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Greening Your Drive: A Method of Effective Conversion from IC Engine Based Vehicle to EV

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ABSTRACT

This research presents the most efficient method for converting vehicles with internal combustion engines (IC engines) into electric vehicles (EVs). With a focus on reducing environmental impact and optimizing energy efficiency, our strategy incorporates cutting-edge technology in electric powertrain components, power electronics, and battery storage systems. This paper evaluates performance indicators by thoroughly analyzing the integration of new electric drivetrain components and the retrofitting of existing ones, including motor starting and energy usage. To enhance efficiency, we propose the use of a supercapacitor bank and an effective battery cooling system. The proposed approach aims to achieve Sustainable Development Goal 11 (SDG11) of sustainable cities and communities, addressing safety concerns, environmental benefits, and economic viability. Simulation results demonstrate the effectiveness of converting gasoline cars to electric using a battery cooling system and integrating a supercapacitor bank. These findings support the global shift towards environmentally friendly transportation methods by providing valuable insights that will expedite the widespread adoption of sustainable EVs.

Keywords: Battery Cooling System, Electric Vehicle, Internal Combustion (IC) Engine, Conversion, Supercapacitor

INTRODUCTION

Electric vehicles (EVs) have gained significant attention in recent years due to their potential to address environmental and energy security concerns. The shift towards electric vehicles is driven by several factors, including environmental benefits, energy efficiency, and technological advancements (Longo *et al*., 2018). One of the primary reasons for the growing interest in electric vehicles is their potential to reduce greenhouse gas emissions and air pollution (Liou & Wu, 2021). Unlike conventional gasoline cars, electric vehicles produce zero tailpipe emissions, which can significantly improve air quality and reduce transportation's environmental impact. Several studies have demonstrated that widespread adoption of electric vehicles could substantially reduce carbon dioxide and other harmful pollutants, thereby mitigating the adverse effects of climate change and promoting public health. The development of innovative approaches to electric vehicle diagnostics is crucial to ensure their ecological impact, especially regarding the sources of the electric current used to charge them (Małek & Taccani, 2021). Overall, the multifaceted benefits of EVs make them a compelling choice for sustainable and environmentally friendly transportation solutions.

The transition from internal combustion engine (ICE) based vehicles to electric vehicles has attracted significant interest due to its potential environmental and economic benefits. This shift aligns with global efforts to reduce greenhouse gas emissions and dependence on fossil fuels (Vishnuram *et al*., 2023). The conversion process involves replacing the traditional powertrain with an electric powertrain, reducing noise pollution and improving overall vehicle efficiency (Qian *et al*., 2018). The shift towards EVs is also driven by the potential cost savings and lower maintenance requirements associated with electric vehicles (Sankaran & Venkatesan, 2022). Furthermore, the integration of EVs into the transportation sector can lead to a reduction in operating costs and a decrease in the environmental impact of vehicle operations. However, converting ICE vehicles to EVs requires careful consideration of various factors, including technological feasibility, regulatory frameworks and infrastructure development (Tezcan & Taşer, 2022).

A most important consideration is that high temperatures can elevate the internal resistance of lead-acid batteries, resulting in

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reduced charge acceptance and increased voltage losses during discharge (Chinnadurai *et al*., 2021). This increase in internal resistance can lead to diminished efficiency and reduced battery energy output. When a lead-acid battery is discharged at a high rate for a short time, it can have several effects on the battery. The discharge rate affects the current and recharging times, and the use of high-frequency pulses can impact the characteristics of the battery (Kim *et al*., 2019). The capacity of a lead-acid battery decreases when the discharge rate increases, leading to a drop in battery capacity from its initial value when fully charged (Cignini *et al*., 2020). According to Ohajianya *et al*. (2021), discharging a lead-acid battery at a high rate can lead to sulfation, which is a major cause of deterioration in lead-acid batteries. Additionally, life cycle assessments and cost-benefit analyses are essential to evaluate the environmental and economic implications of transitioning from ICE vehicles to EVs (Rodríguez-Molina *et al*., 2020). It is crucial to assess the potential impacts on electricity production and distribution infrastructures, as well as the overall societal and environmental implications of large-scale EV adoption.

In this work, the proposed method involves replacing the existing parts like the ICE, clutch assembly, transmission box, fuel tank, and other components with a motor, battery, controller, and converters. The conversion aims to target a specific sector of garbage collection vehicles, where an electric motor can be more efficient than an ICE. The proposed conversion procedure includes the following.

1. Disassembling of parts like the engine, clutch and clutch pedal, gearbox and its mechanism, fuel tank, exhaust system, radiator, catalytic converter, and tailpipe, replacing with an electric motor, which is coupled with the propeller shaft using a universal joint. The propeller shaft transfers the power to the road wheels through a differential.
2. The battery unit is placed in the car's backside, and a new battery cooling system is proposed.
3. The energy efficiency and increased lifetime are achieved by proposing an integrated supercapacitor system with battery storage.

The remaining sections of this paper are organized as follows. Section~II presents a literature review. The proposed EV conversion approach is presented in section~III, and experimental results are shown in section~IV. Finally, we conclude the work in section~V.

LITERATURE REVIEW

Battery cooling systems are essential for electric vehicles to maintain optimal operating temperatures and ensure battery longevity. Various studies have highlighted the significance of effective thermal management for EV batteries. For instance, demonstrated that liquid cooling systems can significantly reduce capacity loss and resistance growth rate, with combined key-on and standby systems offering the best reduction in degradation (Chen *et al*., 2020). Additionally, focused on the structural optimization of lithium-ion battery packs with forced air cooling systems, emphasizing the importance of efficient cooling for battery pack design (Xie *et al*., 2017). It also addressed the optimization of air-cooled battery thermal management systems, further underlining the need for cooling performance enhancement in EVs (Wang *et al*., 2021). Moreover, it emphasizes the necessity of water-cooling-based strategies for lithium-ion battery pack dynamic cycling to ensure adequate thermal management (Li *et al*., 2018). The study by highlighted the importance of direct refrigerant cooling for improving the working efficiency of lithium-ion batteries in EVs and enhancing the economy of battery thermal management systems (Wu, 2022).

Supercapacitors play a crucial role in facilitating the starting of electric motors in EVs by providing high-power bursts during the initial acceleration phase. The integration of supercapacitors in EVs has been recognized as a means to enhance energy management and improve the performance of electric propulsion systems (Ping *et al*., 2018). Supercapacitors can deliver rapid bursts of energy, making them well-suited for applications such as motor starting, regenerative braking, and peak power demands in EVs. In the context of EVs, the use of supercapacitors for motor starting addresses the need for high-power delivery during acceleration, thereby complementing the energy storage capabilities of batteries. This enables efficient utilization of the stored energy in the supercapacitors to meet the instantaneous power demands during motor starting, contributing to improved overall system performance and energy management in EVs.

The integration of supercapacitors in EVs is essential for several reasons. Supercapacitors are crucial components of the hybrid energy storage system for EVs (Wang *et al*., 2019). They can be used with batteries to enhance the vehicle's performance, including powerful acceleration, braking energy recovery, excellent cold weather starting, and increased battery life (Wang *et al*., 2012). Additionally, supercapacitors can improve acceleration performance and reduce power consumption in EVs, enhancing overall vehicle efficiency (Guo & Zhang, 2022). In EVs, supercapacitors primarily serve as an energy storage system for accelerating the vehicle and capturing braking energy, leveraging their high power density and long life cycle (Naseri *et* *al*., 2017). Furthermore, supercapacitors are not limited to EVs, as they can also serve as additional energy storage for hybrid wind and photovoltaic systems, displaying their versatility and potential for sustainable energy applications (Mansour *et al*., 2017). Moreover, supercapacitors can provide high transient power during acceleration and store regenerative energy from braking in hybrid electric vehicles, emphasizing their significance in improving vehicle performance (Zhao, 2017). Including supercapacitors in EVs is crucial for maintaining stability in electrical power systems and enhancing energy supply from batteries and intermittent renewable resources (Mukhopadhyay *et al*., 2020). Additionally, the integration of supercapacitors in EVs is associated with combined sizing and energy management algorithms, which are essential for optimizing the performance and efficiency of the energy storage system in EVs (Araujo *et al*., 2014).

Proposed EV Conversion Approach

The proposed electric vehicle system represents a modified iteration of an ICE-based vehicle. A pivotal aspect of our innovative approach lies in incorporating a control unit designed to optimize energy efficiency within the EV system, leveraging both a supercapacitor and a battery cooling system. Notably, the system introduces several additional components compared to the traditional ICE vehicle. These components include a battery, electric motor, control unit, supercapacitor bank, DC-DC converters, and a battery cooling mechanism, as illustrated in Figure 1. The conversion process entails the disassembly of components such as the engine, clutch and clutch pedal, gearbox and its mechanism, fuel tank, exhaust system, radiator, catalytic converter, and tailpipe. The engine is replaced with an electric motor, seamlessly coupled to the propeller shaft through a universal joint. Power is transferred to the road wheels via the propeller shaft and a differential. The motor is indirectly linked to the accelerator pedal through a potentiometer, transmitting signals to the controller and subsequently to the motor. In our proposed method, the battery is strategically positioned at the rear of the vehicle, accompanied by an effective cooling technique to ensure optimal energy consumption. The conventional fuel indicator is replaced with a panel indicating the state of charge of the battery, reflecting the transformation from traditional ICE components to an advanced and energy-efficient electric propulsion system.

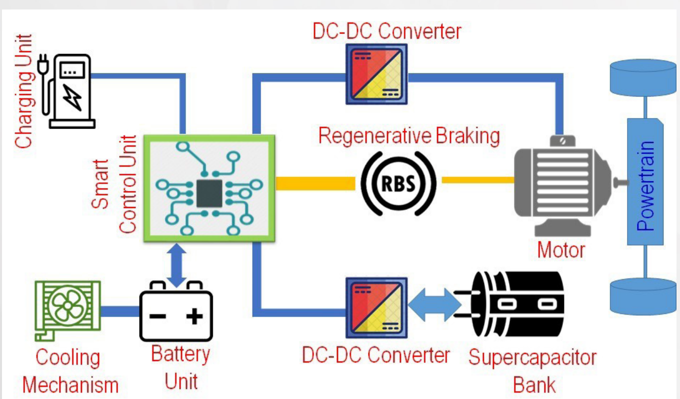

Figure 1: The proposed EV model

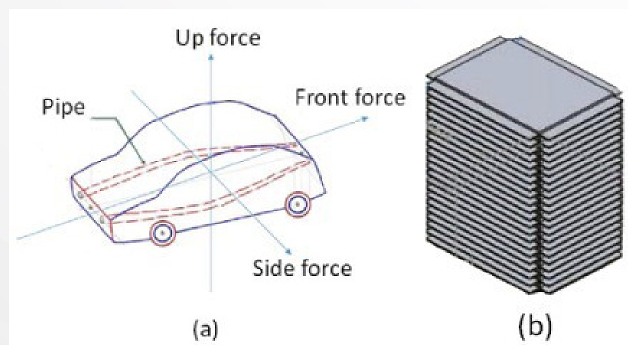

Figure 2: (a) Cooling pipe indication and different forces (b) Metal case

The utilization of a supercapacitor bank serves the purpose of supplying the necessary starting torque to the motor during the startup phase, given that the initial starting current is 3 to 10 times higher than the operating current (Rynkiewicz, R .1999). The time constant for charging and discharging the supercapacitor bank is strategically aligned with the motor's starting current draw period. The supercapacitor bank undergoes charging through regenerative braking and is regulated by the smart controller unit. During the motor's initial startup, motor connected to the supercapacitor bank. Once the motor is successfully started, the controller unit then reconnects the motor to the battery unit. This incorporation of the supercapacitor bank serves as a supplementary source for managing the motor's starting torque, thereby diminishing the energy consumption of the battery. The outcome is an extension of the battery backup time.

Battery Cooling System

This conversion process entails replacing several existing components with new ones. Following this replacement, the battery becomes a pivotal element of the converted vehicle. The crucial aspect of this vehicle lies in its tendency to generate heat, making the minimization of battery heat a primary concern in this conversion. Our proposed system aims to address this issue by integrating a cooling system through the introduction of a new feature. To optimize the battery's heat dissipation capacity, we propose the use of a metal case with external fins. It is essential to minimize the gap between the battery wall and the metal case to enhance heat transfer efficiency. In our proposed model, the rear section of the vehicle houses the battery. The placement of the battery in this enclosed space significantly influences the heat release generated by the battery. To improve cooling efficiency through convection heat transfer, we incorporate an outer casing with external fins, as illustrated in Figure 2(b).

In this system, cooling is achieved through convection heat transfer from natural airflow. Due to the removal of the engine from the gasoline vehicle, the source of heavy vibration can be removed. In this system, the air drag into the front of the vehicle is conveyed to the rear section of the vehicle, where the battery is placed. Two hollow cylindrical pipes are placed in the bottom section of the vehicle, the inlet is placed in the front of the vehicle, and the outlet is placed in the chamber where the battery is placed following the configuration outlined in Figure 2(a). To induce a circular flow of air in the chamber, two different diameter pipes are used and two other small hollow pipes are strategically placed to release air from this chamber.

The transfer of heat through the metal case originates from the battery and disperses into the surrounding air (1).

$Q_{out}=K_{Metal}\times A_{Metal}\times((T_{Battery-}T_{Air})/x)W$ (1)

Where, Q_{out} is the heat transfer rate (W), K_{Metal} is the thermal conductivity of the metal (W/m·K), AMetal is the Metal box wall surface area exposed to the battery (m^2), TBattery is the Battery internal Temperature (K), T_{Air} is the Air temperature (K), x is Metal wall thickness (m).

According to Newton's law of cooling, heat transfer by convection:

$Q_{in}= h_r\times A_h\times(T_{required}-T_{air})$ W (2)

Where, hr as the Convection heat transfer coefficient (W/(m^2·K)), Ah as the Surface area of the heat transfer (m2), Trequired as the temperature to maintain the metal body (K), and Tair as the ambient temperature of the air (K). In steady-state conditions, the heat transfer through the metal box Q_{out} is equal to the heat transfer by convection Q_{in} to the air. The convection heat transfer coefficient h can be related to relevant physical properties and flow parameters through dimensionless numbers (3).

$h= (N_u*K_{air})/L_h$ (W/(m^2·K) (3)

Here, Lh is the characteristic length/diameter of the pipe (m), Kair is the thermal conductivity of the air (W/m·K). Given, Pr is the Prandtl number, ρ is the density of the air (kg/m3), V is the velocity of the air (m/s), D is the diameter of the pipe (m), μ is the dynamic viscosity of the fluid (Pa·s), Nusselt number Nu Represents the ratio of convective heat transfer to conductive heat transfer can be represented by (4) and the Reynolds number Re as outlined in (5).

$N_u=0.023* R_e^{(4/5)}*P_r^{0.3}$ (Turbulent flow) (4)

$R_e=(\rho .V D)/\mu$ (5)

By utilizing fluid dynamics principles, the mass flow rate of air entering the box is equated to the mass flow rate of air exiting from the box. This equivalence is established in accordance with the Continuity equation, which states that Qin is equal to Qout. The value of Q is determined by multiplying the cross-sectional area of the air with its velocity. In order to enhance the cooling system, two pipes with different diameters were strategically placed within the box. The smaller diameter pipe directs the air

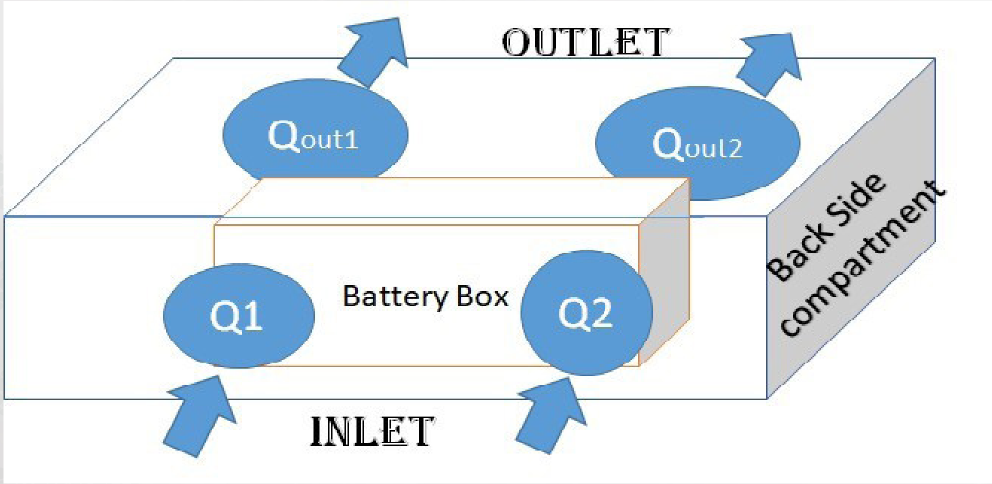

Figure 3: Air inlet and outlet to the back side compartment of the vehicle

with greater force compared to the larger diameter pipe. As a result, airflow continuously circulates throughout the box. This circulation ensures that the air is uniformly distributed across all box surfaces, thereby contributing to the efficient operation of our cooling system.

Given that Area1 represents the cross-sectional area of the first pipe with diameter Dia1 and Area2 represents the cross-sectional area of the second pipe with diameter Dia2, along with Aout1 denoting the cross-sectional area of the first outlet pipe and Aout2 representing the cross-sectional area of the second outlet pipe. Let Q1 and Q2 be the airflow rates for the first and second inlet pipes, respectively, and Qout1 and Qout2 be the air flow rates through the first and second outlet pipes, respectively (Figure 3). The airflow through the two pipes into the box, followed by the exit through two outlet pipes, creates a circulating flow within the box, which can be mathematically expressed by equation (6). Consequently, the mass balance for the air within the box can be articulated. The mass balance equation for the air within the box can be written as:

$$Area_1 * Q_1 + Area_2 * Q_2 = A_{out1} * Q_{out1} + A_{out2} * Q_{out2} \quad (6)$$

Equation (6) embodies the principle of mass conservation within the box, considering the inflow and outflow of air through the pipes. When the two sides are equal, it signifies a steady-state condition, suggesting no net accumulation or depletion of air within the box.

Supercapacitor Bank Integration

In our proposed conversion model utilizing lead-acid batteries, the motor initially draws a high current due to inertial torque, which, if sustained over time, could lead to battery damage or degradation. To mitigate this issue, we introduce a supercapacitor bank to swiftly handle the high current demand during motor startup. Controlled by a smart controller, the supercapacitor bank connects to the motor during startup to provide the necessary current, then disconnects once the motor is operational, rejoining the battery unit. This smart control strategy ensures efficient management of high motor starting currents, enhancing battery longevity. The energy required for vehicle operation over a certain distance is represented by (7).

$$E_{(Total\ Energy)} = P_{motor} * L / _{VSpeed} \text{ Joules} \quad (7)$$

Where $\mathbf{E}_{\mathbf{Total\ Energy}}$ is the energy required (Joules), L is the distance to travel (m), $\mathbf{V}_{\mathbf{speed}}$ is the speed of vehicle (m/s).

Let $\mathbf{V}_{\mathbf{motor}}$ denote the voltage in volts (V) and let $I_{starting}$ be determined as three times I_{rated}. Here, I_{rated} is calculated as the ratio of P_{rated} to V_{rated} in Ampere (A), and t represents the duration of time in hours during which the starting current flows. The energy required for the motor at startup is expressed by (8).

$$E_{(Motor\ starting)} = V_{motor} \times I_{starting} \times t \text{ Joules} \quad (8)$$

Let **N** represent the number of braking events, $M_{vehicle}$ denote the total mass of the vehicle in kilograms (kg), $V_{initial}$ and V_{final} denote the speed of the vehicle in meters per second (m/s) before and after braking, respectively. During travel, if braking events occur, the total energy recovered by the motor due to regenerative braking is expressed as (9). Similarly, if C represents the capacitance of the supercapacitor bank in farads (F), $U_{initial}$ and U_{final} represent the initial and final voltage of the supercapacitor, respectively, in volts (V), then for each braking event, the energy stored in the supercapacitor bank is described by (10).

$$E_{(total\ recovered)} = N * [1/2 * M_{vehicle} * (V_{initial}^2 - V_{final}^2) \text{ Joules} \quad (9)$$

$$E_{supercapacitor} = 1/2 * C * (U_{initial}^2 - U_{final}^2) \text{ Joules} \quad (10)$$

Therefore, Equation (11) represents the discharging current supply from the supercapacitor bank during **T** working time of the supercapacitor bank.

$$I_{supercapacitor} = E_{supercapacitor} / T \text{ Joules} \quad (11)$$

RESULTS

Battery Cooling Unit

In the proposed battery cooling system, two hollow pipes with diameters of 3.5 cm and 4.0 cm, respectively, are implemented. During forward vehicle movement, atmospheric pressure induces a front drag force on the front side. As a result, air enters the hollow pipes, creating a flow from the front to the back chamber. This airflow serves as a coolant, effectively regulating the battery temperature. Notably, a lead-acid battery is employed for energy storage, demonstrating optimal efficiency when maintained within the temperature range of 17^0C to 50^0C.

In this proposal system, the heat transfer through the metal case from battery to air (25^0C) is calculated using equation (1), where k_{Metal} =167(W/m·K),A_{Metal}= 0.2584m^2. We aim to keep the battery temperature below 45^0C and to achieve this; we calculate the amount of heat that needs to be released into the air using equation (2). Figure 4(a) shows that heat generation

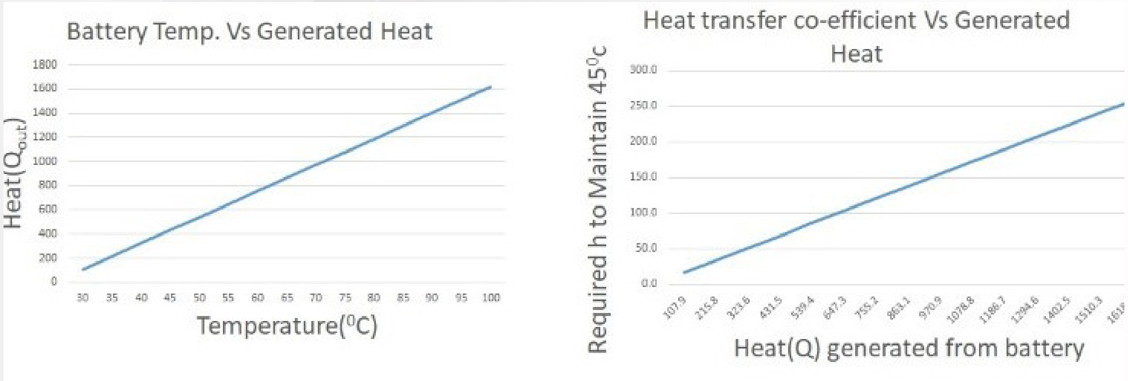

Figure 4: (a) By increasing the battery's temperature, heat needs to be released by air, (b) Required heat transfer coefficient with respect to generated heat

increases with regard to battery temperature. In Figure 4(b), the results are illustrated, indicating that as the battery's internal temperature increases, the amount of heat transfer co-efficient is required to maintain the temperature at 45^{0}C.As the speed of the vehicle rises, the air resistance force intensifies. Consequently, this results in an increased air speed affecting the front surface of the vehicle, leading to a subsequent increase in the battery's temperature while traveling for a long duration. In our designed cooling system, the heat absorption capability from a metal cage through air convection is determined by (3). Table 1 explicitly illustrates that increased air velocity enhances the heat absorption capability. To justify the results of Nusselt number, N_u (4), Reynolds number, R_e (5), and heat transfer co-efficient supply from two different diameter pipes, 3.5 cm and 4.0 cm, respectively, we assess the variation in heat temperature coefficient concerning the impact of air velocity on the battery cage. As illustrated in Figure 5, the heat transfer coefficient shows a rising tendency when the air velocity in the suggested pipe diameters

Velocity (m/s)	Pipe Size 3.5cm			Pipe Size 4.0cm			Total heat transfer co-efficient
	Reynolds number (Re)	Nusselt number (Nu)	heat transfer co-efficient (h)	Reynolds number (Re)	Nusselt number (Nu)	heat transfer co-efficient (h)	
3	7079	25	32	8090	28	24	56
4	9438	31	41	10787	35	30	71
5	11798	37	49	13483	42	36	85
6	14157	43	56	16180	48	42	98
7	16517	49	64	18876	54	47	111
8	18876	54	71	21573	61	53	123
9	21236	60	78	24270	67	58	135
10	23596	65	85	26966	72	63	147
11	25955	70	91	29663	78	68	159
12	28315	75	98	32360	84	73	171
13	30674	80	104	35056	89	77	182
14	33034	85	111	37753	95	82	193
15	35393	90	117	40449	100	87	204
16	37753	95	123	43146	105	91	215
17	40112	100	129	45843	111	96	225

Figure 5: Heat transfer co-efficient increases concerning air velocity

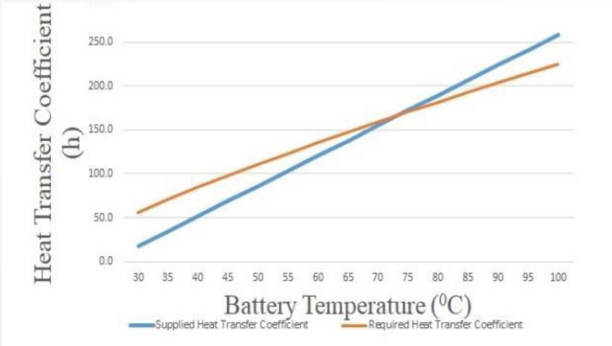

Figure 6: Heat transfer co-efficient Designed vs required

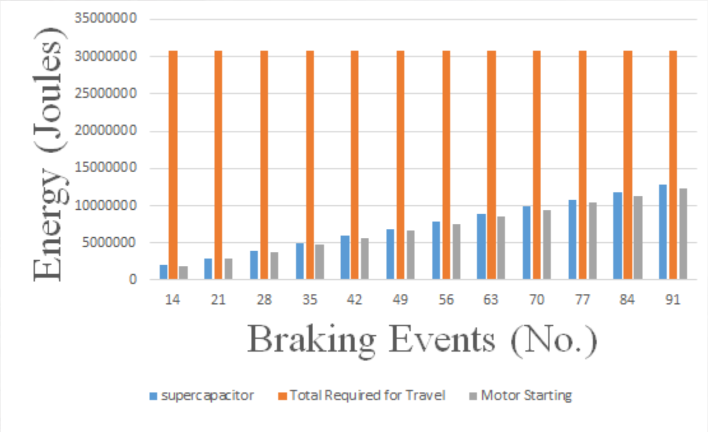

Figure 7: Energy vs braking event

increases. The recorded heat transfer coefficients from both pipes clearly demonstrate their ability to efficiently uphold the battery temperature within 45^{0}C up to a temperature of battery rise of 75^{0}C at a velocity of 12m/s.

Supercapacitor Bank

In this scenario, a vehicle is powered by a 48V, 15kW motor, while two 48V, 200Ah lead acid batteries are con-nected in parallel. The vehicle is expected to travel a distance of 20 km at an average speed of 35 km/hr. Addi-tionally, a 48V, 400F supercapacitor bank is incorporated alongside the battery unit to serve as hybrid storage. During the journey, two types of braking events occur: i) 15 moderate stops, reducing speed from 40 km/h to 10 km/h and ii) three hard stops, reducing speed from 40 km/h to 0 km/h. Based on these criteria, the total energy required to cover the distance is calculated to be 30.86 MJ (7). Furthermore, energy recovered from braking events amounts to 1.58 MJ (9).

If the supercapacitor bank terminal voltage drops to 40V after discharge, the energy stored by the supercapaci-tor bank for each braking event amounts to 140.8 kJ (10). During acceleration following each braking event, the motor draws high current from the storage device for three seconds to restore the vehicle's average speed. As-suming the motor's starting current flow lasts for three seconds, with the motor drawing three times its rated cur-rent, the maximum energy required for the motor to start is 135 kJ (after each hard braking) (8). During this time, the supercapacitor bank delivers 0.977 kA (8) for 3 seconds, whereas the motor needs to start at a current of 0.937 kA (11). Results for various vehicle scenarios are shown in Table 2, with all other data

Table 1: Different scenarios of the vehicle.

Travel Distance (m)	Average velocity (m/s)	Number of moderate Braking event (No.)	Number of hard Braking event (No.)	Total Energy delivered for total breaking event by Supercapacitor (Joules)	Total Energy required for Motor starting for total breaking event (Joules)
20000	9.72	10	4	1971200	1890000
30000	9.72	15	6	2956800	2835000
40000	9.72	20	8	3942400	3780000
50000	9.72	25	10	4928000	4725000
60000	9.72	30	12	5913600	5670000

remaining con-sistent. Figure 6 illustrates the supercapacitor bank's contribution to the proposed model and demonstrates how it supplies the necessary energy for starting.

CONCLUSION

This work presents an optimized technique for transforming vehicles reliant on internal combustion engines into electric vehicles. The strategy mainly focuses on the importance of making minimal alterations to the existing vehicle, thereby converting it into a highly efficient EV. This is achieved by introducing an energy-efficient model that integrates a battery cooling system and a supercapacitor bank. By reusing the majority of the original vehicle components, the cost of conversion is kept to a minimum, with the supplementary elements representing a fixed expense when compared to the price of a new EV. This proposed battery cooling system delivers promising results without the need for extensive modifications. The supercapacitor bank demonstrates its ability to supply an amazing 140.8 KJ of energy at the onset of the motor, where a maximum of 135 kJ is required for starting. Consequently, our proposed system conserves the battery storage for the initial surge of high current, thereby enhancing the battery's lifespan and boosting the efficiency of the envisioned EV system. These research findings hold immense potential for developing nations, wherein a significant number of cars operate on traditional fuel sources. The affordability of EV expenses in these countries renders this conversion approach a feasible and impactful solution.

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