culinary and automation systems has significantly transformed traditional practices by improving efficiency, safety, sustainability, and user convenience. Technologies such as Arduino Nano, IR sensors, ESP8266 Wi-Fi modules, and solar energy systems contribute to the development of intelligent and eco-friendly solutions for home and industrial applications. These innovations support touchless operation, real-time monitoring, and energy-efficient performance while preserving the functional value of traditional systems. Despite challenges related to cost, technical complexity, and user adaptation, continuous advancements in embedded systems and IoT technologies are accelerating adoption across various sectors. The collaboration between engineering, automation, and sustainable energy concepts creates opportunities for future smart environments with enhanced reliability and productivity. Furthermore, renewable energy integration promotes environmental responsibility and reduces operational expenses. As technology continues to evolve, smart automated systems are expected to become more accessible, adaptive, and user-friendly.

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