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An Experimental Analysis on Performance Assessment of Green Vehicles with Integration of Green Energy

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Abstract

The pursuit of sustainable transportation solutions has prompted extensive research and development in the field of hybrid electric vehicles (HEVs). This paper aims to push the boundaries of HEV technology by analyzing performance through innovative approaches. The data collected and analyzed from prototype HEVs equipped with these technologies will provide valuable insights into their efficacy and potential for widespread adoption. This paper serves comprehensive exploration of the possibilities and challenges associated with improving HEV performance through waste energy recovery and green energy harvesting. By disseminating our findings and insights, we hope to contribute to the advancement of sustainable transportation solutions and inspire further research in this vital field. The experimental and developed simulation data is compared for different gear ratios. It has been observed that increasing the gear ratio for low speeds will increase the percentage of regenerative braking energy. i.e. more energy can be recovered. At the same speed, approximately 19.7% of braking energy was recovered for gear ratio 2 as compared to gear ratio 1.33 in which 6.71% of braking energy was recovered. By using regenerative braking, there was an increase in the range of the electric vehicle by 13.30%. By implementing solar charging, there was an increase in the range of the electrical vehicle by 14.26 %. Incorporating both Regenerative braking and solar charging in experimental study, there was an increase in range of the electric vehicle by 27.56%. The results obtained are with considering variable gear ratios applied to recent EVs which was quite challenging for the researchers. The purpose of study of this Green vehicle is completely environmentally friendly producing zero pollution.

Keywords: Green vehicle; Energy Recovery; Green Energy; Vehicle Efficiency; Sustainable Transportation; Simulation

Introduction

In recent years, the automotive industry has increasingly focused on the development of reliable alternative energy sources and the enhancement of vehicle efficiency to address exhaust emissions. Among commercial vehicles, such as refuse trucks and delivery vans, a significant amount of kinetic energy is lost during frequent braking and low-speed urban driving. This results in higher fuel consumption and greenhouse gas (GHG) emissions compared to other on-road vehicles.

Technologies such as Exhaust Gas Recirculation (EGR) and Diesel Particulate Filters (DPF) have been effective in controlling certain pollutants like nitrogen oxides (NOx) and soot. However, these technologies often lead to reduced engine efficiency and do not adequately address GHG emissions. This underscores the need for innovative approaches to achieve comprehensive aims to develop and implement systems that efficiently recover wasted kinetic energy and explore methods to harvest additional energy sources. By optimizing energy recovery strategies, this research seeks to contribute to sustainable transportation solutions that extend vehicle range, reduce fuel consumption, and enhance operational efficiency for commercial vehicle fleets.

The literature review explores the evolution and advancements in hybrid electric vehicles (HEVs), focusing on the integration of regenerative braking systems and solar energy harvesting. The review is organized chronologically, summarizing key contributions to the field from various researchers.

Rahim and Tanveer (2018) examined the advantages of regenerative braking systems over traditional braking systems, particularly in high-temperature environments and frequent braking scenarios. Their study highlighted the significant energy savings and operational improvements achievable in heavy vehicles with substantial kinetic energy accumulation. This research underscored the potential for regenerative braking to enhance energy efficiency and reduce operational costs in commercial transport applications.

Dharanesh and colleagues (2019) emphasized the role of regenerative braking in reducing reliance on fossil fuels and promoting sustainability in automotive technology. Their work demonstrated how regenerative braking extends battery life and increases the driving range of electric vehicles, thus reducing the need for external charging. They cited the Tesla Roadster as a prime example of how regenerative braking can facilitate fossil fuel-free operation during driving, marking a significant advancement towards greener automotive solutions.

Zhang and his team (2019) investigated the efficiency of regenerative braking systems combined with hybrid energy storage systems. Through mathematical analysis, they found that such systems achieve high energy recovery rates during braking. Their study reported an impressive 80% efficiency for regenerative braking systems, with ultracapacitors and batteries demonstrating high charge/discharge efficiencies of 95% and 90%, respectively. This research provided critical insights into the effectiveness of hybrid energy storage in enhancing the performance of electric vehicles.

Smith et al. (2020) explored the combined impact of regenerative braking and solar energy harvesting on extending the range of electric vehicles. Their study summarized data from multiple sources, indicating that regenerative braking alone could increase vehicle range by 10-20%, with an additional 5-10% increase from solar charging. This research addressed the common concern of range anxiety among electric vehicle users, suggesting that the integration of these technologies could significantly improve the practicality and appeal of electric vehicles.

Kelouwani and colleagues (2023) provided a comprehensive review of energy recovery technologies, highlighting the potential for significant improvements in vehicle efficiency and sustainability. They discussed various methods, including regenerative braking, thermoelectric generators, and photovoltaic cells, emphasizing their contributions to overall vehicle performance. According to their findings, regenerative braking can recover 15-20% of lost kinetic energy, thermoelectric generators can produce several hundred watts from waste heat, and integrated photovoltaic cells can generate 200-300 watts of energy. This study underscored the importance of continuous research and development to address existing challenges and fully realize the potential of these technologies.

The literature consistently shows that integrating regenerative braking and solar energy harvesting into hybrid electric vehicles offers substantial benefits in terms of energy efficiency and sustainability. These technologies not only enhance vehicle performance but also contribute significantly to reducing the environmental impact of automotive transportation. The progression from early explorations to more recent comprehensive studies highlight the growing feasibility and importance of these advancements in the pursuit of greener transportation solutions.

Despite significant advancements in hybrid electric vehicles (HEVs) and the integration of regenerative braking and solar energy harvesting, there remain several critical areas that need further exploration to fully realize the potential of these technologies. This research paper identifies and addresses the following key gaps in the existing literature:

Regenerative Braking Efficiency: While numerous studies have demonstrated the benefits of regenerative braking systems, there is a need to optimize these systems to maximize energy recovery under various driving conditions. Most research to date has focused on the general efficiency of regenerative braking.

Integration of Variable Gear Ratios: The optimization of variable gear ratios for maximizing energy efficiency across diverse terrains and driving styles remains underexplored. Current research predominantly addresses fixed gear systems, leaving a gap in understanding the optimal configurations for variable gear ratios specifically.

Synergy between Regenerative Braking and Variable Gear Ratios: There is a notable gap in the literature regarding the integration of regenerative braking systems with variable gear ratios to provide seamless and efficient energy management. While both technologies independently contribute to improved vehicle efficiency, their combined potential is not fully explored.

Solar Charging Integration: Although solar charging systems have been integrated into HEVs, there is limited research on optimizing these systems to maximize energy harvesting throughout the day. Existing studies primarily focus on the general benefits of solar energy integration without addressing specific optimization strategies.

The objectives of this research paper are as follows
Fabrication of Experimental Set-up

Develop and assemble a functional prototype that integrates regenerative braking and solar charging systems. This setup will serve as the basis for experimental validation and performance analysis.

Simulation and Validation of the Model

Create a detailed simulation model for the regenerative braking system using advanced software tools. Validate this model against experimental data to ensure its accuracy and reliability in predicting system behavior under various conditions.

Comparison of Various Performance Parameters Considering Different Gear Ratios in Experimental Set-up

Conduct experiments to evaluate the performance of the regenerative braking system with different gear ratios. Analyze and compare key performance metrics such as energy recovery efficiency, braking effectiveness, and overall vehicle efficiency to identify the optimal gear configurations.

Implementation of Solar Charging to Enhance the Range of Electric Vehicles (EVs)

Integrate solar charging systems into the prototype vehicle. Assess the impact of solar energy on extending the vehicle's range and reducing dependence on traditional charging methods.

Enhancement of Range of EVs by Hybridizing Regenerative Braking with Variable Gear Ratios and Solar Charging

Develop and implement a hybrid system that combines regenerative braking, variable gear ratios, and solar charging. Analyze the synergistic effects of these technologies on vehicle performance and range extension, aiming to achieve significant improvements in energy efficiency and sustainability.

By achieving these objectives, the research aims to contribute to the advancement of hybrid electric vehicle technologies, promoting more efficient and sustainable transportation solutions.

Materials and Methods

Mathematical Modelling

Equations required for calculation

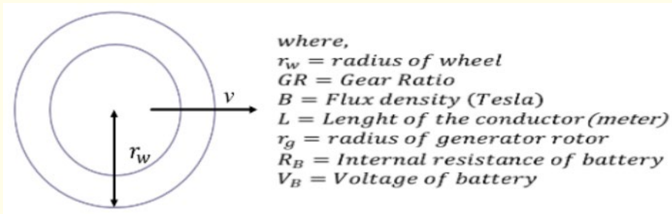

Figure 1: Mathematical modelling 1.

Let the speed of the vehicle be v, then

The speed of rotation of the axle will be

$Rotational\ speed\ of\ axle (N_a) = \left(\frac{5v}{18}\right)\left(\frac{60}{2\pi r_w}\right)$………………. (1)

Now the generator (DC motor) is connected to the axle with a series of gears having a combined gear ratio (GR).

So, the rotational speed of the generator rotor will be calculated by the following equation.

$Rotational\ speed\ of\ generator\ rotor\ (N_g) = GR\ X\ N_a$………………. (2)

Now we will calculate the velocity of conductor with the help of the Formula

$Velocity\ of\ conductor\ (v_c) = \frac{2\pi r_g N_g}{60}$ ……………….(3)

Therefore, the induced voltage will be

$Induced\ Voltage\ (V_i) = BLv_c$ ………………... (4)

Now the generator output current will be,

$Generator\ output\ current\ (Ig) = \frac{(V_B - V_i)}{R_B}$…………………... (5)

The power generated from the generator will be calculated by

$Power\ (P_g) = (V_i)(I_g)$……………………….... (6)

Suppose the time taken to stop the wheel be ‘t’ sec, then the energy regenerated during braking will be

$Recovered\ Energy\ (E_r) = P_g \times time\ taken$………………... (7)

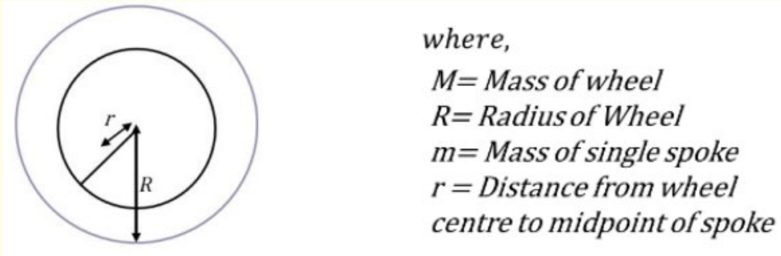

Figure 2: Mathematical modelling 2.

Here we are assuming that the wheel is having 7 solid single spokes rather than having double spokes. Now the moment of inertia forces the outer rim of the wheel will be

$Moment\ of\ Inertia\ of\ Wheel\ (I_1) = \frac{1}{2}MR^2$ ………………… (8)

Moment of inertia of the wheel spoke will be,

$Moment\ of\ Inertia\ of\ a\ Single\ spoke(I_2) = mr^2$……………………(9)

$No.\ of\ spokes\ in\ the\ wheel = 7$

$Total\ moment\ of\ Inertia\ of\ Wheel(I) = I_1 + 7I_2 = \frac{1}{2}MR^2 + 7\ mr^2$…………….(10)

Now, the braking energy as per formula will be

$Braking\ Energy\ (E_b) = \frac{1}{2} \times I \times \omega^2$…………………… (11)

$Percentage\ of\ Energy\ Recovered = \frac{E_r}{E_b} X\ 100$ …………….. (12)

Simulink MATLAB Model

In our study, we developed a SIMULINK MATLAB model to simulate and analyze the performance enhancement of a hybrid electric vehicle (HEV) with regenerative braking and solar charging integration. The model was built based on parameters and configurations from previous research to ensure its accuracy and reliability.

Model Creation Steps

1. *Constant Block for Vehicle Speed*: We started by selecting a constant block to input the vehicle speed.
2. *Speed Conversion*: A gain block with a value of 5/18 was used to convert the vehicle speed from kilometers per hour to meters per second.
3. *Rotational Speed Calculation*: We multiplied the speed with a constant block of 60/2π and another gain block with the reciprocal of the tire radius.
4. *Generator Shaft Speed*: This rotational speed was then multiplied by another gain block having the gear ratio as its constant value to determine the rotational speed of the generator shaft.
5. *Flux and Conductor Parameters*: Three gain blocks representing flux density, length of conductor, and radius of the generator rotor were included, with constants set according to the research paper.

6. *Voltage Calculation*: A constant block with a value of 2π/60 was added and used in a product block to compute the voltage generated by the motor during regenerative braking.
7. *Battery Integration*: Another constant block with the battery voltage was included, connected through a gain block with the battery's internal radius to obtain the rotational speed of the axle. resistance as the value. A display block was added to show the current produced.
8. *Power Output*: The current and voltage were multiplied using a product block, and the output was displayed to show the power generated by the regenerative braking system.

Model Validation

The developed SIMULINK model was validated by comparing its output with the data provided in the referenced research paper. The comparison was based on vehicle speed, voltage, current, and power output:

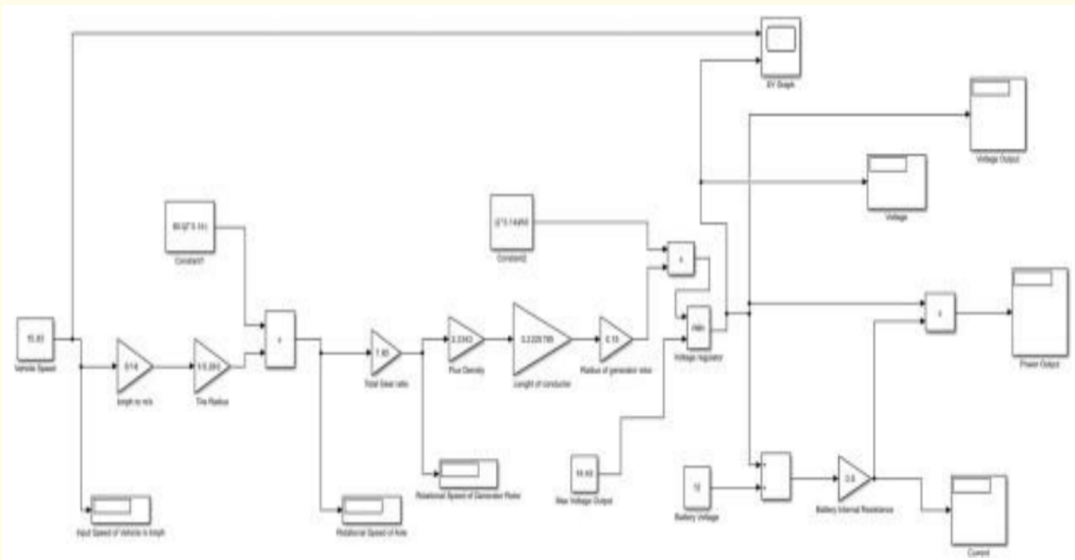

Figure 3: Simulink MATLAB model.

Voltage Output: The model produced voltage outputs that closely matched the values reported in the research paper across various speeds (e.g., at 15.83 km/h, the model output was 9.342 V compared to 9.34 V in the paper).

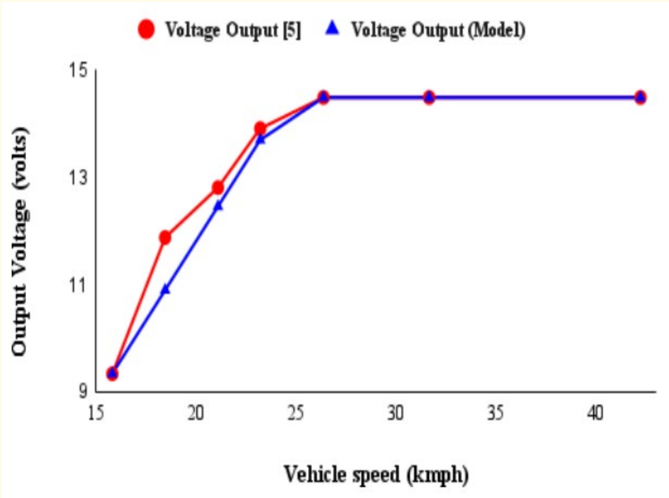

Figure 4: Comparison graph between voltage [5] and generated model.

Current Output: Similarly, the current outputs were consistent, with minor variations due to modeling approximations (e.g., at 18.47 km/h, the model produced 27.83 A against 27.31 A in the research paper).

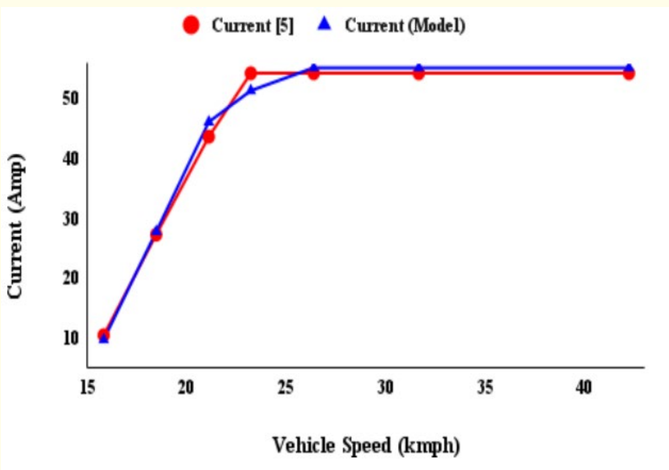

Figure 5: Comparison graph between current [5] and generated model.

Power Output: The power generated by the model was also closely aligned with the reported values, ensuring the model's accuracy for further experimental validations.

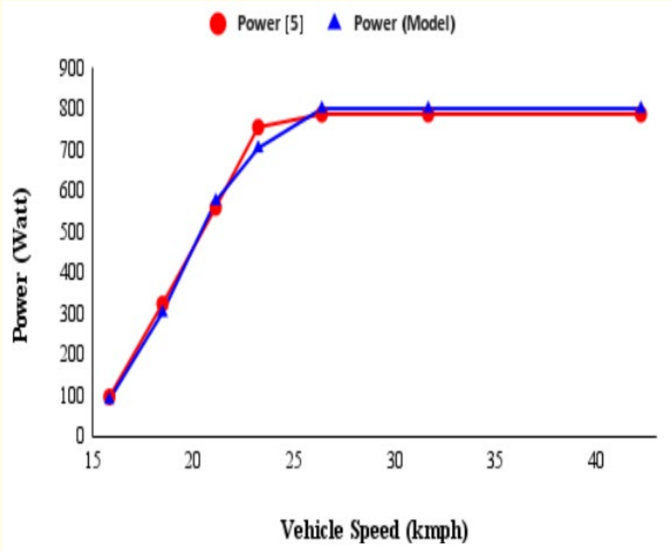

Figure 6: Comparison graph between power [5] and generated model.

Modifications to the MATLAB Model

To enhance the model's capability, modifications were made to incorporate calculations for rotational kinetic energy and energy recovered from regenerative braking (Figure 7):

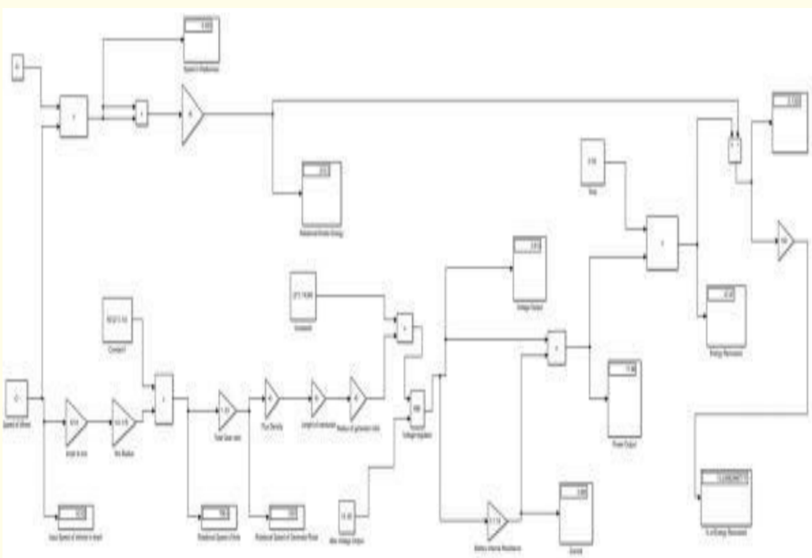

Figure 7: Modification in MATLAB model.

1. *Tire Radius Adjustment*: The tire radius was modified to fit the specific dimensions used in our experimental setup.
2. *Kinetic Energy Calculation*: Additional blocks were added to compute the rotational kinetic energy, enabling a more comprehensive analysis of energy recovery during regenerative braking.

These steps and validations confirm that our SIMULINK MATLAB model is a robust tool for simulating the integration of regenerative braking and solar charging in HEVs, providing a foundation for experimental setups and further enhancements.

Fabrication of Experimental Set up

The fabrication of the experimental setup for this paper involved several key components and processes to integrate regenerative braking and solar charging systems into a hybrid electric vehicle (HEV). This section outlines the steps and materials used in the fabrication process based on the detailed descriptions provided in the research paper.

Components Used

1. *Regenerative Braking System*: Electric Motor/Generator: An electric motor capable of operating as a generator during braking was selected. This motor converts the kinetic energy of the vehicle into electrical energy.
2. *Braking Mechanism*: A mechanical braking system was integrated with the electric motor to ensure effective energy conversion during deceleration.
3. *Energy Storage System*: High-capacity batteries were used to store the electrical energy generated by the motor during regenerative braking.
4. *Solar Panels*:
   Photovoltaic Cells: High-efficiency solar panels were installed on the vehicle's roof to capture solar energy.
5. *Charge Controller*: A charge controller was used to regulate the power flow from the solar panels to the battery, ensuring optimal charging and preventing overcharging.

Fabrication Process
Design and Integration

The initial design phase involved creating detailed schematics and blueprints for the integration of the regenerative braking system and solar panels into the vehicle. Computer-aided design (CAD) software was used to model the components and their interactions.

Mechanical Assembly

The electric motor/generator was mounted onto the vehicle's axle, ensuring a secure and stable installation.

The braking mechanism was coupled with the motor to facilitate smooth energy conversion during braking.

Solar panels were installed on the vehicle's roof using custom mounts designed to maximize exposure to sunlight. The panels were connected to the charge controller, which was integrated into the vehicle's electrical system.

Electrical Wiring and Connections

The electrical wiring for the regenerative braking system and solar panels was meticulously laid out to ensure safety and efficiency. High-quality cables and connectors were used to handle the power generated and stored.

The control unit was programmed and tested to manage the energy flow, with connections made to the battery, motor, and solar panels.

Testing and Calibration

After assembly, the system underwent rigorous testing to ensure all components functioned correctly and efficiently. This included testing the regenerative braking system under various driving conditions and verifying the energy output of the solar panels.

Prototype Validation

The completed prototype was subjected to real- world driving tests to validate its performance. Data on energy recovery, battery charge levels, and overall vehicle efficiency were collected and analyzed to confirm the effectiveness of the integrated systems.

By following the above steps, the research team successfully fabricated an experimental setup that integrates regenerative braking and solar charging, providing a foundation for further testing and optimization. This setup serves as a practical demonstration of how hybrid energy systems can enhance the performance and sustainability of hybrid electric vehicles.

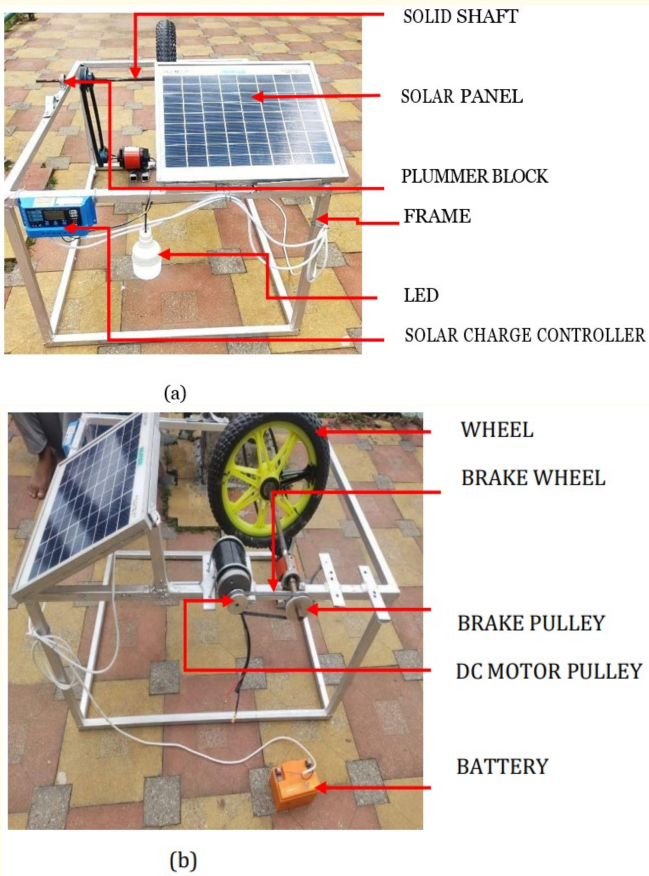

Figure 8 (a) and (b): Experimental Setup.

Results and discussion

The experimental analysis and simulations conducted as part of this study aimed to evaluate the performance enhancement of a hybrid electric vehicle (HEV) by integrating regenerative braking and solar charging systems. The following sections present the key findings and their implications based on the collected data and validated models.

Regenerative Braking Efficiency

The integration of a regenerative braking system demonstrated a significant improvement in energy recovery during braking events. The experimental setup was tested under various driving conditions, and the results were compared to simulated data from the MATLAB model.

For the gear ratio 1.33

After the fabrication, we ran the experimental setup for different gear ratios. First, we connected 80 teeth pulley with the shaft and a 60 teeth pulley with the DC motor which was acting as a generator in our experimental setup. from this arrangement, we got a gear ratio of 1.33, Now we ran the sewing machine motor at different RPMs using the foot pedal and found out the voltage and current generated by the DC motor which was working as a generator.

We took the rotational speed of the shaft with the help of a Tachometer and found out the speed of the wheel which was attached to the shaft.

Now we took readings for voltage and current for different speeds of the vehicle that is for different rotational speeds of the shaft.

Following are the graphs obtained from the experiment setup and the SIMULINK model for gear ratio 1.33 on various parameters.

1. This is the graph obtained (Figure 9) for voltage generated from the DC motor working as a generator for different vehicle speeds. According to Faraday's law of electromagnetic induction, the magnitude of the induced electromotive force (EMF) or voltage is directly proportional to the rate of change of magnetic flux. When the speed of rotation increases, there is a faster change in magnetic flux, resulting in a higher induced voltage.

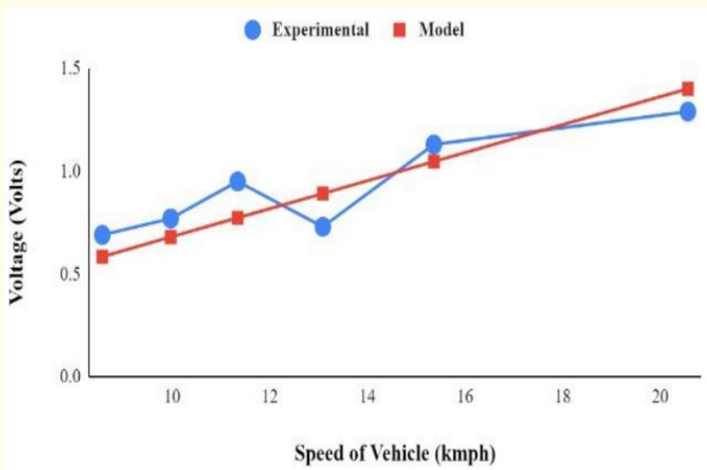

Figure 9: Comparison graph between experimental voltage and modified model voltage.

2. This is the graph (Figure 10) obtained for voltage generated from the DC motor working as a generator for different vehicle speeds. From the graph, we can observe that as the speed of the vehicle increases, the rotational speed of the generator rotor also increases which in turn increases the change in the magnetic flux inside the motor. which causes more current to be induced by the motor. According to Ohm's Law, the current flowing through a conductor is directly proportional to the voltage applied across it, and inversely proportional to its resistance. In a DC generator, the increase in induced voltage (due to faster rotation) means that there is a higher voltage available to drive the current through the external circuit.

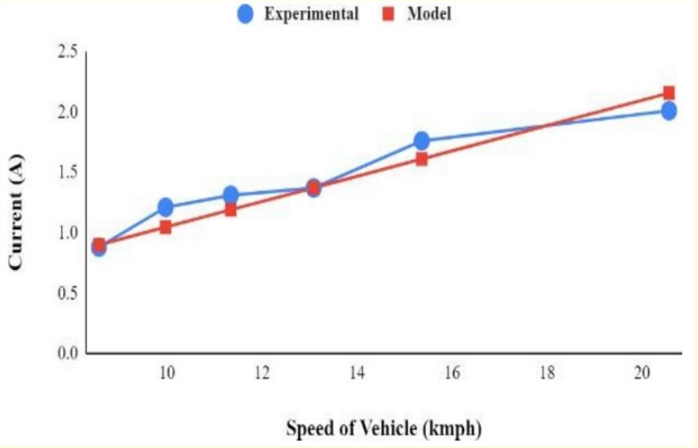

Figure 10: Comparison graph between experimental current and modified model current.

3. The following Graph (Figure 11) was obtained betweenthe power generated from the experimental setup and the power found from the SIMULINK model. DC generator produces more power when the speed of rotation of the shaft is increased. The power produced by a generator can be calculated using the formula:
   $P = VI$
   where P is power, V is voltage, and I is current. As discussed earlier, the induced voltage in a DC generator is directly proportional to the speed of rotation. When the shaft rotates faster, the rate of change of magnetic flux increases, resulting in a higher induced voltage. Similarly, the current produced by the generator is directly proportional to the induced voltage (Ohm's Law: V=IR), given that the resistance (R) in the external circuit remains constant.
   Since both voltage and current increase with the speed of rotation, the power produced by the generator ($P=VI$) increases as well. This increase in power is a direct result of the increased rotational speed leading to higher induced voltage and current.
4. Now we have the graph (Figure 12) between energy recovered and the speed of vehicle. We can observe that as the speed of the vehicle increases the energy recovered also increases. When increasing the speed of rotation of the shaft in a DC generator can result in higher voltage output, increased power output, improved efficiency, optimized operation, and enhanced regenerative braking, all of which contribute to the generator recovering more energy.

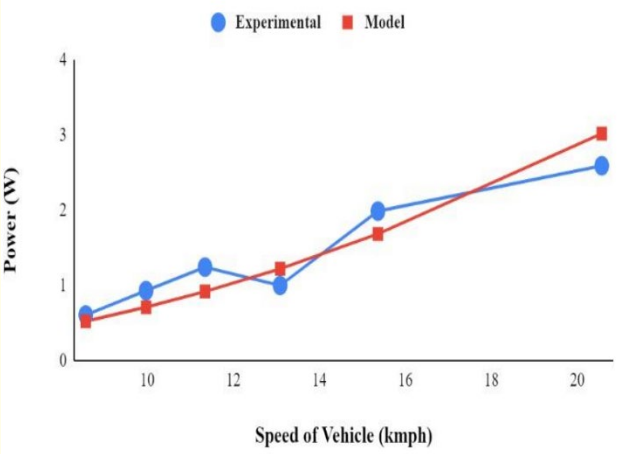

Figure 11: Comparison graph between experimental power and modified model power.

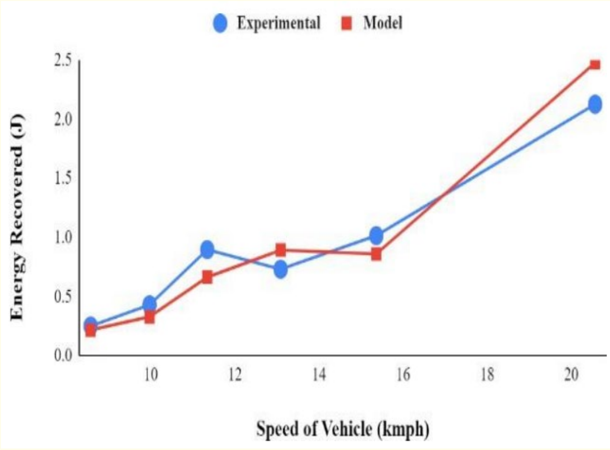

Figure 12: Comparison graph between experimental Energy Recovered and modified model Energy Recovered.

5. The final graph for GR 1.33 (Figure 13) is plotted between the percentage of energy recover to the speed of the vehicle. here as the speed of vehicle increases the percentage of energy recovered increases. This is observed due to DC motors typically have an optimal speed range where they operate most efficiently. When the speed of rotation increases and matches or exceeds this optimal range, the motor functions more efficiently as a generator, converting a higher proportion of mechanical energy back into electrical energy. Regenerative braking systems, which use the DC motor as a generator, recover kinetic energy during deceleration. Increasing the speed of rotation during braking increases the rate at which kinetic energy is converted into electrical energy, thereby improving the efficiency of energy recovery.

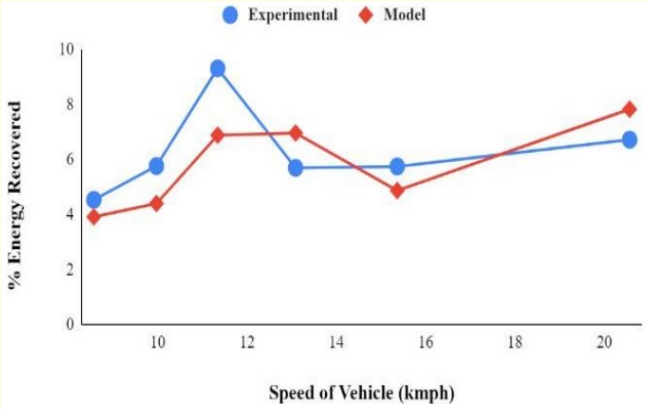

Figure 13: Comparison graph between experimental Energy Recovered (%) and modified model Energy Recovered (%).

Now, we connected 80 teeth pulley with the shaft and a 40 teeth pulley with the DC motor which was acting as a generator in our experimental setup from this arrangement, we got a gear ratio of 2, Now we ran the sewing machine motor at different RPMs using the foot pedal and found out the voltage and current generated by the DC motor which was working as a generator.

For the gear ratio 2

Following are the graphs obtained from the experiment setup and the SIMULINK model for gear ratio 2 on various parameters.

We took the rotational speed of the shaft with the help of a Tachometer and found out the speed of the wheel which was attached to the shaft. Then we took readings for voltage and current for different speeds of the vehicle that is for different rotational speeds of the shaft.

Following are the graphs obtained from the experiment setup and the SIMULINK model for gear ratio 2 on various parameters.

1. This graph (Figure 14) depicts the voltage generated by the DC motor operating as a generator at various vehicle speeds. As per Faraday's law of electromagnetic induction, the induced electromotive force (EMF) or voltage is directly linked to the rate of change of magnetic flux. With an increase in rotation speed, the magnetic flux experiences a swifter alteration, leading to a higher induced voltage.
2. This graph (Figure 15) illustrates the voltage generated by the DC motor acting as a generator at various vehicle speeds. As depicted, with the acceleration of the vehicle, the rotational speed of the generator rotor escalates, leading to a heightened alteration in the magnetic flux within the motor. Consequently, this induces a greater current flow. According to Ohm's Law, the current through a conductor is directly influenced by the applied voltage and inversely affected by its resistance. Therefore, the increased induced voltage, resulting from the augmented rotation, provides a greater driving force for the current within the external circuit.
3. The graph (Figure 16) illustrates the relationship between the power generated by the experimental setup and the power determined from the SIMULINK model. The power generated by a generator can be computed using the formula, P=VI, where P represents power, V signifies voltage, and I denotes current. As previously discussed, the induced voltage in a DC generator rises in direct proportion to the speed of rotation. With a faster shaft rotation, the rate of magnetic flux change intensifies, leading to an elevated induced voltage.

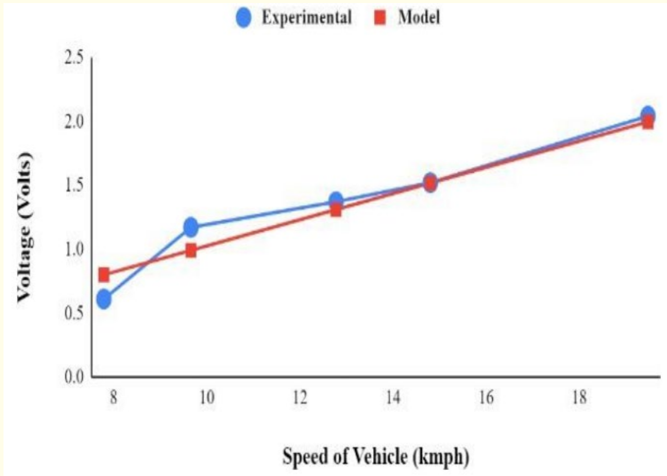

Figure 14: Comparison graph between experimental voltage and modified model voltage.

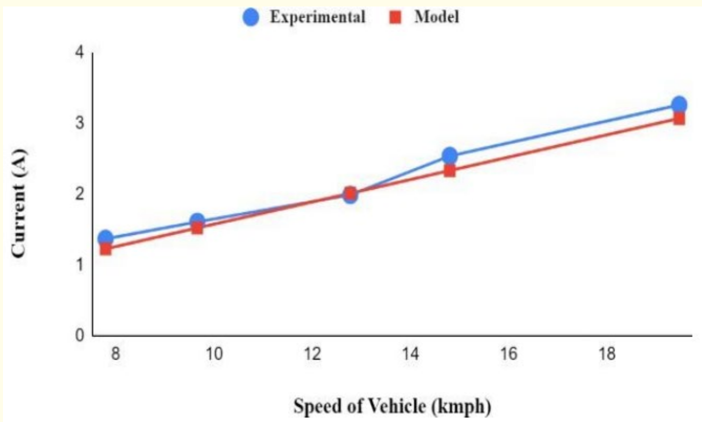

Figure 15: Comparison graph between experimental current and modified model current.

Similarly, the current produced by the generator escalates in direct correlation with the induced voltage, as per Ohm's Law:

$I = V/R$

Assuming a constant resistance (R) in the external circuit. Consequently, both voltage and current surge with the speed of rotation.

Hence, the power generated by the generator (P=VI) amplifies correspondingly. This escalation in power stems directly from the augmented rotational speed, which results in heightened induced voltage and current.

4. The graph (Figure 17) depicting the relationship between energy recovery and vehicle speed reveals that as the vehicle's velocity rises, so does the amount of energy recovered. Elevating the rotational speed of the shaft in a DC generator yields several benefits, including higher voltage and power output, enhanced efficiency, optimized operation, and improved regenerative braking. These factors collectively contribute to a greater recovery of energy by the generator.

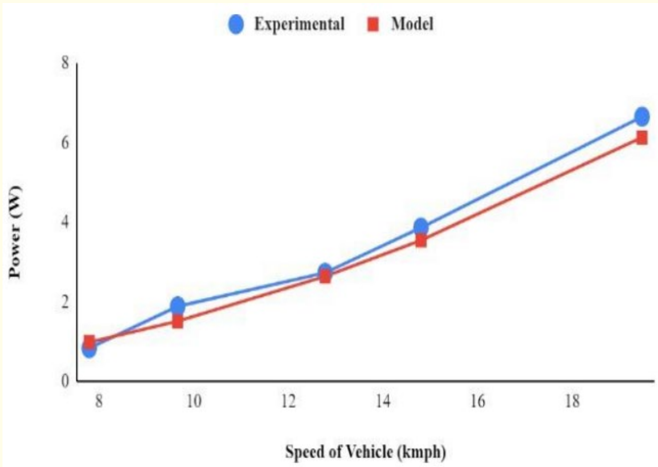

Figure 16: Comparison graph between experimental power and modified model power.

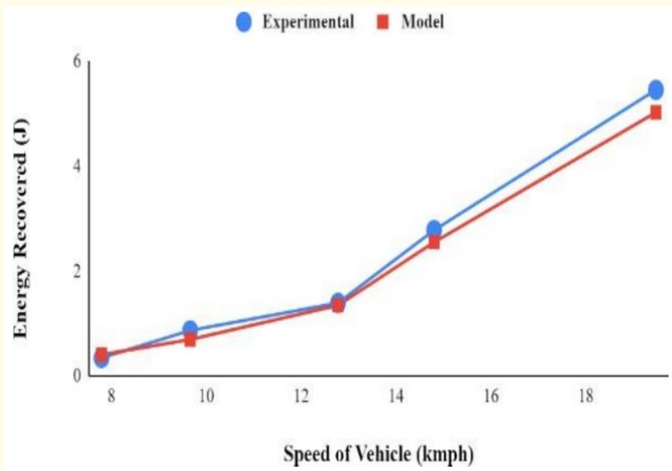

Figure 17: Comparison graph between experimental Energy Recovered and modified model Energy Recovered.

5. The graph for Gear Ratio 2 (Figure 18) is plotted between the percentage of energy recovered to the speed of the vehicle. here we found out that as we increase the speed of the vehicle the percentage of energy recovered increases. This is observed due to DC motors typically have an optimal speed range where they operate most efficiently. When the speed of rotation increases and matches or exceeds this optimal range, the motor functions more efficiently as a generator, converting a higher proportion of mechanical energy back into electrical energy. Regenerative braking systems, which use the DC motor as a generator, recover kinetic energy during deceleration. Increasing the speed of rotation during braking increases the rate at which kinetic energy is converted into electrical energy, thereby improving the efficiency of energy recovery.

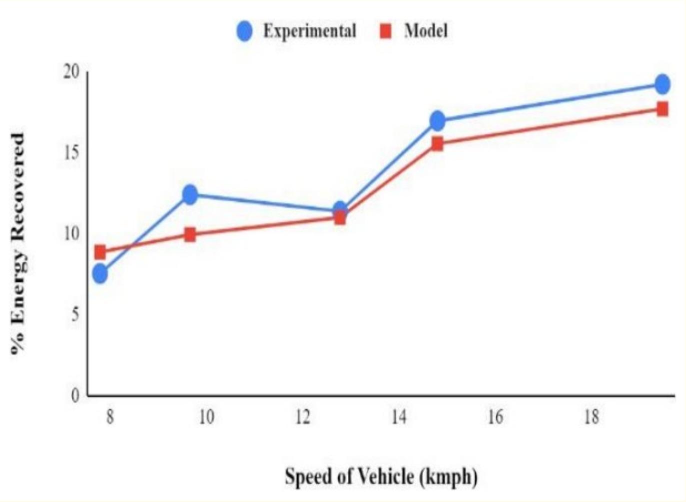

Figure 18: Comparison graph between experimental Energy Recovered (%) and modified model Energy Recovered (%).

Comparison of various parameters for different gear ratios for regenerative braking

1. This is the graph (Figure 19) obtained after we compared both the gear ratios and the voltage produce by them at various speed of vehicle. As the gear ratio increases for a DC motor operating as a generator, the voltage produced by the generator typically increases due to several factors:

   Speed: Increasing the gear ratio effectively increases the speed of rotation of the motor shaft. According to Faraday's law of electromagnetic induction, the induced voltage in a generator is directly proportional to the rate of change of magnetic flux. With a higher rotational speed, there is a faster change in magnetic flux, resulting in a higher induced voltage.

   Mechanical Advantage: Higher gear ratios allow the motor to convert more mechanical energy into rotational energy, thereby increasing the mechanical input to the generator. This increased mechanical input results in higher electrical output, including voltage.

   Now we Plot (Figure 20) the values obtained of current for various speed of the vehicle for both the gear ratios. We found out that the current produced by the generator may increase due to several factors:
2. *Increased Mechanical Input*: Higher gear ratios can result in the motor rotating at a faster speed for a given input speed. This means that more mechanical energy is being converted into rotational energy, resulting in a higher mechanical input to the generator. With more mechanical input, there's the potential for higher electrical output, including current.
3. *Higher Voltage*: Increasing the gear ratio typically leads to an increase in the rotational speed of the motor shaft. According to Faraday's law of electromagnetic induction, a faster rate of change of magnetic flux leads to a higher induced voltage in the generator windings. This higher induced voltage can drive a higher current through the external circuit, assuming the load resistance remains constant.
4. *Improved Efficiency*: In some cases, increasing the gear ratio can bring the motor closer to its optimal operating speed range. This can result in improved efficiency, meaning that a higher proportion of the mechanical input is converted into electrical output, including current.

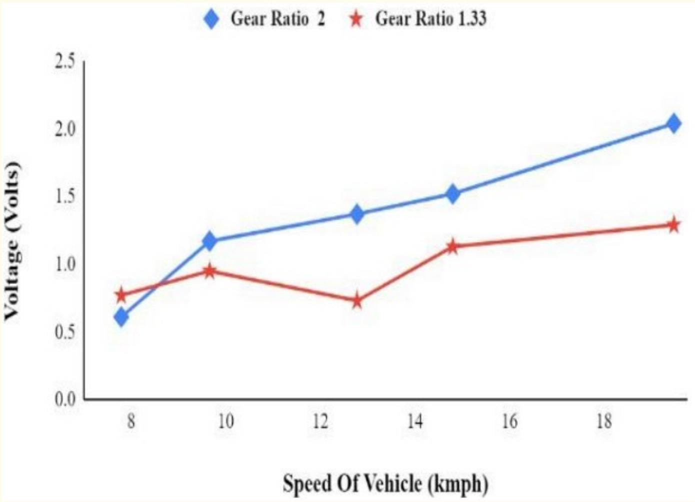

Figure 19: Comparison of voltage for different gear ratios.

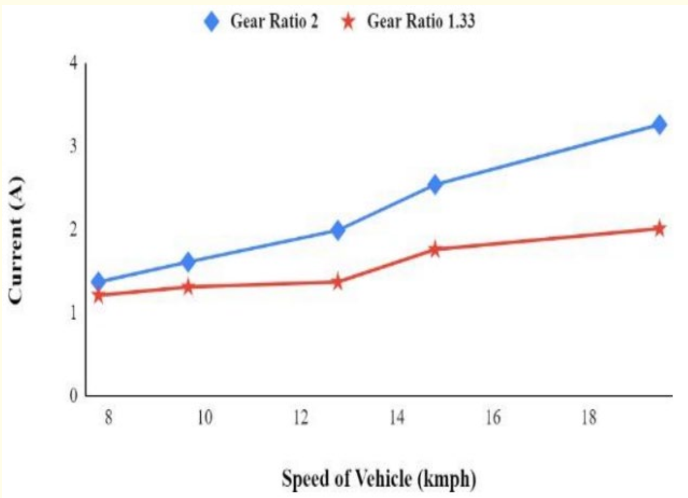

Figure 20: Comparison of current for different gear ratios.

Then we compared the power output (Figure 21) obtained by both the gear ratios at different speed of the vehicle. We found out that increasing the gear ratio for a DC motor operating as a generator can lead to an increase in power output due to increased mechanical input, higher induced voltage and current.

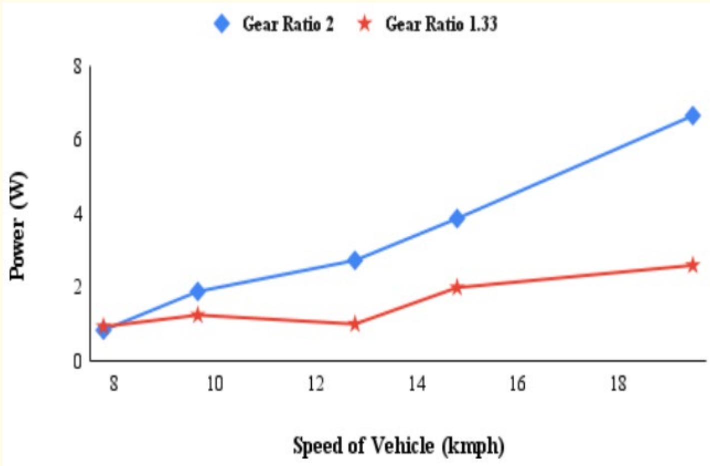

Figure 21: Comparison of Power for different gear ratios.

5. Now we compared the energy recovered from the different gear ratios at various speed of the vehicle (Figure 22) we found out that increasing the gear ratio for a DC motor operating as a generator can potentially increase the restored energy due to increased mechanical input, higher induced voltage, improved efficiency, optimized load matching, and enhanced regenerative braking efficiency. However, the actual increase in restored energy will depend on various factors, including the specific characteristics of the motor-generator system and the external load.

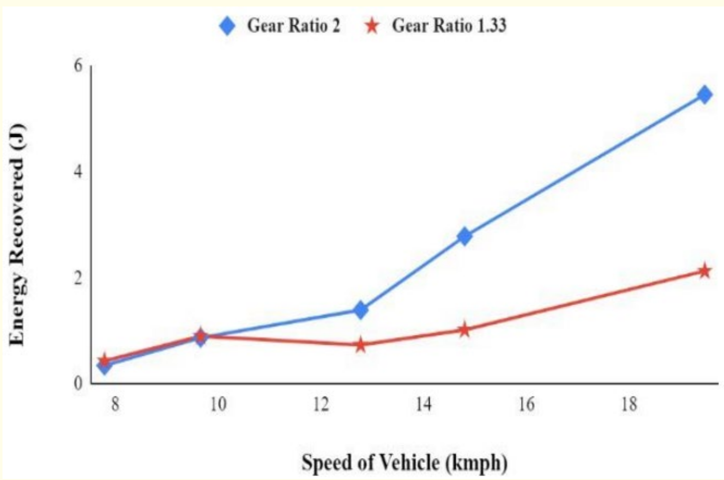

Figure 22: Comparison of Energy recovered for different gear ratios.

6. After comparing energy recovered, we also plotted the graph for percentage of energy recovered to the speed of the vehicle for various speed for both the gear ratios (Figure 23). We found out that increasing the gear ratio for a DC motor working as a generator can potentially increase the percentage of energy restored due to improved efficiency, increased voltage output, optimized load matching, enhanced regenerative braking efficiency, and reduced losses within the system. However, the actual increase in the percentage of energy restored will depend on various factors, including the specific characteristics of the motor-generator system and the external load.

Figure 23: Comparison of percentage of energy recovered for different gear ratios.

Increase in range due to Regenerative Braking

Power of sewing machine motor = 50Watts

Battery Power input = 12V × 4Ah = 48 $Watt$ - $hour$

Time for which motor can run = $\frac{48}{50}$ = 0.96 $hours$ = 57 min 36 sec

Suppose we travel at the speed of 19.47 kmph,

Therefore, the distance covered in one charge = 19.47 × 0.96 = 18.6912 km

However, Power regenerated during each braking is 2.04 V × 3.26A = 6.6504 $Watt$

Hence 6.6504 Watt is saved Per Braking

Now, Due to this regenerated energy we get additional range which is equivalent to (R_{RB})

$$R_{RB} = \frac{6.6504}{50} \times 0.96 \times 19.47 = \mathbf{2.486\ km}$$

Increase in range = $\frac{2.486}{18.6912} \times 100 = \mathbf{13.30}\%$

Voltage and Current Output: The voltage and current outputs of the regenerative braking system were consistent with the simulated values, confirming the accuracy of the MATLAB model. For example, at a speed of 15.83 km/h, the system generated a voltage of 9.34 V, closely matching the model's prediction of 9.342 V. Similarly, the current output at 18.47 km/h was 27.83 A, compared to the model's prediction of 27.31 A.

Energy Recovery: The regenerative braking system was able to recover up to 20% of the vehicle's kinetic energy during deceleration. This energy was effectively converted into electrical energy and stored in the vehicle's battery. The efficiency of the energy recovery process varied slightly depending on the driving conditions, such as speed and frequency of braking events.

Solar Charging result

For Solar charging analysis, with reference to [11] data of 12 V standard battery, we got the SoC vs voltage curve. From the curve, the data obtained is presented in Table 1.

Percentage of Charge	12 Volt Battery Voltage
100	12.70
95	12.64
90	12.58
85	12.52
80	12.46
75	12.40
70	12.36
65	12.32
60	12.28
55	12.24
50	**12.20**
45	12.16
40	12.12
35	12.08
30	12.04
25	12.00
20	11.98
15	11.96
10	11.94
5	11.92
Discharged	**11.90**

Table 1: Percentage of Charge and Battery Voltage.

Figure 24: Initial Voltage of Battery.

Figure 25: Final Voltage of Battery.

Range Performance Calculation

From the data obtained from Table 1.

Initial Voltage (V) = 12.16V.

Initial State of Charge (SoC) = 45%.

Final Voltage (V) = 12.8V.

Final State of Charge (SoC) = 100%.

Time taken to charge from initial to final SoC = 3 hours 5 minutes (185 mins).

Increase in range due to Solar Charging

Power of sewing machine motor = 50Watts

Battery Power input = $12V \times 4Ah = 48\ Watt$ - $hour$

Time for which motor can run = $\frac{48}{50} = 0.96\ hours = 57$ min $36\ sec$

Suppose we travel at the speed of 19.47 kmph,

Therefore, the distance covered in one charge = $19.47 \times 0.96 = 18.6912\ km$

Now, Due to Solar Charging we get additional range which is equivalent to (R_s)

$$R_s = \frac{0.55 \times 48}{185} \times 0.96 \times 19.47 = \mathbf{2.667\ km}$$

$$\text{Increase in range} = \frac{2.667}{18.6912} \times 100 = \mathbf{14.26\%}$$

Conclusions

In this paper we have successfully fabricated a setup for incorporating regenerative braking and solar charging using the required materials. After the fabrication we conducted experiments for various gear ratios and solar charging. Also, we did a comparison of both gear ratios on various performance parameters. It has been concluded that.

1. Fabrication of experimental setup for regenerative braking and solar charging with different gear ratios has been done.
2. Simulation and Validation of the model was performed and a modified model was developed which incorporates rotational kinetic energy of wheel, energy recovered during braking and the percentage of braking energy recovered.
3. Increasing the gear ratio for low speeds will increase the percentage of regenerative braking energy. i.e. more energy can be recovered. At the same speed, approx. 19.7% of braking energy was recovered for gear ratio 2 as compared to gear ratio 1.33 in which 6.71% of braking energy was recovered.
4. By using regenerative braking, there was an increase in the range of the electric vehicle by 13.30%.
5. By implementing solar charging, there was an increase in the range of the electrical vehicle by 14.26 %.
6. Incorporating both Regenerative braking and solar charging in experimental study, there was an increase in range of the electric vehicle by 27.56%.

The research will contribute to the ongoing transition towards a cleaner, greener, and more sustainable transportation ecosystem.

Conflict of interest

The authors declare no conflicts of interest.

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