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ELECTRICAL ENEGRY GENERATION FROM EXHAUST HEAT

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Abstract: The increasing demand for sustainable energy solutions has led to the exploration of alternative methods for energy generation, one of which is harnessing waste heat from industrial processes. This thesis focuses on the development of a system that converts exhaust heat into electrical energy. Exhaust gases, often considered a byproduct, contain significant thermal energy that can be efficiently utilized to produce power. The proposed system utilizes thermoelectric generators (TEGs), which exploit the temperature gradient between hot exhaust gases and the cooler environment to generate electricity. The research explores various heat transfer techniques, thermoelectric materials, and system configurations to maximize efficiency. In addition, simulations and experimental setups are used to evaluate performance parameters such as output voltage, power generation capacity, and overall system efficiency. The results of this study aim to contribute to the field of energy recovery by offering a viable solution to reduce energy consumption and environmental impact, thereby improving the sustainability of industrial operations. This work highlights the potential for integrating waste heat recovery technologies in real-world applications, emphasizing their role in the transition to a more energy-efficient and sustainable future. The core technology employed in this study is thermoelectric generation (TEG), a solid-state method of converting temperature differences directly into electrical voltage through the Seebeck effect. Thermoelectric materials are central to the success of TEGs, and this research evaluates various materials based on their thermoelectric performance, including their electrical conductivity, thermal conductivity, and Seebeck coefficient.

Keywords: Waste heat recovery, Seebeck effect, Exhaust heat energy, Renewable energy,

Voltage generation, Current generation, Power generation, DC-DC Converter

INTRODUCTION

This thesis explores the concept of converting exhaust heat into electrical energy using thermoelectric generators (TEGs) and other waste heat recovery technologies. By harnessing the Seebeck effect, where a temperature difference generates electrical voltage, TEGs provide a sustainable and efficient way to convert exhaust heat into usable electricity. This process has to enhance energy efficiency in industries, automotive applications, and power plants. The study focuses on the design, implementation, and performance evaluation of an exhaust heat-to-electricity conversion system. It aims to assess the feasibility, efficiency, and practical applications of this technology, highlighting its benefits in reducing fuel consumption and greenhouse gas emissions. The research will also explore advancements in thermoelectric materials, system optimization, and integration possibilities for various applications. Energy demand is continuously increasing due to rapid industrialization and technological advancements, leading to a greater reliance on fossil fuels. However, a significant amount of energy is lost as waste heat in various industrial processes and internal combustion engines. Recovering and utilizing this waste heat can improve energy efficiency and reduce environmental impact. TECs make use of what is known as the Seebeck effect. When one side of the cell is heated and the other side cooled, a voltage is generated. The voltage generation means there are applications for these cells to generate electricity where temperature differences are present. This makes them heat engines much like ICEs. The advantages they have over mechanical heat engines are that they are silent, very small, completely scalable and durable. Their key advantage is that they have no moving parts and no chemical reactions therefore there is little maintenance required due to wear and corrosion. Their efficiency is typically 5% [3] compared to about 25% for ICEs but they can generate power from any temperature difference unlike ICEs. As with all heat engines, their efficiency is limited by the Carnot efficiency so the higher the temperature difference, the more efficient they will be. Heat engines have rejected heat which is why one side needs to be cooled. Conversely, when a voltage is applied to it, it creates a temperature difference. At the atomic scale, an applied temperature gradient causes charge carriers in the material to diffuse from the hot side to the cold side.

OVERVIEW OF THE SYSTEM

This system captures waste heat from the exhaust of an automobile using thermoelectric generators (TEGs), which convert heat energy into electrical energy. The generated energy is then processed, regulated, and utilized for various applications such as powering auxiliary vehicle electronics, charging batteries, or running cooling fans.

The key functions of this system include:

- Heat-to-Electricity Conversion: Thermoelectric modules use the Seebeck effect to generate electricity from the temperature difference between the hot exhaust gases and a cooling side.
- Power Conditioning: The raw output from the TEGs is conditioned using current and voltage sensors, a boost converter, and an active relay to maintain efficiency.
- Energy Utilization: The system regulates power for various applications, such as powering a cooling fan to maintain TEG efficiency.

1. **Display:** A Liquid Crystal Display (LCD) used to present real-time data, system status, and alerts. It provides a clear and user-friendly interface for monitoring safety parameters.
2. **ESP32:** The ESP32 is a versatile and widely-used microcontroller and Wi-Fi/Bluetooth system -on- chip (SoC) produced by Expressive Systems. A SoC, is essentially an integrated circuit that takes a single platform and integrates an entire electronic system onto it, for an specific application.
3. **BOOST CONVERTER:** A boost converter (step-up chopper) is a device that increases the input DC voltage to a higher output DC voltage. The boost converter circuit includes an inductor, switch, diode, capacitor, and load, each playing a vital role in its operation. Pulse Width Modulation (PWM) controls the switching in the converter, with time-based PWM preferred for its simplicity and constant frequency.
4. **INA219:** The INA219 is a high-side current and voltage monitor chip with an I2C interface, designed to measure DC current and voltage, and calculate power, typically used in applications like battery monitoring or solar panel tracking The INA219 module is designed to detect variations in voltage across shunts on buses within the range of 0 to 26 V.

5. **RECHARGEABLE BATTERY:** A rechargeable battery is a crucial component in many electronic projects, providing a reusable and sustainable power source. Unlike disposable batteries, rechargeable batteries can be charged multiple times, reducing waste and long-term costs. The choice of battery depends on factors such as voltage, capacity, discharge rate, size
6. **DHT11:** The DHT11 is a basic, ultra low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor to measure the surrounding air, and spits out a digital signal on the data pin (no analog input pins needed). Its fairly simple to use, but requires careful timing to grab data. You can get new data from it once every 2 seconds, so when using the library from Adafruit, sensor readings can be up to 2 seconds old. Comes with a 4.7K or 10K resistor, which you will want to use as a pullup from the data pin to VCC.
7. **COOLING FAN:** A cooling fan plays a crucial role in a thermoelectric energy generation system by maintaining a stable temperature gradient across the TEC1-12706 thermoelectric module. Efficient heat dissipation on the hot side enhances power generation efficiency by ensuring a greater temperature difference (ΔT) between the hot and cold sides of the module.
8. **TEC1-12706:** TEC1-12706 is a thermoelectric cooler (TEC) module that operates based on the Peltier effect. While it is commonly used for cooling applications, it can also function as a thermoelectric generator (TEG) by utilizing the Seebeck effect, converting waste heat into electrical energy. This makes it suitable for energy harvesting from exhaust heat in thermal-to-electric conversion systems.
9. **SCHOTTKY DIODE:** The schottky diode is a type of metal – semiconductor junction diode, which is also known as hot-carrier diode, low voltage diode or schottky barrier diode. The schottky diode is formed by the junction of a semiconductor with a metal. Schottky diode offers fast switching action and has a low forward voltage drop. As we are aware that in a PN junction diode, p-type and n-type are joined together to form a PN junction. Whereas, in a Schottky diode metals like platinum or aluminum are used instead of P type semiconductors.
10. **SWITCH:** Switch is an electrical component that can disconnect or connect the conducting path in an electrical circuit, interrupting the electric current or diverting it from one conductor to another. The most common type of switch is an electromechanical device consisting of one or more sets of movable electrical contacts connected to external circuits.

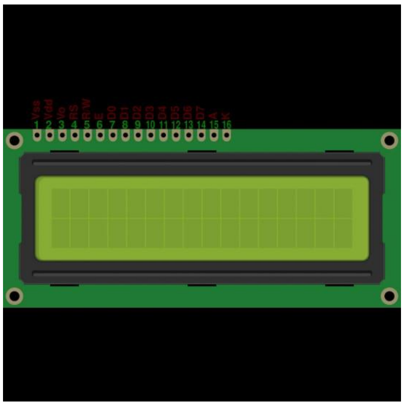


Fig.1 DISPLAY

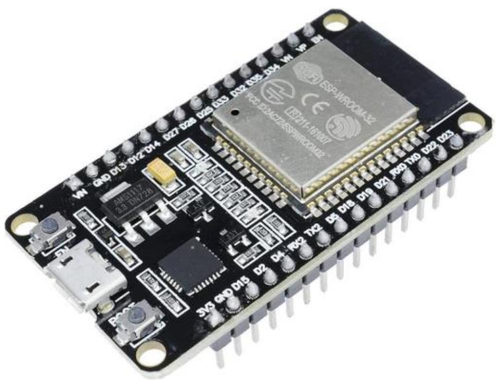


Fig.2 ESP32

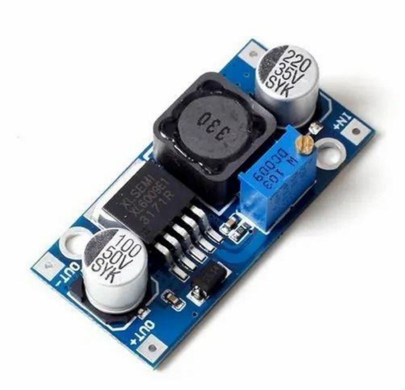


Fig.3 BOOST CONVERTER

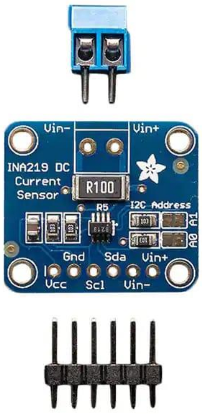


Fig.4 INA219

Fig.5 RECHARGEABLE BATTERY

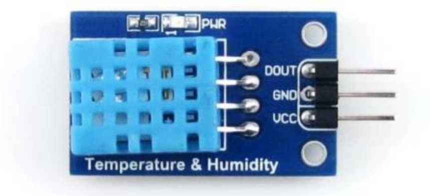


Fig.6 DHT11

Fig.7 COOLING FAN

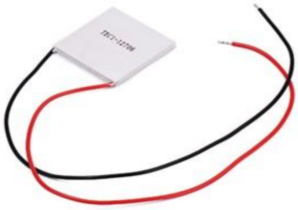
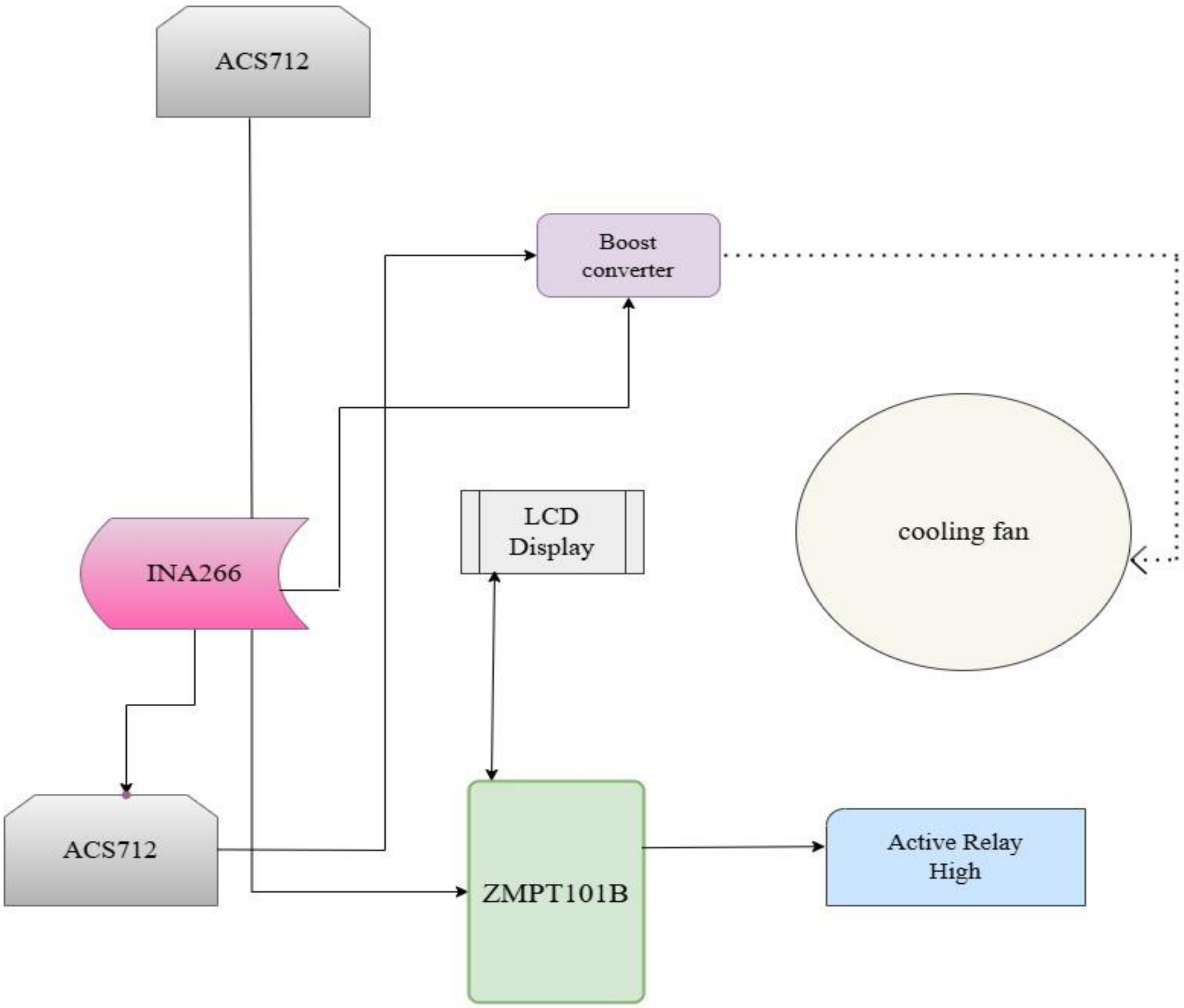


Fig.8 TEC1-12706

Fig.9 SCHOTTKY DIODE

Fig.10 SWITCH

BLOCK DIAGRAM OF THE SYSTEM:



ANALYSIS AND DISCUSSION

The project successfully demonstrates the generation of electrical energy from exhaust heat using a thermoelectric generator (TEG)-based system. The system effectively captures waste heat from an exhaust source and converts it into electrical energy through the Seebeck Effect. Experimental observations indicate that the power output depends heavily on the temperature difference between the hot and cold sides of the TEG. When the temperature difference is high, the voltage output increases significantly, enhancing the overall energy conversion efficiency. Although TEGs generally have lower efficiency (around 5-10%), their ability to continuously generate power from waste heat makes them a practical solution for energy recovery. The voltage output from the TEG without additional components was found to be low and unstable, ranging from 0.5V to 2.5V, depending on the exhaust heat level. This voltage was insufficient for direct use in most applications. However, the integration of a booster converter successfully increased the voltage to a regulated 12V to 24V, making it suitable for battery charging and powering various components. The booster converter played a critical role in stabilizing the power output, ensuring that fluctuations in exhaust heat did not affect the system’s performance. By using multiple TEG modules, the system's power generation capacity was improved, making it more practical for small-scale applications like operating sensors and auxiliary systems. To manage the fluctuations in power generated by the TEG, a supercapacitor was employed as an energy buffer before transferring the energy to the battery storage system. The supercapacitor efficiently absorbed excess power during peak heat conditions and released it during lower heat conditions, ensuring a steady energy supply. The battery storage component further stabilized the power supply, allowing stored energy to be used even when the exhaust heat was not continuously available, such as when a vehicle engine was turned off. This combination of a supercapacitor and battery enhanced the reliability of the system, making it capable of providing consistent electrical output despite variations in exhaust temperature.In conclusion, the project effectively demonstrates the feasibility of converting waste heat into electrical energy using a thermoelectric generator and an efficient power management system. The combination of TEG, supercapacitor, booster converter, power sensors and battery storage ensures stable and usable electrical power output. This technology presents a promising approach to energy recovery in automobiles, industrial waste heat utilization, and renewable energy applications, ultimately contributing to energy efficiency and sustainability.

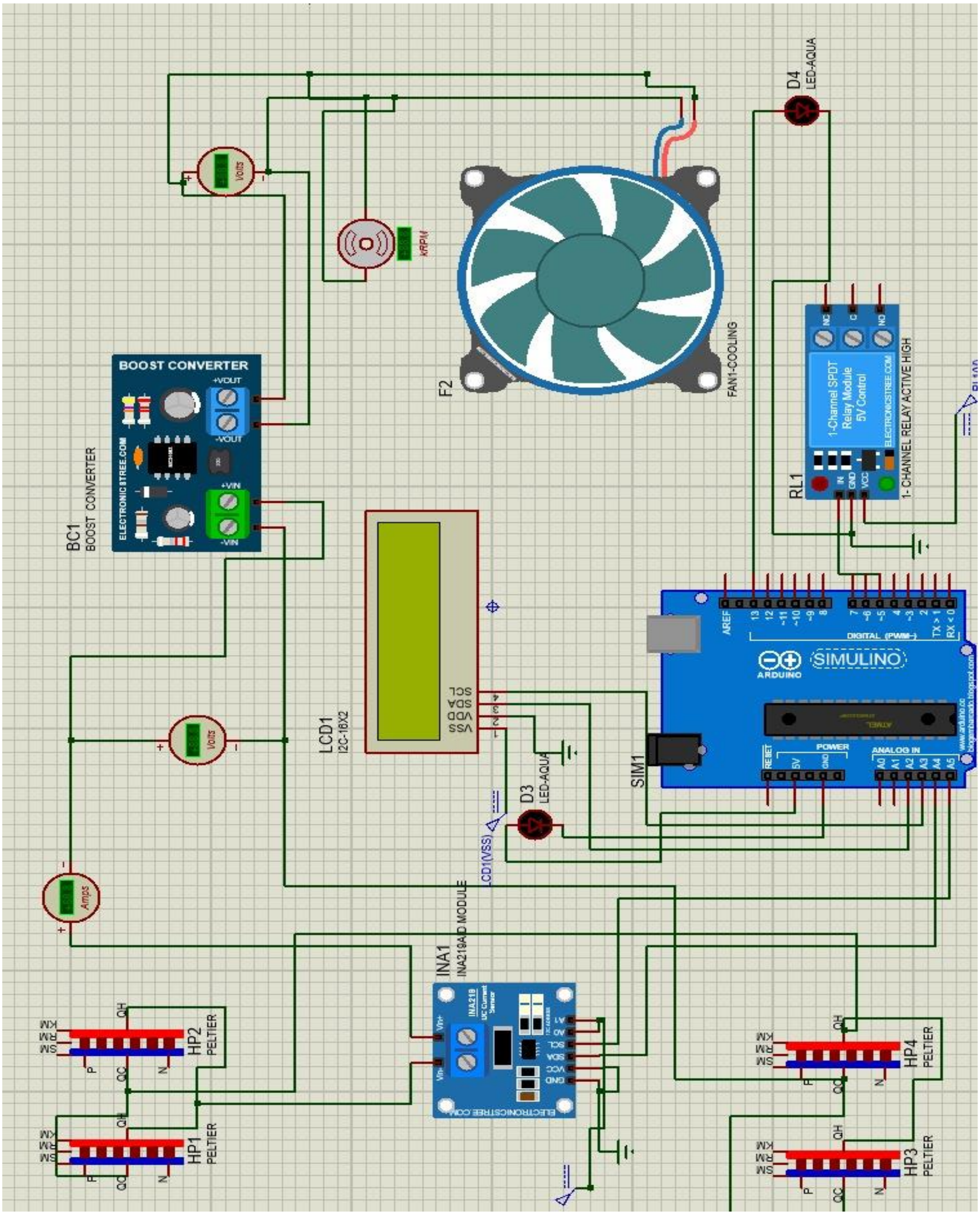


Fig.10. Architecture of the project

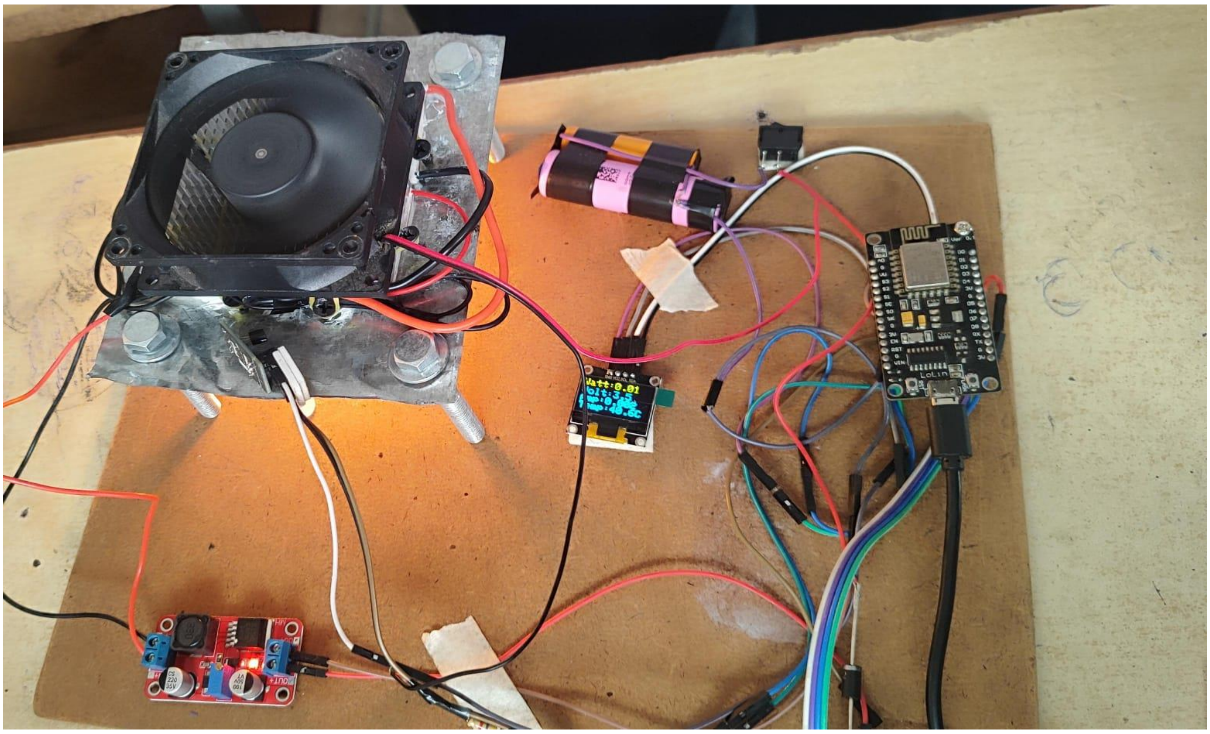


Fig.11. Top View of the Project

WORKING:

The project focuses on converting waste heat from exhaust gases into usable electrical energy through a thermoelectric generator (TEG) and an efficient power management system. This process involves multiple stages, from heat absorption to energy storage and utilization. Below is a detailed explanation of how each component works together to achieve this energy conversion.

1. Capturing Exhaust Heat:

The process begins with an exhaust heat source, such as a vehicle's exhaust system or industrial machinery. These systems release a significant amount of heat as a byproduct of combustion or mechanical operations. Instead of allowing this heat to dissipate, the system captures it and directs it to the thermoelectric generator.

2. Conversion of Heat to Electricity using TEG:

A thermoelectric generator (TECH-12706) is placed near the exhaust system to harness the thermal energy. The TEG works based on the Seebeck Effect, which states that when there is a temperature difference between its two sides (hot side facing the exhaust and cold side exposed to the surroundings), an electric current is generated. This direct conversion of heat into electricity is highly efficient and requires no moving parts, making it ideal for continuous energy generation. However, the power output from the TEG is usually low and unstable, requiring further processing.

3. Voltage Regulation using a Booster Converter:

Since the voltage generated by the TEG is usually low (in the range of millivolts to a few volts), it is stepped up using a booster converter. This converter increases the voltage to a level suitable for charging a battery or powering other electronic components. The booster ensures that a constant voltage is supplied, despite fluctuations in the exhaust heat levels.

4. Power Monitoring and Control:

A power monitoring system is integrated to ensure efficient operation and prevent damage to components. This system includes multiple sensors:

ACS712 (Current Sensor): Measures the amount of current flowing through the circuit.

INA266 (Voltage Sensor): Monitors the voltage levels, preventing overcharging or under-voltage issues.

ZMPT101B (Voltage Sensing Module): Detects voltage variations, ensuring stable power delivery.

These sensors provide real-time data about the system's performance, helping to optimize energy conversion and protect components from electrical failures.

5. Storing Energy in the Battery:

Once the voltage is regulated and monitored, the electrical energy is stored in a battery storage system. The battery serves as an energy reservoir, allowing the power to be used when needed, even when the exhaust heat is not available (e.g., when the vehicle engine is turned off).

6. Managing Power Distribution with an Active Relay:

An active relay acts as an automated switch, controlling the flow of electricity from the battery to various loads. Depending on the system's needs, the relay ensures that power is supplied efficiently without wastage.

7. Powering the Load (Cooling Fan and LCD Display):

Finally, the stored energy is used to power essential components such as a cooling fan and an LCD display. The cooling fan helps dissipate excess heat from the system, ensuring optimal performance and preventing overheating. The LCD display provides real-time information on voltage, current, and power output, allowing users to monitor system performance effectively.

This project efficiently captures and converts waste heat from an exhaust system into usable electrical energy. By integrating a thermoelectric generator, supercapacitor, booster converter, power sensors, and energy storage system, it provides a sustainable and eco-friendly solution for energy recovery. This technology can be applied in automobiles, industrial waste heat recovery, and renewable energy applications, reducing energy wastage and improving efficiency.

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