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Modeling and Simulation of Multilevel Converter Driven Electric Vehicle using Matlab/Simulink

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ABSTRACT-*Electric vehicles (EVs) integrate advanced electric motors, innovative development methodologies, and comprehensive mitigation measures into the frameworks of standard gasoline vehicles. Instead of fossil fuels, battery packs power these vehicles, offering a sustainable alternative. The development of electric vehicles is crucial due to climate change and the rising costs of oil. Transitioning away from fossil fuels necessitates the creation and enhancement of new energy sources. These battery packs are essential for Plug-in Hybrid Electric Vehicles (PHEVs), Hybrid Electric Vehicles (HEVs), and EVs. However, many people hesitate to purchase electric vehicles due to concerns about reliability and cost. EVs are generally more expensive than internal combustion (IC) automobiles due to higher production costs and the complexity of construction. This project aims to develop a simple, efficient, and dependable electric vehicle model capable of performing in harsh and real-life scenarios. The vehicle will undergo extensive testing to ensure its quality and performance. This model will utilize a multi-level converter to control the speed of the motor, instead of the basic H-Bridge drive. The multi-level converter offers several advantages, including improved efficiency and reduced voltage stress on the components. Additionally, a DC Link voltage controller will be employed to maintain a consistent voltage, ensuring the reliable operation of the motor.*

1. INTRODUCTION:

The world today faces the critical challenge of overpopulation, which brings with it a host of environmental issues. In 1800, the global population was around 1 billion, but today it has surged to approximately 6 billion, with half of this population residing in urban areas[1]. This rapid urbanization has led to increased consumption of fossil fuels, which were formed millions of years ago from the compacted and calcified remains of plants and animals. These fuels, including coal, oil, and natural gas, are high in carbon content and are being depleted at an alarming rate due to their extensive use over the past 200 years. [2] If we continue to consume fossil fuels at our current pace, they are expected to be exhausted by 2060. [3] India, like many other countries, is grappling with severe air quality issues, particularly in its metropolises[4]. The federal government has highlighted the need for planning and developing mitigation solutions to improve air quality and promote better health for its residents[5]. Surveys conducted by an organizational center in Delhi have mapped CO2 emissions on Indian highways, projecting an increase from 208 million tons in 2005 to 122 million tons by 2035[6].Electric vehicles (EVs) present a promising solution to this problem. By reducing CO2 emissions and air pollution, EVs can significantly enhance public health and contribute to climate change mitigation goals[7]. The transportation sector, particularly passenger cars, accounts for approximately 60% of the sector's carbon footprint. Transitioning to EVs powered by renewable, zero-carbon electricity by 2050 is essential to addressing most climate change challenges[8]. While the initial cost of electric cars may be higher, they offer considerable savings in fuel, service, and maintenance over time. Moreover, the cost of recharging with a solar-powered system can further reduce the overall expenditure, making EVs an economically viable option in the long run[9]. This paper proposes the use of multilevel converters in electric vehicles as a means to enhance their efficiency and performance[10]. Multilevel converters are a type of power electronics that can convert DC to AC power and vice versa, which is crucial for the operation of electric vehicles[11]. By employing multilevel converters, it is possible to achieve higher efficiency, lower harmonic distortion, and better voltage regulation, all of which are essential for the optimal performance of EVs[12].

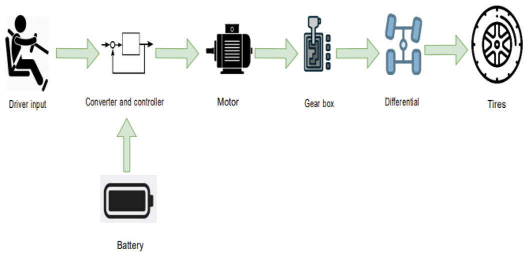

Fig. 1. Block diagram of Proposed System

Multilevel Converters in Electric Vehicles

Multilevel converters offer several advantages for electric vehicles. These include:

1. **Improved Efficiency**: Multilevel converters can operate at higher efficiencies compared to traditional converters. This leads to reduced energy loss and better utilization of the battery power, extending the range of the vehicle.
2. **Reduced Harmonic Distortion**: Harmonic distortion in the electrical signals can cause unnecessary heating and losses in the motor and other components. Multilevel converters reduce this distortion, enhancing the longevity and reliability of the vehicle's electrical systems.
3. **Better Voltage Regulation**: Maintaining a stable voltage is crucial for the performance of electric vehicles. Multilevel converters provide better voltage regulation, ensuring that the motor and other systems operate within their optimal parameters.

II. PROPOSED SYSTEM:

Figure 1 shows the block diagram of the proposed system. The model can be broken into five sections, which include the driver input, multilevel converter-controller, battery, motor, and vehicle body. The driver input comprises a signal builder and driver, cyclic input, and longitudinal driver. The multilevel converter-controller consists of a multilevel converter and a controller.

A permanent magnet DC motor is employed here. The vehicle's body consists of a chassis, tires, and gearbox. The battery system includes the battery and Battery Monitoring System (BMS).

A. Inputs:

A vehicle will receive input in the form of acceleration, deceleration, or braking. This input to the EV can be delivered by the driver input system, which consists of signal input and a longitudinal driver. The longitudinal driver is a MATLAB Simulink component that serves as the real driver for the EV. It compares the EV's actual velocity to the reference input velocity and accelerates or decelerates the EV accordingly.
1) Custom input. 1: The signal builder block provides input for the driver's reference velocity. Signal builder is a MATLAB block for creating and modifying custom signals. Acceleration and deceleration signals are generated and sent to the driver. This input will be referred to as Input 1.

2) Another input is provided via the FTP75 driver cycle block. The US Environmental Protection Agency (EPA) developed the EPA Federal Test Procedure (FTP-75) to assess passenger automobile exhaust emissions and fuel costs. It controls the vehicle's acceleration and deceleration based on different cycles. It tests the vehicle's performance and mileage. This input will later be known as input 2.

B. Converters and Controllers:

Multilevel converters convert and control DC to meet the needs of the motor. A multilevel converter consists of multiple switches that govern current flow to a load. The motor is regulated by the multilevel converter. The pulldown resistor disables the MOSFET gates, ensuring precise control of the switches. By delivering a PWM signal to the gates, the MOSFETs alternately switch on and off in a sequence, allowing for efficient power management and smoother operation. This configuration provides better voltage regulation and reduces harmonic distortion, enhancing the overall performance of the motor.

C. Battery:

The suggested system relies on a 3.6v 5Ah Li-ion battery for energy storage due to its superior performance compared to other technologies [13]. BMS relies heavily on cell balancing. A battery is balanced when all cells have an equal state of charge (SoC) [14]. The battery can be balanced using several ways, including capacity, inner resistance, self-discharge current, and SoC. There are two balancing techniques: active balancing and passive balancing.

The passive cell balance technique involves sampling all batteries' voltages and balancing them to the lowest level by removing surplus voltage from high voltage cells [13]. Active cell balancing involves sampling all voltages and calculating averages across cells. It transfers charge from above-average cells to below-average cells [Average cells]. Modern electric automobiles employ a 400v, 100Ah battery that costs around 2,50,000-3,00,000INR [15].

D. Motor:

The motor is the heart of the electric vehicle. There are various motor options for EV applications. EV motors can serve various purposes. A permanent magnet DC motor is employed for its high starting power, low cost, and easy speed control. Induction and BLDC motors are popular choices for EVs due to their efficiency, power density, and low maintenance costs. Based on the parameters stated, PMDC is a preferable alternative due to its mobility and reduced vehicle mass. It uses no filed winding, resulting in lower manufacturing costs, improved mobility, and reduced copper loss, making it more efficient. The PMDC motor has a rated voltage of 360V, a no-load speed of 14000 RPM, a rated speed of 12000 RPM, and a load capacity of 50KW. PMDC motors provide a wide range of speed control, both below and above the rated RPM.

E. Vehicle body:

The vehicle body is made up of tires, chassis, and gear. The vehicle body plays a significant role in determining speed, performance, and fuel efficiency. Vehicle body constructions vary depending on the vehicle's needs and requirements. A balanced vehicle has well-balanced qualities for optimal efficiency and performance. The first factor to consider in vehicle dynamics is the drag coefficient. The aerodynamic drag coefficient measures how much a car's compact body form reduces air resistance while moving forward.

A vehicle's compact design allows for easy movement through viscous air, resulting in a lower drag coefficient. Poor body profile streamlining leads to high drag coefficient, resulting in significant air resistance when driving. Drag coefficient can be modified in car body characteristics. Building an aerodynamic chassis, such as the teardrop design, can minimize drag coefficient. To reduce the drag coefficient, decrease the frontal area and ground clearance.

$$C_d = -\frac{2F_d}{\rho u^2 A} \tag{1}$$

where;
Cd = Drag coefficient
Fd = Drag force
ρ = Mass density of the fluid
u = flow speed of the object relative to the
fluid A = reference area

Table 1 shows that a balanced car should have a drag coefficient of 0.25-0.35.

The frontal area and mass of the vehicle also impact its performance. The front region is where a vehicle hits the airhead. The vehicle's overall resistance is calculated as the product of its drag coefficient and front area.

Sedan cars usually have a frontal area of 2-2.5m2. .The mass of sedan cars ranges from 1250 to 1600 kg.

A. Working:

The system operates on the principle of comparing the reference velocity provided to the longitudinal driver from inputs 1 and 2 with the actual velocity of the vehicle. Based on this comparison, the driver determines whether to accelerate or decelerate the system. The acceleration or deceleration command from the driver input is then directed to the multilevel converter. This component is the functional part of the circuit that controls the motor. By utilizing the multilevel converter, the system can efficiently manage the power delivered to the motor, ensuring smoother and more precise control over the vehicle's acceleration and deceleration.

Vehicle type	Drag coefficient
Saloon car	0.22-0.4
Sports car	0.25-0.4
SUV	0.35-0.45
Light van	0.35-0.5
Buses and coaches	0.5-0.8
Articulated trucks	0.55-0.8
Ridged truck	0.7-0.95

TABLE I VEHICLE TYPE AND DRAG COEFFICIENT

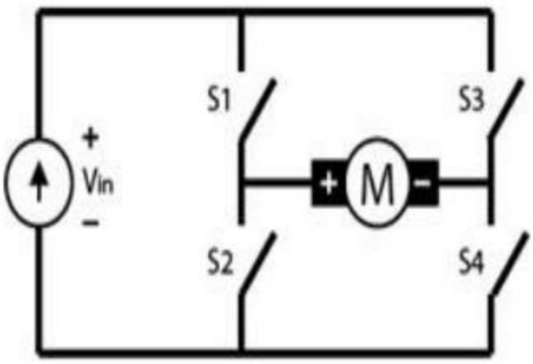

Fig. 2. Reference velocity Vs vehicle velocity for input 2

The MOSFET gates are typically pulled low by a pulldown resistor. This causes both P-channel MOSFETs to switch on, which is not a problem as no current is flowing.
The H-Bridge in this circuit reverses the polarity of the voltage provided to the load, providing a simple and effective solution for regenerative breaking.
It has two working modes: PWM and Averaged. Using averaged and smoothed modes leads to faster and more accurate results. The motor uses energy from the battery during acceleration and charges it during deceleration through regenerative braking. Braking reverses the motor's polarity, resulting in regenerative braking. Regenerative braking charges the battery until the brakes are used. Mileage will be determined on the initial SoC, load (vehicle mass) velocity, battery capacity (Ah), and distance. The speedometer depicts the vehicle's instantaneous velocity. The odometer displays the distance traveled over a specific time period. Average speed is derived by taking the average speed and time period.

III. SIMULATION AND RESULT ANALYSIS:

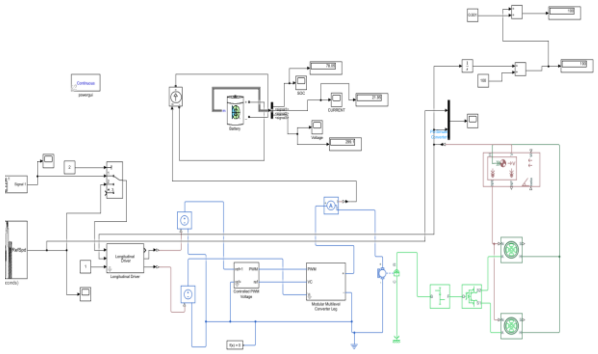

Fig. 3. Simulation of electric vehicle with H-Bridge

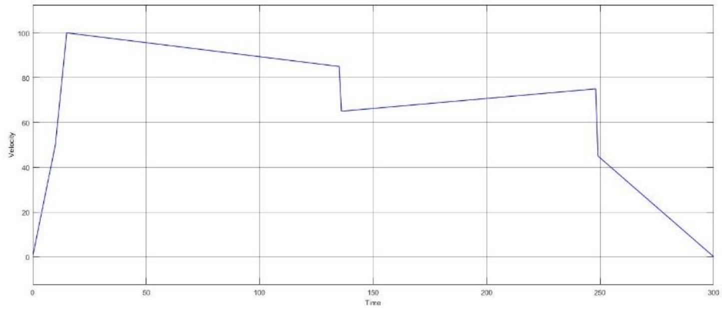

Fig. 4. Reference velocity Vs vehicle velocity for input 1

Figure 3 depicts the simulation of an electric vehicle with an H-Bridge converter using Matlab/Simulink. The model input is passed to the driver. The EV accelerates steadily for 13 seconds, followed by a rapid acceleration of 13 seconds till it hits 100kmph. After reaching 100kmph, the EV decelerates for 133s before dropping to 62kmph. It accelerates again, reaching 78kmph in 243 seconds. Then it decelerates until 300s.

Figure 4 displays the reference velocity vs vehicle velocity for input 1. The y axis displays velocity in km/hr, while the x axis represents time in seconds. The blue plot represents input 1, whereas the red plot shows the vehicle's velocity as a result of input 1. The driver's input is compared to the vehicle's velocity. At rest, the vehicle's velocity is zero kilometers per hour.
If we input 20 km/hr, the driver will send an instruction to the controller to increase acceleration by 20 km/h. If the car is driving at 50 km/hr and the driver inputs 20 km/hr, the controller will send a deceleration instruction. The plot is obtained for a stop of 300

seconds. The graph clearly shows that vehicle velocity follows the reference input.

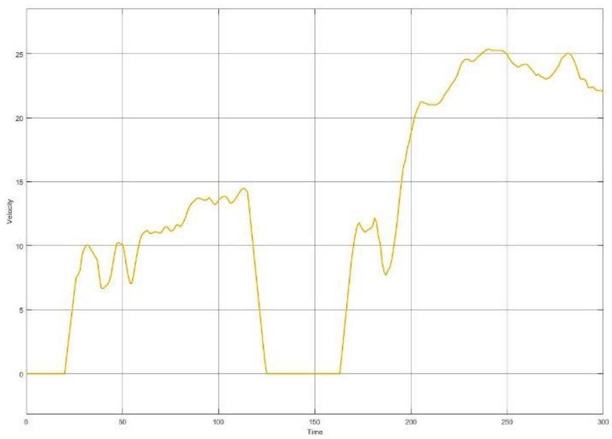

Fig. 5. Reference velocity Vs vehicle velocity for input 2

Another signal is sent to the FTP75 driver. This rigorous test input evaluates vehicle performance, mileage, and stability. Figure 5 displays the reference velocity vs vehicle velocity for input 2. The y axis displays velocity in km/hr, while the x axis represents time in seconds. The blue plot indicates input 2, while the red plot represents the vehicle's velocity. The US Environmental Protection Agency (EPA) developed the EPA Federal Test Procedure (FTP-75) to assess passenger automobile exhaust emissions and fuel costs.

It adjusts the vehicle's acceleration and deceleration based on specific cycles. It tests the vehicle's performance and mileage. This rigorous test ensures the car follows the input in all conditions. The graph shows that the vehicle closely matches the reference input, with the only deviation being due to drag coefficient and wind variables.

A. SoC and regenerative braking

The state of charge (SoC) of a battery displays its remaining charge capacity. Electric vehicles rely primarily on battery packs for electricity. The voltage capacity of the battery pack affects the vehicle's operating speed and torque. Higher voltage leads to greater torque and speed. The range of an EV is determined by the pack's current capacity in Ah. A bigger capacity pack allows for longer travel.

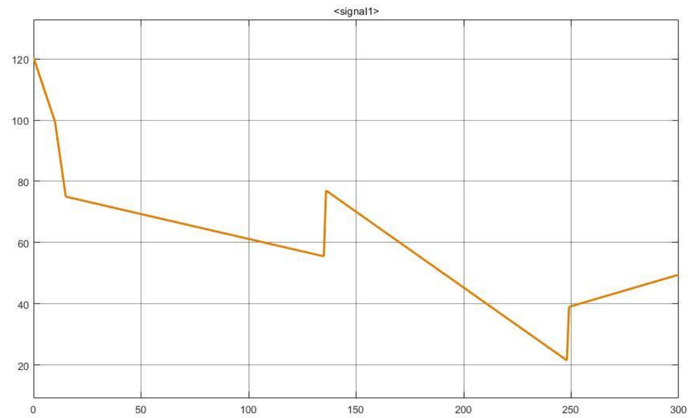

Fig. 6. SoC of battery due to input 1

Fig.6 shows the SOC of battery due to input 1. Whenever brakes are applied battery is charged which can be clearly seen in 133s and 245s.

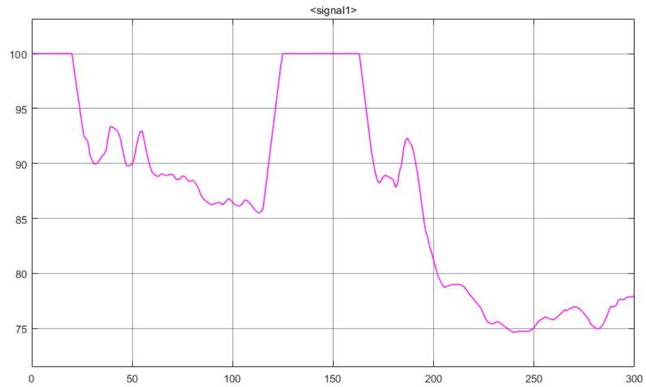

Fig. 7. SoC of battery due to input 2

Regenerative braking causes an increase in the battery's state of charge (SoC). When braking, the controller reverses the polarity of the motor, converting it into a generator. This not only stops the vehicle instantaneously but also charges the battery in the long term.

Figure 6 depicts the battery's state of charge after input 1. Applying the brakes charges the battery, as shown in 133s and 245s. Figure 7 depicts the battery's state of charge as a result of input 2.The SoC % is represented on the y axis, while the time in seconds is plotted on the x. When the vehicle brakes, the battery charges. This kind of braking is effective and efficient, allowing for faster vehicle stopping and battery charging. The vehicle's usual operating voltage ranges from 430-380V and gradually falls over time owing to discharge. A voltage pack of 396V can be created by connecting 110 3.6V Li-ion cells in series. Extreme input conditions lead to sudden voltage spikes.

Figures 8 and 9 show the current and voltage plots of the battery for input 2. Due to the severe input state, there are noticeable current spikes. The battery has a rated capacity of 50Ah and can be attained by connecting five 10Ah or ten 5Ah batteries in parallel. Figure 8 plots current in Amperes on the y-axis and time in seconds on the x-axis. In Figure 9, voltage in volts is displayed in y.

A. Performance test:

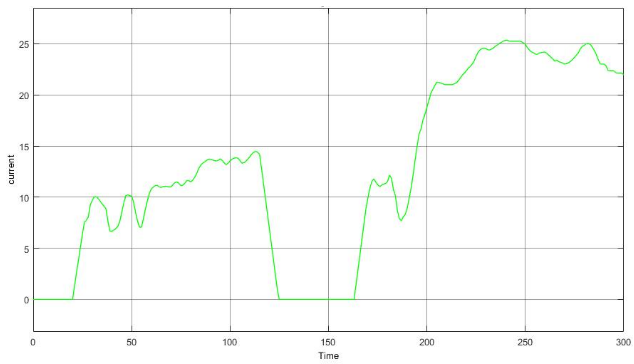

Fig. 8. Battery current

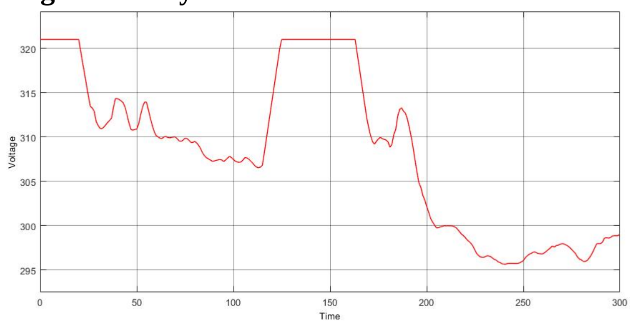

Fig. 9. Battery Voltage

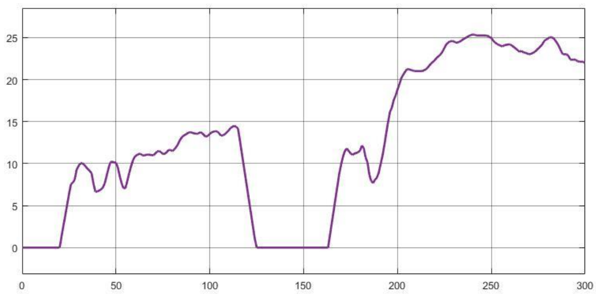

Fig. 10. Input 2 velocity Vs vehicle speed with different vehicle body parameters

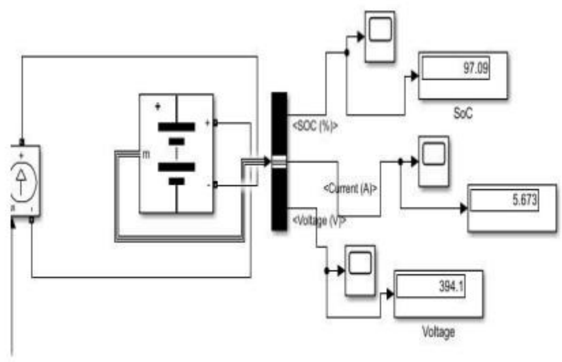

Fig. 11. SoC of battery with actual set parameters

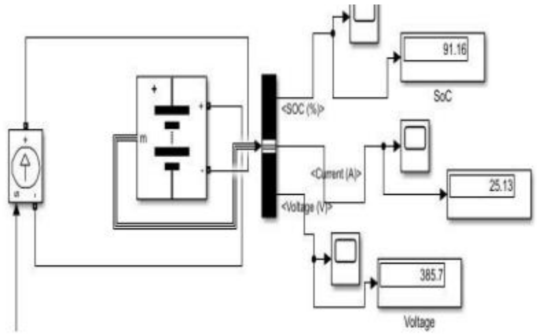

Fig. 12. SoC of battery with newly set parameters

An EV's performance depends on elements such as vehicle mass, drag coefficient, wind velocity, rated voltage, and current capacity. A performance test evaluates the vehicle's efficiency. The test involves adjusting vehicle characteristics such as weight, gear ratio, frontal area, and departure angle. Simulink tools are useful for making these adjustments. The vehicle body, gears, and tire block influence these factors.

Fig.10 shows the reference velocity versus vehicle velocity graph for input 2. The vehicle's mass was increased from 600kg to 1800kg, the drag coefficient was increased from 0.25 to 0.4, and the frontal area was increased from 2m2 to 3m2. The y axis displays velocity in km/hr, while the x axis represents time in seconds. The EV's inability to match the reference input velocity can be attributed to parameter changes that reduce its efficiency.

Figure 11 displays the SoC of a lithium-ion battery for a vehicle with a mass of 800kg, a frontal area of 2m2, and a drag coefficient of 0.25. After 300 seconds of simulation, the battery's State of Charge (SoC) is approximately 97%.

Figure 12 displays the SoC value of a battery pack for a vehicle weighing 1800kg, having a frontal area of 3m2 and a drag coefficient of 0.5. After 300 seconds of simulation, SoC is approximately 91%. This is 6% greater than the vehicle's prior configuration. Additionally, the model requires less current. A vehicle with lower mass, frontal area, and drag coefficient will have greater range and efficiency.

IV. CONCLUSION:

This research presents a novel motor control paradigm for EVs that improves efficiency. The high cost of electric vehicles is a barrier to their adoption. While the initial cost of an EV is more than that of an internal combustion engine automobile, maintenance and other costs are significantly lower. The suggested EV design incorporates a multilevel converter and controller for a PMDC motor, which has been tested under various conditions. Simulations are performed using Matlab/Simulink models. The multilevel converter control approach is utilized for faster and more cost-efficient control. This also adds compactness to the system.

The regenerative braking technology increases the efficiency of the model, lowering the cost of electric vehicles. This reduces the use of fossil fuels and pollutants, contributing to a safer and better future world.

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