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Thermoelectric Generator Module in Driving the Vehicle and Monitoring using IoT

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Abstract: This paper presents a thermoelectric generator (TEG)-based system for driving a vehicle and monitoring performance using IoT technology. A significant portion of energy in automobiles is lost as waste heat, which can be converted into useful electrical energy using TEG modules based on the Seebeck effect.

Keywords: Thermoelectric Generator (TEG), Waste Heat Recovery, Seebeck Effect, IoT Monitoring, ESP32, DC–DC Boost Converter, Energy Efficiency

I. INTRODUCTION

The automobile industry has significantly increased energy consumption and environmental pollution. A large portion of fuel energy is wasted as heat in vehicle engines. Thermoelectric generators provide a method to convert this waste heat into electrical energy.

In this system, a TEG module is placed near the exhaust to generate power. Since the output is low and unstable, a DC–DC converter is used. Additionally, IoT-based monitoring using ESP32 enables real-time tracking of system parameters. In this project, a **thermoelectric generator module is installed near the vehicle's heat source** to capture the wasted thermal energy produced during vehicle operation. The generated electrical output is usually small and varies depending on temperature conditions. Therefore, a **DC–DC converter** is used to regulate and stabilize the voltage to make it suitable for powering low-power electronic devices in the vehicle. This generated power can be used to support auxiliary loads such as sensors, monitoring circuits, and small electronic systems, thereby reducing the load on the vehicle battery.

II. LITERATURE REVIEW

1. Waste Heat Recovery in Automobiles
   Many researchers have identified that a large amount of energy in vehicles is lost as heat through exhaust systems, which can be effectively utilized for power generation.

2. Thermoelectric Generator Principle
   Studies based on the Seebeck Effect show that temperature differences can be directly converted into electrical energy using thermoelectric modules.

3. Improvement in Thermoelectric Materials
   Research has focused on enhancing semiconductor materials to increase efficiency, durability, and output performance of thermoelectric generators.

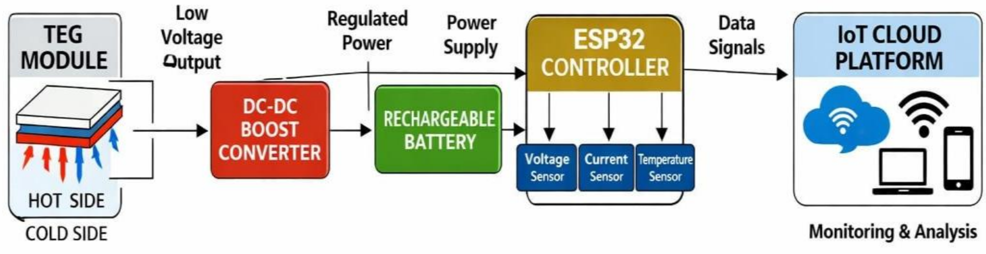
III. SYSTEM DESIGN AND COMPONENTS

The proposed system is designed to convert waste heat energy into electrical energy and monitor system performance using IoT. It consists of a thermoelectric generator module, sensors, power conditioning circuits, and a microcontroller for data processing and communication.

A. Thermoelectric Generator (TEG) Module
The TEG module is the main component used to generate electricity from heat. It works based on the Seebeck Effect, where a temperature difference across the module produces voltage. It is placed near the vehicle exhaust to capture heat energy.

B. Sensors
- O Temperature Sensor
- o Voltage Sensor
- o Current Sensor

C. Microcontroller (ESP32)
The ESP32 microcontroller is used for processing sensor data and transmitting it to the cloud using Wi-Fi. It plays a key role in enabling the Internet of Things based monitoring system.



The block diagram illustrates the working of the thermoelectric generator (TEG) based energy harvesting and monitoring system. The TEG module converts waste heat into electrical energy using the Seebeck effect, where a temperature difference between the hot and cold sides generates a low voltage output. Since the generated voltage is small and unstable, it is fed into a DC–DC boost converter to increase and regulate the voltage to a usable level.

The regulated power is stored in a rechargeable battery, which acts as an energy storage unit and provides a stable power supply to the system. An ESP32 microcontroller is used as the main controller to process and manage system operations. Various sensors such as voltage, current, and temperature sensors are connected to the controller to monitor system parameters in real time.

IV. WORKING

The operation of the proposed circuit is based on converting waste heat energy into electrical energy using a thermoelectric generator and monitoring the generated parameters using an IoT-based system. The complete system consists of a thermoelectric generator module, a DC–DC boost converter, sensors, an ESP32 microcontroller, and a cloud monitoring platform.

Initially, heat is applied to the thermoelectric generator module from a heat source such as the vehicle exhaust system. The thermoelectric module works based on the Seebeck effect, where a temperature difference between the hot side and cold side of the module generates a small electrical voltage. The hot side of the module is exposed to the heat source, while the cold side is maintained at a lower temperature using a heat sink or surrounding air. Due to this temperature difference, electrical energy is produced at the output terminals of the thermoelectric module.

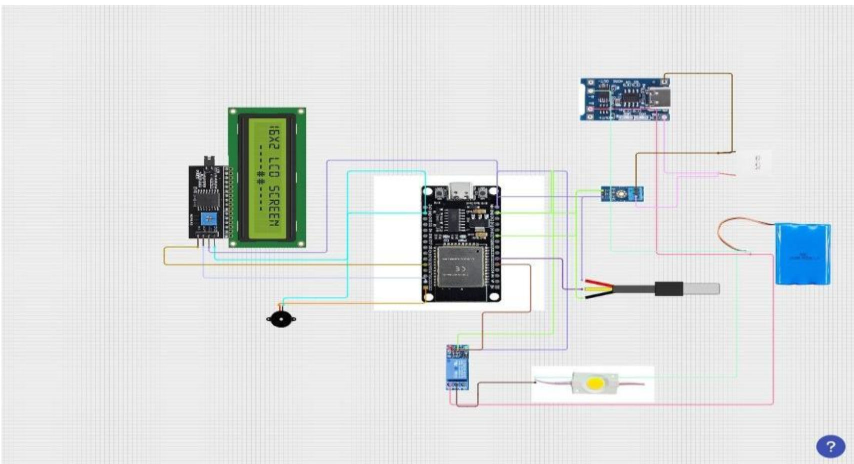


Fig. 2 Circuit Diagram

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The voltage generated by the thermoelectric generator is usually low and unstable. Therefore, a DC–DC boost converter is used in the circuit to increase and regulate the voltage to a suitable level. The boost converter steps up the low input voltage and provides a stable output voltage required for the operation of the electronic components in the system.

The regulated voltage is supplied to the ESP32 microcontroller, which acts as the main control unit of the system. Sensors connected to the ESP32 measure important parameters such as temperature, voltage, and current produced by the thermoelectric generator. The analog signals from the sensors are converted into digital values using the analog-to-digital converter (ADC) available in the ESP32.

V. RESULT

The proposed system for **thermoelectric power generation and IoT monitoring** was successfully implemented and tested. The thermoelectric generator module was placed near the heat source to create a temperature difference between the hot side and cold side of the module. When heat was applied, the thermoelectric module generated electrical voltage due to the Seebeck effect

The generated voltage was initially low and unstable. A DC–DC boost converter was used to increase the voltage to a stable level suitable for powering the electronic circuit and the ESP32 microcontroller. The boost converter successfully increased the output voltage and maintained a steady power supply.

The IoT monitoring system successfully displayed the system parameters in real time. Users were able to observe the temperature difference, generated voltage, and current values through the cloud dashboard. The monitoring system allowed continuous observation of the thermoelectric generator performance

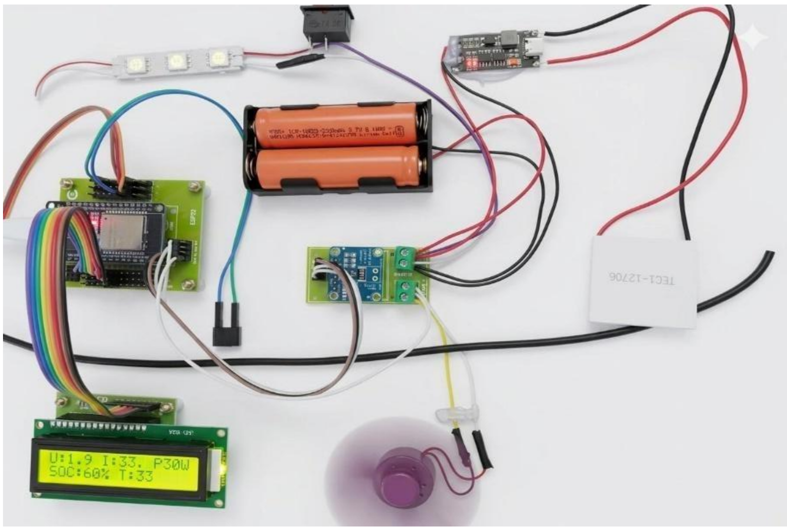

Fig. 3 Output with Hardware

The experimental results showed that the system effectively converts waste heat energy into electrical power while simultaneously monitoring system parameters through IoT technology.

VI. CONCLUSION

The proposed IoT-based overvoltage and undervoltage protection system using ESP32 provides an effective solution for protecting electrical equipment from harmful voltage fluctuations. In this system, the AC voltage sensor and AC current sensor continuously monitor the electrical parameters of the power supply. The ESP32 microcontroller processes the collected data and compares it with predefined threshold values to detect abnormal conditions.

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