IOT-BASED THERMOELECTRIC GENERATOR MODULE FOR VEHICLE POWER GENERATION AND PERFORMANCE MONITORING

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Abstract - **Electric vehicles (EVs) have become popular, high growth around the world as a green alternative to systems that run on gas or diesel. This project represents a Thermoelectric Energy Harvesting System (TEG) aimed at enhancing the energy efficiency, balanced power production and sustainability of electric vehicles (EVs). The system's main job is to use thermoelectric generator (TEG) modules to turn the heat from the vehicle's battery pack into usable electrical energy. The primary function in this TEG where, temperature sensor kept close to the battery casing that aware on the temperature difference and turns ON the TEG when it goes over a certain level.**

The generated low-voltage output is then boosted using a DC–DC converter and stored in an auxiliary lithium battery managed with an small Battery Management System (BMS). This stored energy powers to low-voltage components sensors, microprocessors , microcontrollers , and IoT modules, ensuring efficient power utilization without depending on the main battery on EV cars. The overall design not only enhances energy recovery but also contributes to extended battery life, improved system reliability, self real-time , and the development of intelligent self-sustaining EV architectures for future mobility.

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Keywords— Wireless Power Transfer (WPT), LLC resonant converter, Synchronous rectification, Portable electronic devices, High-frequency DC–DC conversion, Air-gap tolerance, Energy efficiency.

I. INTRODUCTION

The transportation industry in EV is changing quickly that were good for the environment and reduce the consumption of High energy. Electric vehicles (EVs) are a big part of this change because they are a cleaner option than traditional fuel-based systems. But when EV batteries are charging and discharging, a lot of the energy is lost in form of heat. This waste parameter thermal energy not only makes the system less efficient, but it also weak down the battery power and slows down the system over time.

To overcome this challenge, One factor of tech approach involves **Thermoelectric Generator (TEG)** technology, which works on the **Seebeck effect**—a phenomenon where temperature differences across materials produce an electric voltage. In the proposed system, TEG modules are placed on the outer surface of the EV battery casing to capture the heat produced during operation. A temperature sensor continuously monitors battery temperature and activates the TEG only when the heat exceeds a predefined safe limit means to trigger then leads to ON TEG. This ensures that the system operates efficiently even in maintaining safety and reliability.

In earlier or one of the **existing systems**, thermoelectric energy harvesting has been widely used in **Internet of Things (IoT)** applications, where **Machine Learning (ML)** algorithms are incorporated to predict the amount of harvestable energy and manage power distribution intelligently. These models allow IoT devices to operate efficiently in remote or off-grid locations by regulating storage and consumption dynamically. Although effective in small-scale devices, such systems face challenges in large-scale EV environments due to irregular heat availability and environmental variations.

Building upon these prior developments, the proposed **TEG-based EV system** combines heat energy harvesting, voltage conversion, intelligent control, and IoT-based monitoring into a unified framework. The low-voltage output from the TEG modules is amplified using a **DC–DC boost converter** and stored in a **lithium-ion auxiliary battery** managed by a **Battery Management System (BMS)**. From there the Rasperry pi receives the input to take charge on IOT sensor controls

The system's compact and modular architectue makes it suit able for a wide range of EV type,from small electric bikes to bigger cars.

It improves battery performance by keeping temperature b alanced, saves waste energy, andmaintains operating safety.

By integrating thermoelectric conversion with smart IoT cha racteristics, the suggested model expands previousTEG rese arch beyond smallscale IoT devices scale EV applications , offering a sustainable, intelligent, and energy, efficient option for future electric transpotation

II .OBJECTIVE

The main goal of this project is to make electric vehicles (EVs) more efficient and environmentally friendly by using thermoelectric energy harvesting to turn waste heat from battery packs into usable energy. The goal is to create an intelligent auxiliary power generation system that uses Thermoelectric Generator (TEG) modules to turn battery heat into usable electricity. A temperature sensor keeps an eye on the battery's thermal state and turns on the TEG system when the right amount of heat is reached. A DC–DC converter boosts the power that is made and stores it in an.

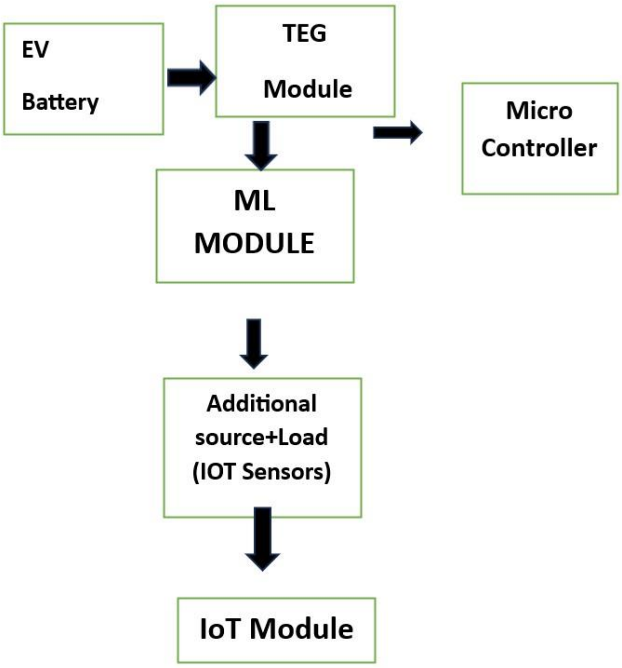

Fig-1 BLOCK DIAGRAM FOR EXISTING SYSTEM

III. PROPOSED SYSTEM

The proposed Thermoelectric Generator (TEG) system uses surface mounted TEG modules to absorb waste heat from EV battery packs, connected towards TEG module to convert it into electrical energy utilizing the Seebeck effect. A temperature sensor activates the system only when the temperature exceeds a predetermined threshold(like an trigger). A DC-DC converter boosts the low voltage output, because not TEG can produce more than 1.2v(single cell) which is then stored in a lithium ion auxiliary battery controlled by a BMS for safe operation.This energy drives sensors, IoT modules, and microprocessors such

The proposed system involves a series of consists of number interconnected processes efficient energy harvesting and management from EV batt ery heat.It begins with Temperature Detection and System A ctivation, in which a sensor near the battery pack continuous ly analyzes thermal conditions and activates the Thermoelec tric Generator (TEG) modules .
The temperature surpasses a predetermined threshold.The next step is Heat Energy Collection and TEG Integration, w hich involves TEG modules on the battery shell to convert te mperature differences into electrical voltage using the Seebe ck effect, allowing for direct thermal-to-electrical energy conversion.

- Temperature Detection and System Activation
- Heat Energy Collection and TEG Integration
- Voltage Boosting and Power Conditioning
- Energy Storage and Battery Management
- Microprocessor-Based Control Unit
- IoT-Based Real-Time Monitoring and Safety Regulation

Then comes Voltage Boosting and Power Conditioning, where the TEG's low output voltage (2V is increased to rou ghly 12V using a DC boost converter using components suc h as an inductor, MOSFET, diode, and capacitor regulated b y PWM for stable output.The process continues with Energy Storage and Battery , whera 4S lithiumion auxiliary battery pack, monitored by a Battery Management System (BMS),st ores the conditioned energy, Energy ensuring overcharge, deep discharge, and cell balance protection.

A Microprocessor-Based Control Unit, powered by a Raspberry Pi, manages sensor data, energy flow between TEG, converter, and battery, and executes safety algorithms for fault conditions. Finally, IoT-Based Real-Time Monitoring and Safety Regulation enables continuous tracking of parameters (temperature, voltage, current, SOC) via Wi-Fi/GSM to a cloud or mobile app, incorporating automatic safety cutoffs and cooling systems to maintain optimal operation of TEGs and the battery pack.

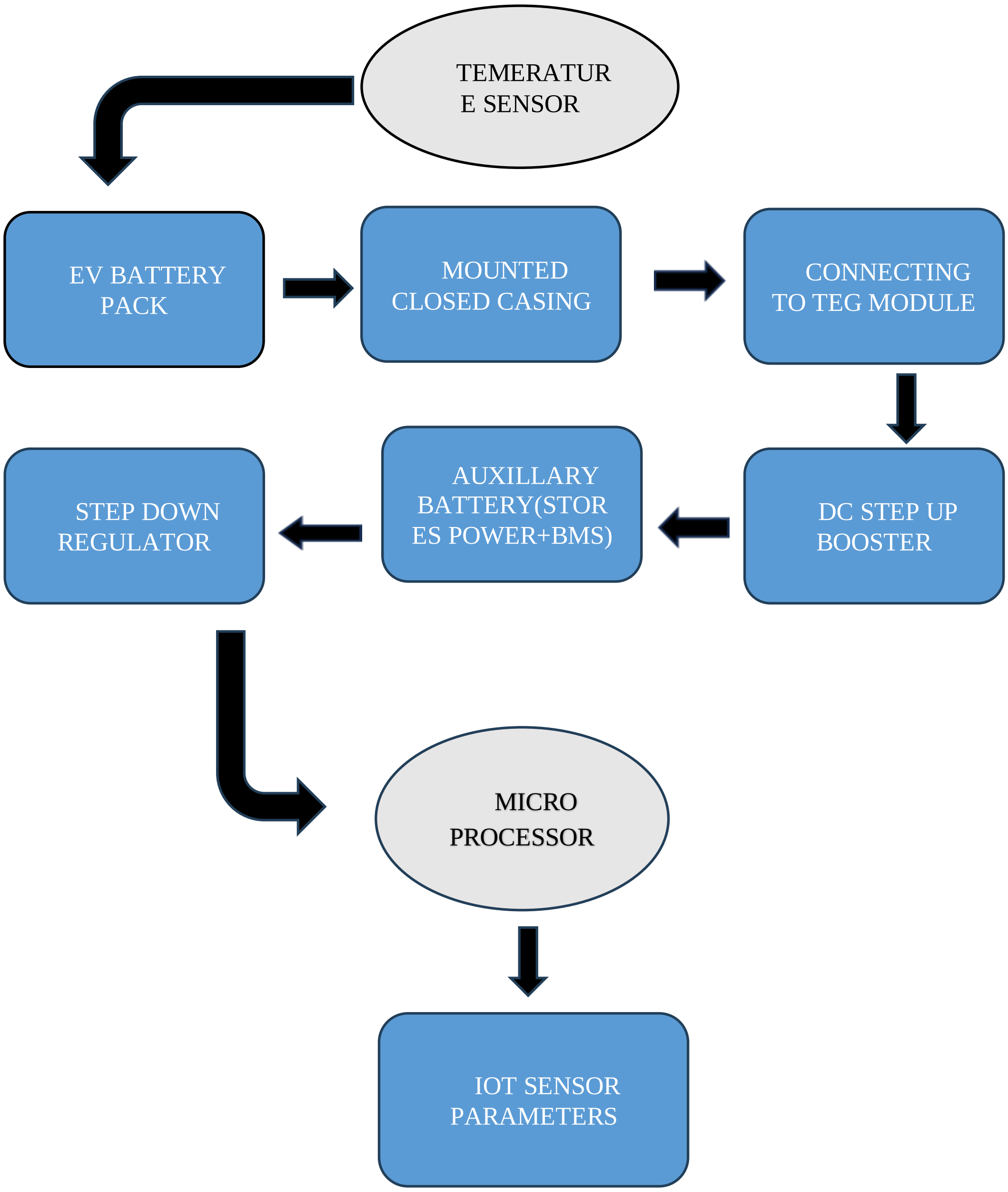

Fig-2 BLOCK DIAGRAM FOR PROPOSED TEG

IV. RESULT

The image depicts a simulation interface for a thermoelectric generator (TEG) module on the nanoHUB platform, aimed at studying cooler behavior when the heat input (Q_{in}) is knoThe graphic illustrates the structure of the TEG module, showing temperature regions (T_1, T_2), (constant structure of TEG sensir from nanohub Software)

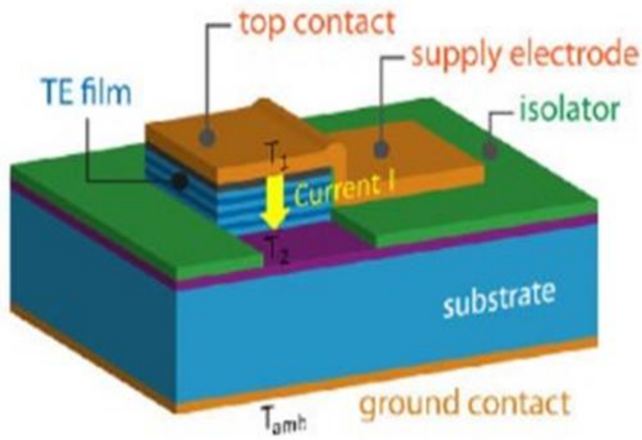

Fig-3 BASIC INTERIOR STRUCTURE OF SINGLE TEG SENSOR

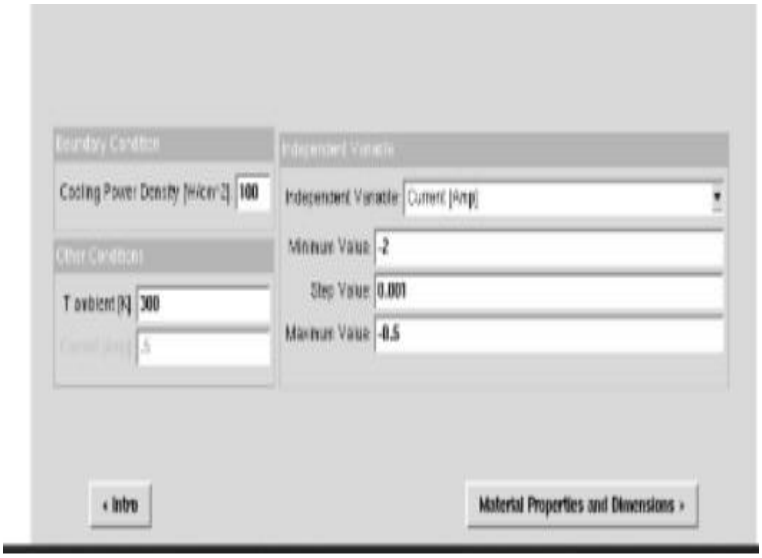

Fig-4 BASIC SINGLE TEG PERFORMANCE CONSTANT VALUE(nanohub Software)

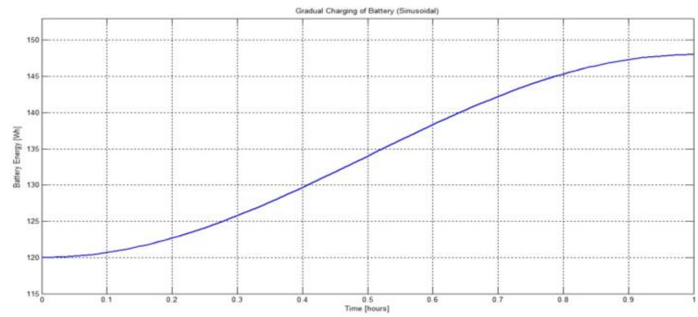

Fig-5 GRADUAL INCREASE IN ENERGY STATE IN TEG wh (MATLAB Software)

GRADUAL INCREASE:

As the temperature difference gradually increases, the efficiency rises smoothly from **1.2% to 1.55%**, while voltage output increases from **4 V to 9 V**, showing steady improvement in thermoelectric generation.

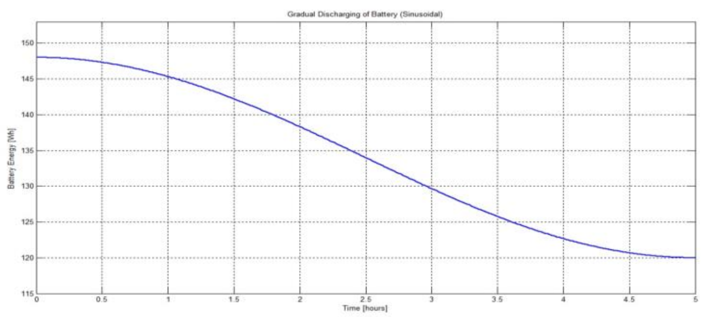

Fig-6 GRADUAL DECREASE IN ENERGY STATE TEG wh (MATLAB Software)

GRADUAL DECREASE:

When the temperature difference slowly decreases, the efficiency reduces from 1.55% to 1.3%, with voltage falling from 9 V to 5 V, confirming a consistent decline in system performance.

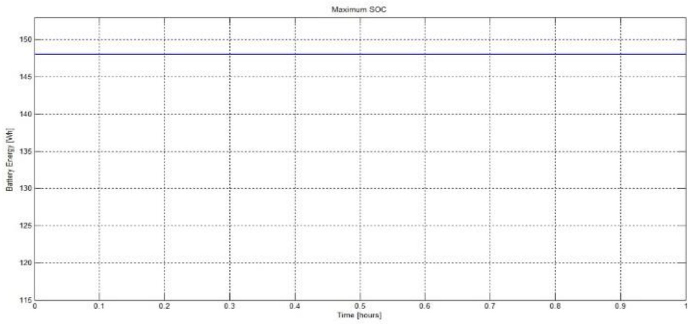

Fig-7 MAXIMUM ENERGY IN TEG wh (MATLAB Software)

MAXIMUM PERFORMANCE

At maximum operating range, the 100-TEG module system reaches an efficiency of **1.75%**, producing nearly **12 V** output, which represents peak thermoelectric conversion under strong temperature differences.

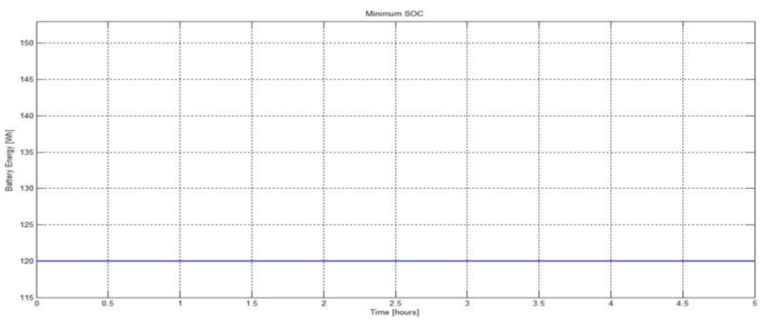

Fig-8 MINIMUM ENERGY IN TEG Wh(MATLAB Software)

Minimum Performance:

At the lowest thermal gradient, the system efficiency drops to about **1.2%**, producing nearly **2 V** output, indicating weak thermoelectric activity due to minimal heat flow.

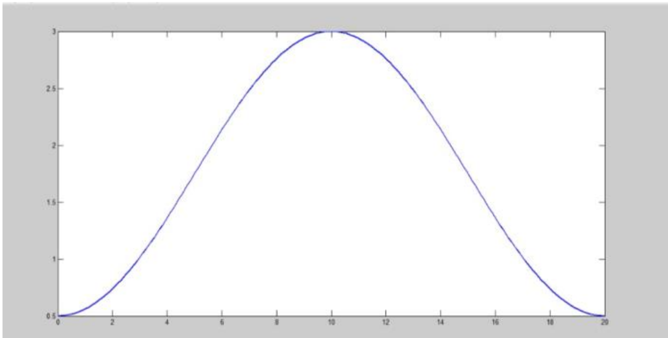

Fig-9 THE AVERAGE VALUE IN TEG wh (1.75% MATLAB Software)

AVERAGE PERFORMANCE

Under normal and steady-state temperature conditions, the 100-TEG module system maintains an average efficiency of around 1.45%, makea stable output voltage of approximately, it represents an balanced performance between thermal input and electrical output in typical EV operation.

V. EQUATIONS FOR THE EFFECIENCY AND CHARACTERISTICS

- instantaneous *system* efficiency (TEG → usable power after boost).
- $\eta_{\min}$, $\eta_{\max}$— minimum and maximum efficiency (unitless, e.g. 0.01 → 1%).
- $\Delta T(t)$— temperature difference across the TEG at time t(K).
- instantaneous *system* efficiency (TEG → usable power after boost).
- $\eta_{\min}$, $\eta_{\max}$— minimum and maximum efficiency
- $\Delta T(t)$— temperature difference across the TEG at time t(K).
- $\Delta T_{\max}$— maximum expected ΔT (K).
- t— time.
- T_c — charging period (hours) during which efficiency rises.

- T_d — discharging period (hours) during which efficiency falls.

(A)=ΔT-Based (Linear) Efficiency

η(t)= ηma x ΔTm(t)/ ΔTmax **(0≤ΔT(t)≤ΔTmax)**

(B)=Time-Based Smooth

1) Gradual Increase

η inc(t) = ηmin + (ηmax−ηmin)* (1−cos(πt/Tc))/2, **0≤t≤Tc**

2) Gradual Decrease

η dec(t) = ηmin + (ηmax−ηmin)* (1+cos(π t/Td)) **,0≤t≤Td**

(C) Average Efficiency Over One Cycle

If the heating and cooling cycles are symmetric, the average efficiency becomes:

$$\bar{\eta} = \frac{\eta_{\min} + \eta_{\max}}{2}$$

(D) Discrete (Simulation-Friendly) Form

For discrete simulations, efficiency can be updated each step (Δt) as:

For increase:

$$\eta[n] = \eta_{\min} + (\eta_{\max} - \eta_{\min}) \cdot \frac{1 - \cos(\pi \frac{n}{N_c})}{2}$$

For decrease:

$$\eta[n] = \eta_{\min} + (\eta_{\max} - \eta_{\min}) \cdot \frac{1 + \cos(\pi \frac{n}{N_d})}{2}$$

where $N_c = T_c/\Delta t$and $N_d = T_d/\Delta t$.

VI. CONCLUSION:

The proposed thermoelectric generator design marks compact, self-sustaining energy systems by utilizing thermoelectric in a substantial step forward modules to capture energy from ambient heat sources. Through the integration of a DC-DC step-up boost converter, the system is able to elevate the low voltage generated by the thermoelectric module to a stable level suitable for storage in an array of lithium cell batteries as an auxillary battery type. From there its get step up down as in the form of input in Microprocessor. The implementation of a voltage regulator LM7805. It ensures a steady 5V input supply along with connected sensor modules, making the system particularly well-suited for embedded ,automatic control for our needs of function, portable applications where traditional power sources are unavailable.

By this kind of system there's no damage on Main BMS battery on EV mechanism. Leads to increase the lifespan of the EV battery. From this Main battery replacement and Main battery high stress is reduced. This flexibility makes it viable for both single-sensor use cases and more complex Internet of Things (IoT) applications involving multiple sensing and communication components. This focus on energy efficiency and durable storage, extends EV vehicle life and reduces maintenance, positioning this approach as a practical solution for off-grid deployment, environmental monitoring.

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