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Converting Conventional Automobiles into Super-efficient and Sustainable Electric Vehicles through Retrofitting

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ABSTRACT:For the global automobile industry, achieving an emission-free environment is a major challenge. Electric vehicles (EVs), a replacement for the widely used gasoline-powered cars, have not yet become well-established in the market. Consumers' worries about a limited driving range are still crucial for the adoption of EVs, even if EVs and hybrids have been promoted as an alternative mode of transportation for urban use with a driving range of 100 to 120 kilometers. The conversion of present internal combustion (IC) engine vehicles to Electric vehicles (EVs) is an efficient strategy in this transition. In this brief project, we concentrate on retrofitting battery EVs, which includes, among other things, architectural planning for all [2] drive train components, driving pattern analysis, packaging for the vehicle's battery, and efficiency measures to make the overall retrofit more efficient. Our study uses in-depth research to identify the obstacles of converting IC engine cars to electric ones. The barriers were then ranked, and the top 5 barriers each had a solution. Additionally, we provided a few [3] architectural solutions. The usage of the TEG modules on the PMSM motor to regenerate power through waste heat recovery is our primary unique approach. To increase the performance of converting current cars to EVs in terms of durability, cost-effectiveness, and efficiency, further study is required. The performance of the battery in a functional state is also taken into account [4] while retrofitting EVs. The performance of the battery during a vehicle accident must be consistent with dynamic qualities and safety concerns, thus a balanced retrofitting system must be developed. This paper explains how including a retrofitting kit for converting IC engine vehicles to electric vehicles can reduce pollution while also providing clients with an affordable alternative to pricey EVs.

KEYWORDS: Retrofitting, Electric Vehicles, Sustainability, Energy efficiency, Mechanical engineering

I. INTRODUCTION

1.1 Background and Motivation

In India the fossils fuels prices are pocket pinching day by day. Hence it is a strong competitive development parameter for government [3] considering GDP growth and for example conservation. There is a 40% share of air pollution due to road transport alone. Hence this is a detrimental factor for climate change. In today's time if an average middle-class person looks to tackle these problems and thinks of buying an electric vehicle it will cost him about 10-15 lakhs and the Tesla models can go up to 60 lakhs and also, vehicle end of life is a big environment concern. To tackle this problem, we thought of making a retrofitting kit to convert an IC engine car into an Electric vehicle. It will be cost effective and a better alternative rather than using old since 2x to 5x – Amount of [2] emissions from older vehicles, compared to new vehicles.

1.2 Problem Definition

Environmental requirements compel the need for emission-free transportation. Even with their limitations in terms of range, price, and infrastructure for charging, EVs have emerged as one of the most promising solutions [1] ever presented to the automobile industry. Retrofitting is the ideal option during the transitional period when taking into account the costs, production delays, and adoption challenges as a new technology in the well-accepted ICE automotive sector. To create new EVs on a wide [4] scale, automakers must invest a considerable sum of money, but at this point, the difficulty in adjusting to the new technology is preventing this investment.

When weighing the speedier time to market and lower cost associated with using already-existing chassis and bodies, retrofitting provides a balance of benefits. However, the sector is ruled by the adaptation problem since retrofitting involves a lack of dynamic performance data. Due to the placement of the [2] bulky battery pack, retrofitting involves a significant increase in the weight of the vehicle and a noticeable shift in how the weight is distributed. The dynamic equilibrium of the car in driving state is impacted by this alteration.

Existing automakers are significantly investing in electrification, spending \$14.3 billion on battery technology since 2010, \$19 billion on EVs and charging infrastructure, and 300 new EV models are expected to be released by 2025. With the exception of Tesla, all well-known EV manufacturers nonetheless [1] continue to struggle with profitability. As a result, they could be interested in exploring business prospects related to ICE to EV retrofitting. Retrofitting ICE cars with EV components may speed up ICE vehicle resource use, improve public acceptance of EVs, and accelerate the construction of EV infrastructure. The goal of this project is to provide a kit for converting an [2] internal combustion engine to an electric car.

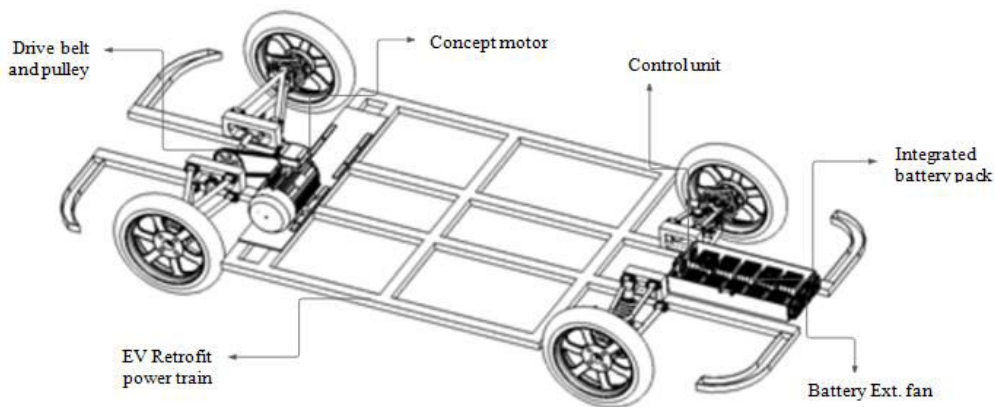


Fig. 1 Base Architecture

II. RELATED WORK

Mobility is undergoing a sustainable shift, driven by growing societal issues like air pollution and advancements in technology enablers like battery cell technologies. Regulation of supply and demand has accelerated [4] the development of electric vehicles (EVs) and their market adoption rate, promising fewer greenhouse gas emissions during the life of the vehicle. Existing automakers are significantly [3] investing in electrification, spending \$14.3 billion on battery technology since 2010, \$19 billion on EVs and charging infrastructure, and 300 new EV models are expected to be released by 2025.

Retrofitting ICE vehicles to EVs might be a temporary solution to accelerate the transition to a [1] more commonplace EV use. EV retrofitting may accelerate the adoption of EVs, improve public acceptance of EVs, raise the resource efficiency of ICE cars, and quicken the construction of EV infrastructure. Lower operating expenses, quieter operation, and a cleaner atmosphere could be advantageous to customers. In essence, the solution may enable a quicker [3] transition to green mobility. We swap out ICE-related parts like the gasoline tank, exhaust system, and combustion engine for EV parts like the electric motor, controller, battery packs, and inverter. The majority of conversions preserve the power transmission to the wheels by flanging the electric motor to the conventional gearbox using an adapter plate.

The existing innovation for automotive waste heat recovery used in ICE which was analyzed and found to be limited due to its low efficiency during harnessing the waste heat. This existing innovation uses TEG modules which are integrated with the exhaust of the vehicle. The main aim for applying automotive TEG in exhaust was to harness the liberated waste energy produced by exhaust, which has been the most heated element of the vehicle. This has led to inappropriate heat dissipation at the cooler side of the TEG module. This issue was not able to baffle with the use of air



cooling and water cooling systems so also if heavy cooling systems were used it would have only added weight to the exhaust and also it would require greater power consumption which could have nullified the harvested power.

III. DATA COLLECTION AND METHODOLOGY

3.1 Data Collection

Our group studied a variety of research paper on retrofitting of EV and the implementation challenges faced then through many brainstorming sessions we identified various flaws/loopholes which can be common people’s concern and were the main bottlenecks of not getting retrofitting of EV still in market. These challenges are tabulated:

Barriers [source]	Description
Electricity consumption for charging battery of retrofitted EV	Recharging of retrofitted EVs is still majorly depending on non-renewable source which [2] mainly come from coal. This source is on the verge of depletion by 2030 if consumption increases.
Recycling Lithium-Ion battery	Recycling conventional lithium-ion battery is one of the significant contributors of [3] GHG emissions in its life cycle analysis.
Government policies or norms and subsidies for retrofitting industry.	The retrofitting technology for EV is nascent stage so the government finances and safety check bottleneck affect largely the implementation [4].
Traffic density during recharging	The fastest supercharger charges EV in 20 minutes which is twenty times the ICE [3] vehicle refueling speed this will lead to traffic during recharging
Indigenous technologies required for developing retrofitted parts.	Manufacturing retrofitting parts in EV has a critical role to play since there are [1] various company models for a particular vehicle segment.
Time for household charging using power supply of 230V AC.	Life cycle assessment of household charging costs a person more than charging at station [4] considering time frame of 4-5 years which will be average age after retrofit.
Change management to change from conventional to retrofitted EV.	Incentive for people to change from conventional ICE to retrofitting EV is less [1] since there are less reputed companies implementing the same.
Infrastructure for super charging of EV vehicles.	Supercharging infrastructure for premises unless renewable sources would [2] require constant capital flow with the demand for the electric sources.
Vehicle part maintenance after retrofitting EV.	The part maintenance cost of second life of vehicle used in retrofitting is more than the new EV purchased [3].
Limiting age of car on which retrofitting is taking place.	Age of vehicle considering the second life since [1] it is retrofitting.
Replacement of battery	Battery life cycle analysis give CO2 during recycling phase hence nullifying [2] the actual greener cause.
Impact of Safety standards mentioned by FAME	FAME and ARAI bottleneck are heavy on retrofitting in comparison to [3] pure EV

Table 1 Bottlenecks of implementation of retrofitting of EV



3.2 ISM Methodology

ISM creates knowledge snippets to [5] gather relationships' conclusions. The first step in this modelling process is the identification [7] of all relevant components for a certain topic or situation. In our situation, these are the difficulty and bottleneck encountered while retrofitting for EV adoption.

This procedure is made easy to grasp by using the four symbols (V, A, X, and O). The SSIM is built using these symbols I and j), [6] which depict the direction in which challenges interact with one another. The ISM for the [9] recognised difficulties is displayed in the ISM Matrix.

V: The impact of the (i) challenge on the (j) challenge;

A: The (i) difficulty will be impacted by the (j);

X: Both of the problems in (i and j) will have an impact on one another; and

O: None of the problems in (i and j) will [8] have an impact on one another.

Variables	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
Electricity consumption for charging battery of retrofitted EV	1	V	A	A	O	O	A	A	O	O	A	A	O
Recycling Lithium-Ion battery		1	A	A	A	A	A	O	A	O	A	A	A
Government policies or norms and subsidies for retrofitting industry.			1	V	V	O	V	V	O	V	O	V	V
Traffic density during recharging				1	V	O	V	V	O	O	O	O	O
Indigenous technologies required for developing retrofitted parts.					1	V	O	X	V	V	V	V	V
Time for household charging using power supply of 230V AC.						1	V	V	O	O	V	O	V
Change management to change from conventional to retrofitted EV.							1	A	V	V	O	X	O
Infrastructure for super charging of EV vehicles.								1	O	O	V	V	V
Vehicle part maintenance after retrofitting EV.									1	V	A	A	O
Limiting age of car on which retrofitting is taking place.										1	O	A	O
Replacement of battery											1	V	O
Impact of Safety standards mentioned by FAME												1	O
Retrofitting for various car types hatchback, sedan and SUVs.													1

Table 2. ISM Matrix - Matrix of Barriers affecting implementation

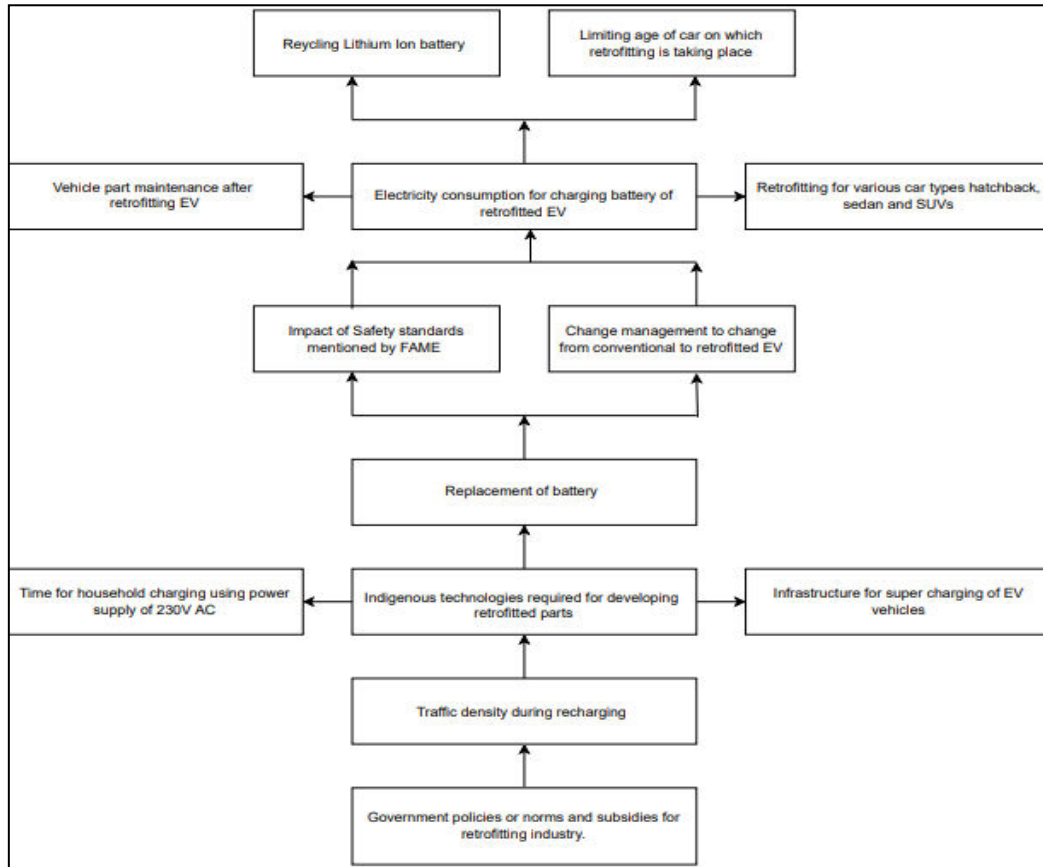


Fig. 2 Diagraph

3.3 Solution framework to the challenges and bottlenecks

Barriers	Solution
<p>Recycling Lithium-Ion battery</p>	<ul style="list-style-type: none"> • Mechanical processing To recover polymers, aluminium, copper, and black mass, the lithium-ion batteries are first dismantled and processed. The black substance from the battery, which [15] contains important metals, is removed and taken for hydrometallurgical processing. By using a chemical precipitation technique, the hydrometallurgical recycling process enables the recovery of rare minerals from the black mass and their delivery to battery producers for reuse in the creation of new batteries. • Pyrometallurgical recovery In pyrometallurgical [14] metals reclamation, the component metal oxides are reduced to an alloy of Cobalt, Copper, Iron, and Nickel in a high-temperature furnace. • Physical materials separation Recovered materials can be subjected to a variety of physical separation techniques for reclamation [16] following comminution that take advantage of changes in characteristics including particle size, density, ferromagnetism, and hydrophobicity. • Direct recycling Direct recycling is the process of removing cathode or anode material from the electrode for reconditioning and reuse in a remanufactured LIB [14].



Vehicle part maintenance of retrofitted EV	<ul style="list-style-type: none"> • Battery Maintenance <p>To preserve the health and lifetime of a lithium-ion battery, charge it to 90% capacity and then disconnect it [18] immediately. Batteries can also lose charge when exposed to extremely low temperatures, so if feasible, store your automobile in a moderately temperate location.</p>
Retrofitting for various car types hatchback, sedan and SUVs.	<ul style="list-style-type: none"> • Versatile Compatibility <p>Based on the build and class of vehicle, multiple generic retrofitting systems/kits can be developed [19] that can be installed on different vehicles of the same class, irrespective of their make.</p>
Infrastructure for super charging of EV vehicles / Time for household charging using power supply of 230V AC.	<ul style="list-style-type: none"> • Improved Battery technology & Charging systems <p>With an increase in research and development in the field of EV battery optimization, [11] the capacity of batteries can be increased to a good amount, hence reducing the time required for a full battery charge. / Improved charging technology in terms of hardware and electronics can also cut down the time required for charging [12].</p>
Traffic density during recharging	<ul style="list-style-type: none"> • Increase in frequency of Charging Stations <p>The only viable solution for reducing congestion during EV recharging significantly [10] is to increase the number of charging stations available to users in a region. An increased integration of charging stations in places like offices and malls can help utilise [13] the stationary time of vehicles for charging, while also reducing traffic at on-road charging stations and gas stations [17].</p>

Table 3. Framework Matrix

Framework Matrix depicts the solution framework for the prime challenge/bottlenecks faced for implementing retrofitting in Indian market condition.

Architecture Retrofitting:

Development area	Features	Native/Conventional EV versus Retrofitted SW model
Battery placement	Load distribution in consideration to CG is more balanced in conventional EVs with ground battery placement [21] Whereas, Retrofitting model cannot append this feature since deriving from IC vehicle [20].	
Electric motor selection	The motor [22] selected in both the system is similar although the PMSM [23] class F is better for continuous running.	
Brake system analysis	The propulsion system is having a huge scope of innovation [22] considering making of a versatile kit for all vehicles.	

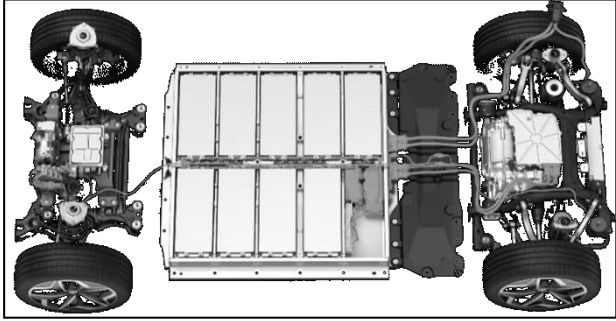
Chassis system analysis	Chassis of conventional EVs is appropriately designed to accommodate the components based on their optimal position and size. This is difficult to achieve in retrofitted vehicles.	
Suspension System analysis	Suspension system is also an important [24] concern with the increment of total weight of the vehicle and the position change of the significant weight items of the vehicle.	

Table 4. Architecture Framework

IV. NOVELTY SOLUTION TO ADDRESS THE EV RETROFITTING POWER EFFICIENCY

The efficiency of the retrofitted EV can be increased in two ways. The one is a very common solution which is by introducing regenerative braking which is brought to a significant level by use of permanent magnet synchronous motor (PMSM) which at a specific gear ratio increases the overall efficiency by 15%. The other novelty solution to the problem is by using the same PMSM motor but integrating thermoelectric generator with it since 80% of the heat produced is waste heat which is of no use and can cause wearing in long term.

The motor casing encounters the high temperatures of the stator and rotor windings during the working of the motor. For the same reason, a cooling system is necessary for maintaining the optimum working temperature of the motor. In the proposed design, we have integrated TEG modules with the casing of a PMSM Motor. The TEG modules are placed in between two concentric cylinders wherein the inner cylinder will be exposed to the stator, while the outer cylinder will be exposed to the integrated cooling system accompanied by the casing of the motor. There is a significant temperature difference between the inner and outer cylinders, such that the TEG module starts generating electricity.

Parameter	Value
Rotor outer diameter	432 mm
Stator outer diameter	396.74 mm
Shaft diameter	324.94 mm
Magnet width/height	15.7/3.5mm
Slot area	354.88 mm ²
Rated output power	15.3 kW
Rated speed	850 rpm
Rated torque	170 Nm
Line current	92.41 A
Current density	6.57 A/mm ²

Table 5: PMSM Motor Specifications Table 6: PMSM Motor Heat Output

Heat Source	Value
Stator copper windings	722.06 W
Stator core	39.45 W
Rotor core	26.3 W
Permanent magnets	22 W

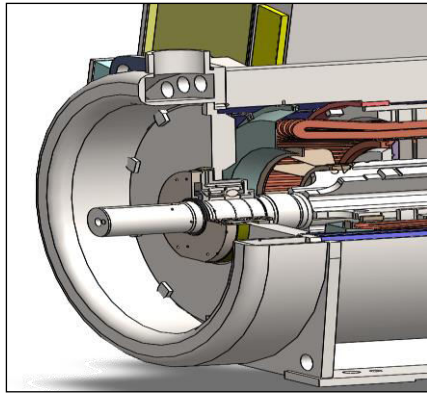


Fig 3 Front View

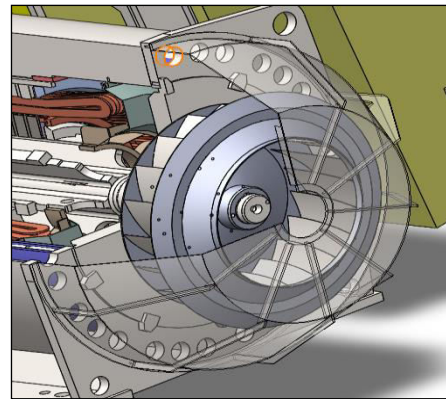


Fig 4 Turbine for Cooling

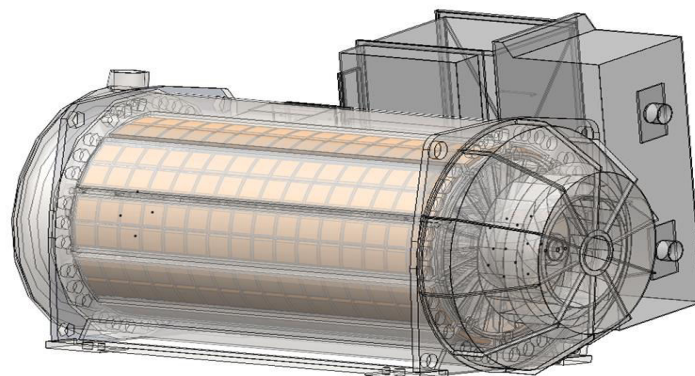


Fig 5 Mesh view of Motor

The design of the motor casing created is the roadmap of the novelty solution proposed. The motor casing encounters the high temperatures of the stator and rotor windings during the working of the motor. For the same reason, a cooling system is necessary for maintaining the optimum working temperature of the motor. In the proposed design, we have integrated TEG modules with the casing of a PMSM Motor. The TEG modules are placed in between two concentric cylinders wherein the inner [25] cylinder will be exposed to the stator, while the outer cylinder will be exposed to the integrated cooling system accompanied by the casing of the motor. There is a significant [25] temperature difference between the inner and outer cylinders, such the TEG module starts generating electricity.

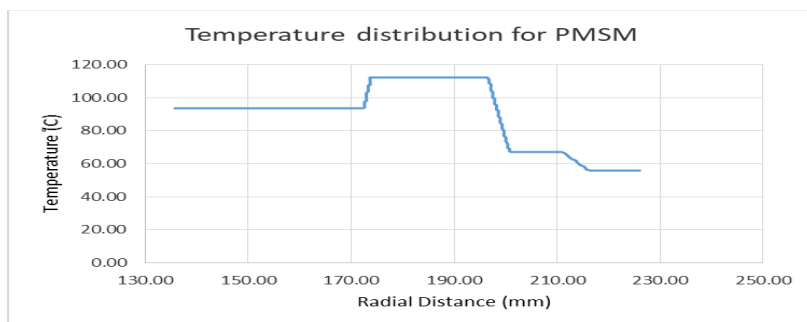


Fig 5 Temperature distribution for PMSM graph

In order to maximize sustainability we have designed an [25] integrated cooling system. In this cooling system the pumping action is provided by the centrifugal fan attached directly to the motor shaft this allows the flow of coolant through the hollow chamber in the motor casing which has the TEG modules on one side of it and the outer surface of the casing on the other side which is exposed to atmosphere. After collecting the heat from the TEG modules in the motor the coolant gushes through sets of pipes in the radiator which consist of heat exchangers. With cooling, Fig. 6 depicts the temperature distribution at PMSM in radial direction (from inner stator to outer rotor surface).

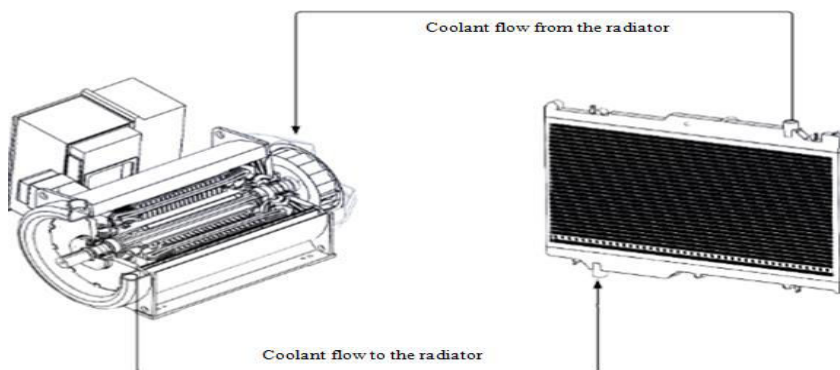


Fig. 7 Coolant Flow

The heat collected by the coolant in the complete process is dissipated in the radiator and the coolant is pumped back into the motor casing completing the cycle again. Execution of the conceptual design can be done by provision of retrofitting kits with the applied concept of power generation. Implementing this method for execution will be much more effective and will pitch in for more people from the IC domain willing to convert into EV.

V. RESULTS

5.1 Mathematical model to solution

The discussed theoretical aspect of the solution gave an understanding to formulate the solution by providing a mathematical model to it. In order to re-verify the asserted results we calculated a MATLAB model is also created. In the initial process of numerating the model we used technical datasheets of the TEG modules wherein we specified the material the P-N junctions present, the basic dimension and area occupied. Then for the motor specification class F PMSM motor was considered. The results for the mathematical model are as follows:

Material: Bismuth Telluride (β -Zn₄Sb₃)

TEG Module Dimensions: 50mm x 50mm

Area: 2500 mm² = 0.0025 m²

Number of TEG Modules: 1280

Rotor Temperature (F Class Motor): 150 (\pm 10) °C

Ambient Temperature: 40°C

Temperature Difference= Rotor Temperature – Ambient Temperature

Temperature Difference= 110°C

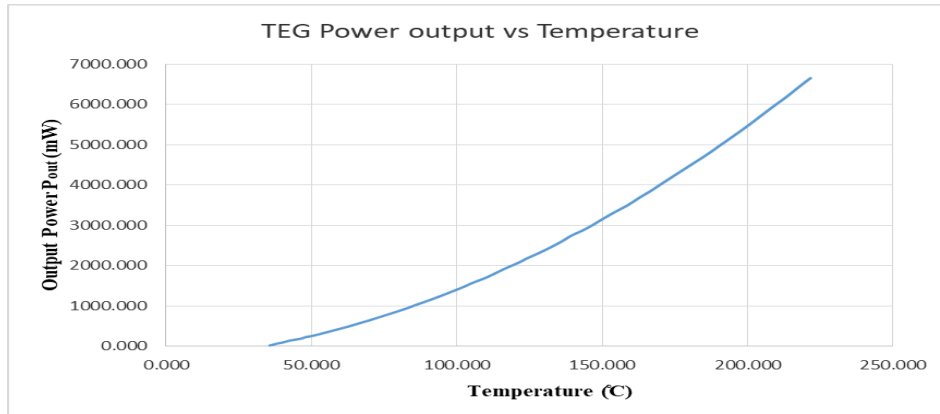


Fig 8 TEG power output vs Temperature

From curve fitting, for the above graph we have developed a quadratic equation which gives the power generated in W/m². The equation is as follows:

$$P_{out} = 0.117\Delta T^2 - 5.534\Delta T - 327.308$$

$$P_{out} = 0.117(110)^2 - 5.534(110) - 327.308$$

$$P_{out} = 479.64 \text{ W/m}^2$$

$$\text{Power Generated by TEG Modules} = P_{out} \times \text{Number of TEG Modules} \times \text{Area}$$

$$\text{Power Generated by TEG Modules} = 479.64 \times 1280 \times 0.0025$$

$$\text{Power Generated by TEG Modules} = 1534.84 \text{ W}$$

The selected PMSM motor configuration is known for its regenerative braking system (RBS). The driving pattern graph shown below depicts a slump while braking during which, the RBS system converts the wasteful energy to electricity which otherwise would be dissipated as heat. The harvested energy is stored in the auxiliary battery and it increases the efficiency by 20%. Thus considering the complete for derived solution and RBS we get an estimated combined efficiency of 35-40%.

To validate the theoretical results Matlab model is created considering the following parameters.

Material: Bismuth Telluride (β -Zn₄Sb₃)

TEG Module Dimensions: 50mm x 50mm

Area: 2500 mm² = 0.0025 m²

Number of TEG Modules: 1280

Rotor Temperature (F Class Motor): 150 (\pm 10) °C

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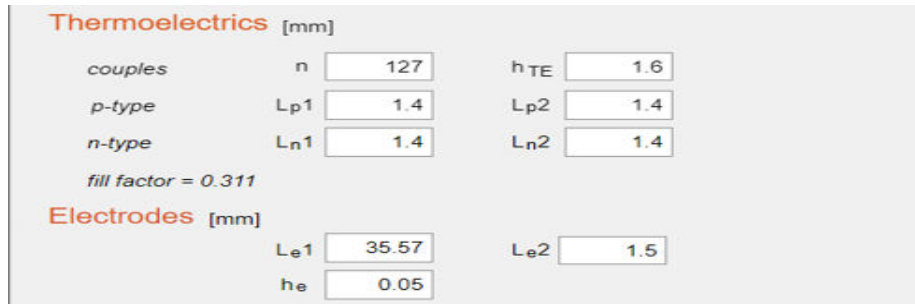


Fig 9 MatLab Model Parameters

The data variables for TEG were pre-specified. The Matlab model expressed the following graph these graph were then idealised for the PMSM motor temperature difference of 110°C.

This provided us with the power output which is 1.5 W for each module then by considering the number of modules which were integrated we calculated the total power harnessed during the cycle of vehicle movement.

This result comes out to be 1.9KW which was at the ideal conditions hence the mathematically model solution of the non-ideal motor was complimenting the Matlab model of the solution.

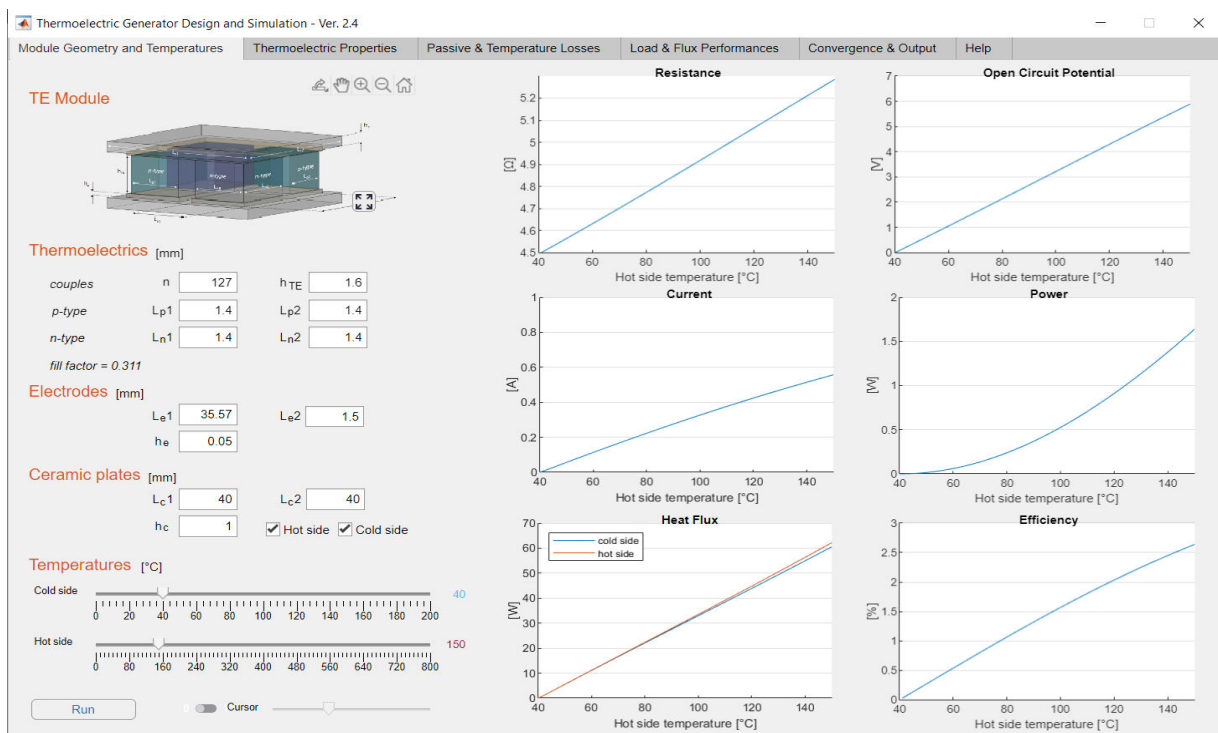


FIG 10 MATLAB RESULTS

V. CONCLUSION AND FUTURE SCOPE

Almost every bottleneck for implementation of retrofitting of EVs was identified from multiple surveys conducted; and using MCDM (Multi Criteria Decision Making) method the major concerns were addressed in the framework. The research study, the bottleneck of prime importance- energy consumption, which needed immediate addressing was identified and was provided a novel solution including the architecture of the retrofitting and its CAD solution. These estimated results were justified using a mathematical model along with MatLab and SimuLink results. Comparisons were also made between the effectiveness of currently available solutions and the solution provided by us.

While a CAD model was developed along with carrying out simulations, physical validation is of extreme importance. For this purpose, collaboration with other individuals with the similar projects and implementing/working on the derived solution physically is necessary. This will also help in validating the current theoretical calculations via a proof of concept. Along with this, more work needs to be carried out on research and generation of sustainable power as well as improving the vehicle safety for electric vehicles so as to overcome the bottlenecks posed by the guidelines of the Automotive Research Association of India (ARAI).

Apart from this, an in-depth comparison of different battery types for electric vehicles has to be carried out in order to carry out research and optimize the performance of retrofitted vehicles. Presently, consumer electric vehicles are considerably newer to the markets thus making it difficult to estimate overall costs throughout the lifecycle of the vehicle. Comparative analysis between electric vehicles and internal combustion engine vehicles on parameters like long-term cost of ownership, running and maintenance costs can help bridge this gap. Various simulations and investigations over the cooling system's parameters, such as its dimensions, coolant's inlet temperature and flow rate were performed. Finally, based on the results it is obvious that the proposed cooling system proves to be a suitable candidate for such an application. It is to note that verification by a prototype combined with experimental results could provide an interesting object of future study. Also, implementing it in actual vehicles considering the driving force of sustainability moving towards a decarbonizing economy will be the end result.

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