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An integrated Control of Carbon Effluence in Fuel Cell Based Plug-In Hybrid Electric Vehicle

J. Priyadharshini[1], Dr. K. Lakshmi[2], T. Nandhakumar[3]
[1]PG Student[PED], Dept. of EEE, Sri Krishna College of Engineering & Technology, Coimbatore, Tamilnadu
[2]Professor, Dept. of EEE, Sri Krishna College of Engineering & Technology, Coimbatore, Tamilnadu
[3]Assistant Professor, Dept. of EEE, Sri Krishna College of Engineering & Technology, Coimbatore, Tamilnadu

Abstract— *This paper proposes an "Integrated control of carbon effluence in fuel cell based hybrid electric vehicle". The hybrid system is used to produce energy without interruption and it uses Proton Exchange Membrane fuel cell. Therefore, prospective vehicle designs favour improved exhaust emissions and energy consumption without compromising vehicle performance. Hybrid Electric Vehicles (HEV) provide improved fuel economy due to extra degree of freedom provided by battery energy storage and one or more electric machine's which allow running a smaller combustion engine in a higher efficiency region. Compared with conventional Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs) have a larger battery pack and can replace a certain amount of fossil energy with grid electricity. As a result, the fuel economy and emission reduction can be improved remarkably. The energy demand of the PHEV is supplied both by the fuel tank and by the fuel cell or battery, which makes the power distribution among different power components more complex than HEVs, meanwhile the energy management strategy has a significant impact on the vehicle performance.*

Keywords— *Emission control, Plug-in control, Fuel cell.*

I. INTRODUCTION

The energy crisis and climate change have become increasingly serious issues, thus greatly promoting research on and applications of energy-saving and emission-reducing technologies in the automobile industry. Conventional vehicles tend to consume considerable amounts of fuel, which generates exhaust gases and environmental pollution during intermittent driving cycles. The hybrid system is used to produce energy without interruption and it uses Proton Exchange Membrane fuel cell [3]. Therefore, prospective vehicle designfavor improved exhaust emissions and energy consumption without compromising vehicle performance. Among possible configurations of a hybrid electric power train, power-split, or parallel-series which provides both series and parallel functionality are produced by several auto-makers [4].

Compared with conventional Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs) have a larger battery pack and can replace a certain amount of fossil energy with grid electricity. As a result, the fuel economy and emission reduction can be improved remarkably. The energy demand of the PHEV is supplied both by the fuel tank and by the fuel cell or battery, which makes the power distribution among different power components more complex than HEVs, meanwhile the energy management strategy has a significant impact on the vehicle performance.

II. ZERO EMISSION VEHICLES

The least polluting mode of transportation with zero percent fossil fuel consumption is the Battery powered Electric Vehicle and it is generally referred as 'Zero Emission Vehicle'. Pure electric vehicles currently do not have adequate range when powered by batteries alone and also recharging of it requires several hours. Hence, the electric vehicles are viewed as impractical for driving extended distances. Though the Battery powered electric vehicle is advantageous over conventional IC vehicle in several aspects, it bagged its own downside such as the requirement of large package sizing for storing sufficient energy that predominantly increases the initial installation cost, applicable only for low driving range with a limitation on operational period. The shortcoming arises with the Battery powered electric vehicle can be effectively sorted out with the discovery of hybrid electric vehicle. The selection on the right choice of energy source to be hybridized with the battery in the hybrid electric vehicle is a mandatory issue [9]. The International Energy Agency, 2010 proposed a strategy that defines the World primary energy demand shares is shown in Figure 1. The growing rate of the renewable energy demand share intense researchers to incorporate renewable energy in the development of the hybrid electric vehicle model. The ultimate objective behind the development of this hybrid electric vehicle is to significantly reduce the shares of fossil fuels such as the share of coal from 27 % in 2009 to 16 % in 2035, share of oil from 33 % in 2009 to 25 % in 2035, and dramatically increase the share of renewable energy, from 1 % in 2009 to 8 % in 2035.

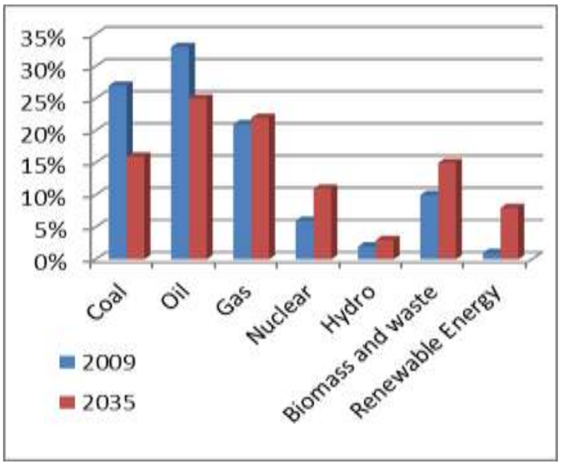


Fig. 1. World primary energy demand shares.

A. Hybrid Electric Vehicles

The increase of depletion of fossil fuels for multiple purposes like generation of other forms of energy (electricity, heating and transportation) is growing. This growth is much faster than the time it takes to aggregate the energy stored in new oil and coal, so new solutions for finding other energy sources is needed.

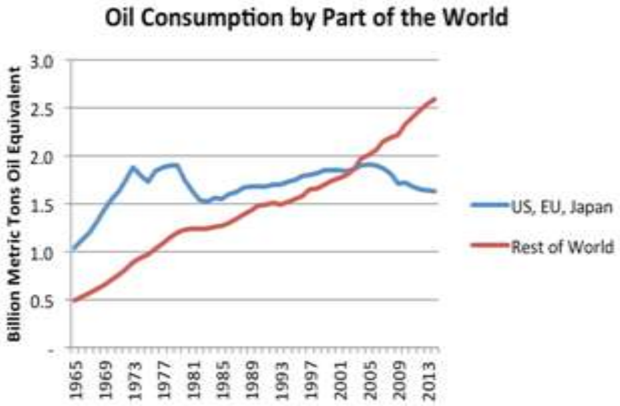
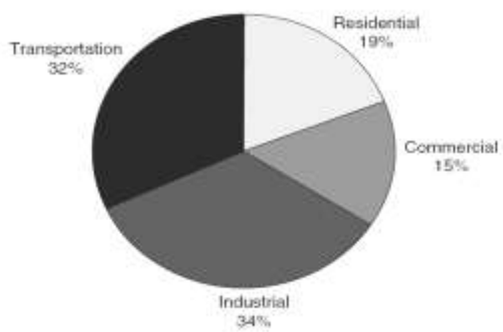


Fig. 2. Oil consumption in the world.

The Other environmental effects of the usage of fossil sources are really going to become a serious problem in the near future. Air pollution and global warming are two of the most important ones. Most of the conventional vehicles use internal combustion engines (ICE) in which the fuel reacts with oxygen and produces heat, some gases (CO2,CO, HC and NOx) and mechanical power. The combustion of hydrocarbon fuel in combustion engines is never ideal so some other gases are produced after the reaction besides carbon dioxide and water. The combustion products contain a certain amount of nitrogen oxides (NOx), carbon monoxides (CO), and unburned hydrocarbons (HC), all of which are toxic to human health. The carbon dioxide and other green house gases like methane play a significant role in global warming. These gases trap the Sun's infrared radiation reflected by the ground, thus retaining the energy in the atmosphere and increasing the temperature. An increased earth temperature results in major ecological damages to its ecosystems and in many natural disasters that affect human populations. The part of transportation effect on global warming and air pollution is indicated in figure.



B. Plug-in Hybrid Electric Vehicle

Plug-in Hybrid Electric Vehicles (PHEVs) differ from Hybrid Electric Vehicles (HEVs) with their ability to use off-board electricity generation to recharge their energy storage systems. In addition to possessing charge-sustaining HEV operation capability, PHEVs use the stored electrical energy during a charge-depleting operating period to displace a significant amount of petroleum consumption.

PHEVs have the potential to reduce fuel consumption to levels even lower than those achieved by the commercially-available HEVs now manufactured by many major automakers. Current HEVs offer efficiency improvements by means of enabling the engine (ICE) to shut off rather than idle, recapturing a portion of normally wasted braking energy and permitting engine downsizing to improve average in-use efficiency. While such hybridization benefits do improve the fuel economy of these vehicles, all of the available energy still comes from the fuel tank of Internal Combustion Engine (ICE). PHEVs enjoy the same hybridization benefits as HEVs and also provide an opportunity for fuel switching obtaining some of the vehicle's usable energy in the form of electricity through a charging plug, which displaces some of the energy that would otherwise be obtained by burning fuel in the vehicle's engine.

The PHEV concept allows coupling of vehicles with the power grid and hence, utilization of alternative sources of energy for vehicle propulsion. Driving cycles play an important role in analysis and optimization of PHEVs. Electric driving ranges, such as "All Electric Range (AER)" or "Mostly Electric Range (MER)" are directly dependent on driving cycles since driving patterns influence the specific energy consumption and the vehicle driving mode.

III. PROPOSED SYSTEM

Based on the analytical equations, the vehicle dynamics model is created, the inputs of the vehicle dynamics model are wind speed, grade and tractive forces produced from rear and front tyres. The dynamic behavior of the hybrid electric vehicle is modeled with the consideration of total resistive force acting on the vehicle. The tractive force (F_{drive} in N) applied to the wheels of the vehicle is opposed by the total resistive forces ($F_{resistive}$ in N). Hence, the net force on the wheels of the vehicle (F_{Net} in N) for its propulsion (Equation is computed by using the tractive force (F_{drive}) that acts along the direction of the movement of the vehicle and the total resistive forces ($F_{resistive}$) that acts against the direction of movement of the vehicle.

$$F_{Net} = F_{drive} - \sum F_{resistive}$$

The total resistive force acting on the wheel is the combination of forces such as grade force, rolling resistance force, aerodynamics drag force and inertial force.

The Proton Exchange Membrane fuel cell is more preferable than other type of fuel cell, because it hold the features of high power density, uses solid electrolyte, low operating temperature (50◦C100◦C), fast start-up, low sensitivity to orientation, favorable power to-weight ratio, long cell and stack life, and low corrosion [02]. The attractive features of PEM fuel cells have instigated the interest in dc power generation using fuel cell and they are ensuing in transport application for developing fuel cell driven electric

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vehicle model. Recently many ongoing researches are focused on the development of the fuel cell electric vehicle. The standalone fuel cell driven electric vehicle is considered to be a prominent one for replacing the conventional fossil fuel powered vehicles that would provide better solution for the fuel depletion and global warming. But some of the practical issues are also raised with the development of the standalone fuel cell operated electric vehicle that are the cold start period issues, enormous hydrogen fuel consumption and regenerative braking power loss. The shortcoming raised with the standalone energy source powered electric vehicle made us to think about an alternative option for electric vehicle that motivate us towards the Hybridization of energy sources in electric vehicle. In the worldwide, the attention for the hybrid electric vehicles is growing because of oil price fluctuations, uncertainties in the future oil security and increased attention for environmental issues. The proposed system in fig. 3 explains fuel cell based hybrid vehicle where there is zero emission of tail pipe gases.

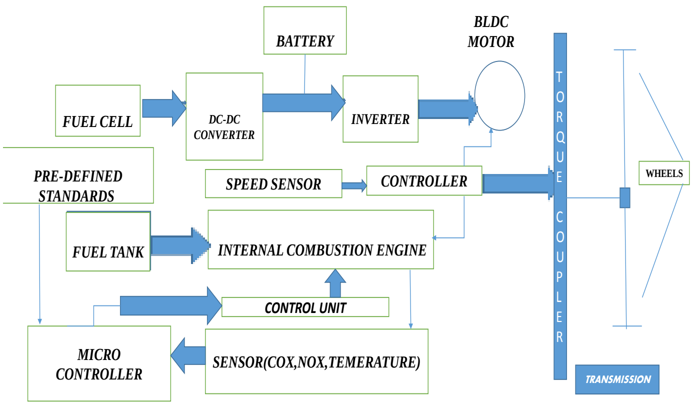

Fig. 3. Proposed block diagram of fuel cell hybrid electric vehicle.

A. Battery Modelling

The focus of an EV design tends to be the acceptable range with a single charge. Therefore, the ESS is sized to meet the designed range of the vehicle. For battery powered vehicles, the size of batteries is determined by its energy requirements (*kWh*/*kg*) as power requirements (*kW*/*kg*) can be easily satisfied for a reasonable vehicle acceleration performance need. The load cycles of batteries on an EV are usually deep discharging and charging. The shortened life of deeply discharged battery is a major consideration since the minimum battery life has to be satisfied. The Ni-MH battery is the most widely used battery to power electric automobiles at present. The Ni MH battery has a higher energy density than a SLA (sealed lead acid) battery. Its specific energy (*Wh*/*kg*) can be up to four times that of a SLA battery and 40% higher than Ni-Cad battery. The battery is also relatively environmentally friendly, as it contains very mild toxic materials that can be easily recycled.

As batteries play an important role in hybrid electric vehicles there should be a good model in the simulation tool, representing the actual behaviour of the battery. There are many types of batteries and many factors that affect battery performance. To predict the performance of batteries, different mathematical models exist. None of these models are completely accurate nor do any include all necessary performance effecting factors. In order to measure the open circuit voltage in different state of charges a constant current is drawn from a fully charged battery in time intervals. After each time interval the open circuit voltage of the battery is measured according to the state of charge of the battery. The block diagram is shown in figure 4.

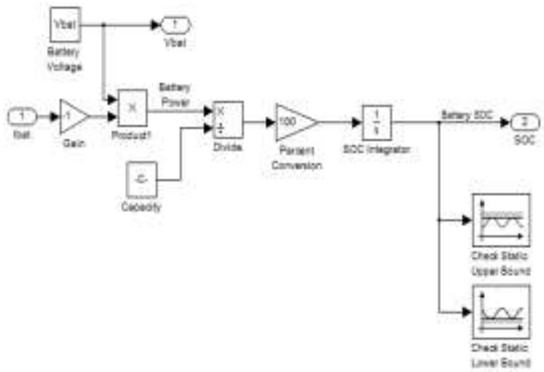

Fig. 4. Battery model block in MATLAB/Simulink.

B. Bidirectional DC-AC Converter

The bidirectional DC-AC converter in the PHEV model performs the inversion operation (DC to AC) during forward acceleration mode and rectification operation (AC to DC) during regenerative braking mode along the entire trip. The mode of operation is based on the determination of current flow direction across the input terminals of the bidirectional converter module. During motoring mode, the power flow is from source to load (DC-AC conversion) where the AC output electrical power at the AC bus is the product of DC input electric power and efficiency of the bidirectional converter module.

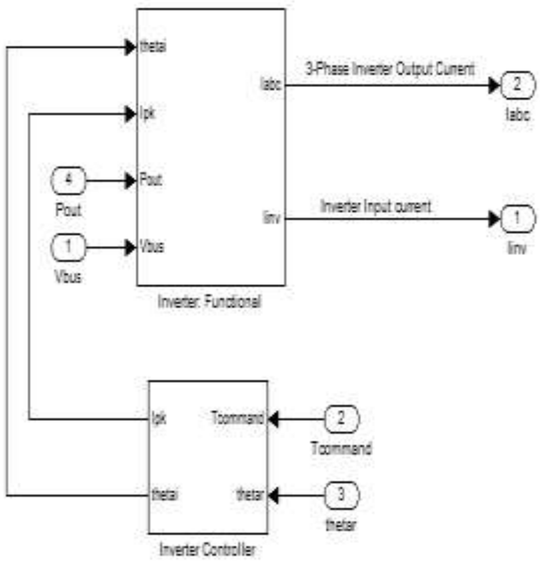

Fig. 5. Inverter model block in MATLAB/Simulink.

C. Driving Cycles

A vehicle could be driven in different ways. It means that it depends on the driver how to drive the car in terms of acceleration, braking, and maximum speed. To simulate a specific vehicle and evaluate its performance, the way that the driver drives has a significant impact on the vehicles performance especially for fuel consumption and emissions. So in the simulation drive train, there should be different driving cycles. The NEDC cycle is a rather simple pattern consisting of periods of constant acceleration, constant deceleration and constant speed. This cycle, however, is not a true resemblance of actual driving conditions in an urban scenario. It is presented here, as these are standards with which European car manufacturers have to refer when stating their vehicle's performance in terms of achievable range and emissions.

To simulate the behaviour of a driver following up a certain drive cycle, a model is required to calculate the required wheel torque. It consists of a PI controller having the reference driving cycle, actual speed of the vehicle and reference speed as inputs. It produces the output torque command which vehicle system to work accordingly with the given drive cycle. In order to increase the functionality of the PI controller a feed forward loop is used. This loop based on the reference speed and actual speed, calculates the traction torque needed for tracing the reference drive cycle. The error between the reference speed and the actual speed is compensated by adding another torque calculated by the PI controller. In order to prevent integrator windup, the integrator is reset each time the speed falls down to zero.

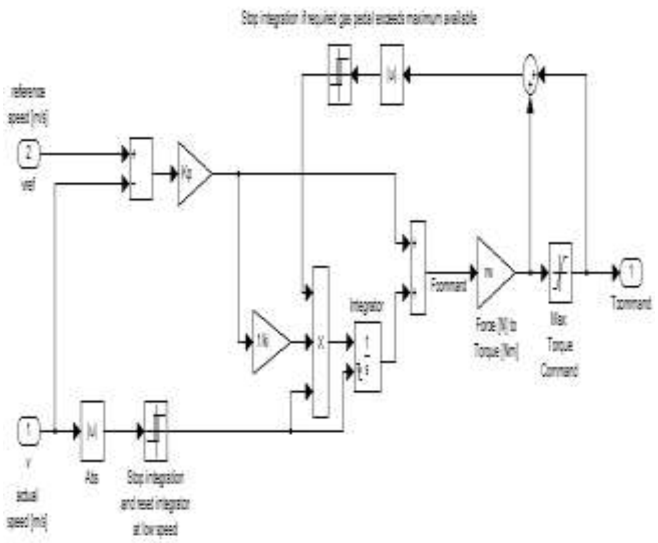

Fig. 6. Driver model block in MATLAB/Simulink.

To simulate the behaviour of a driver following up a certain drive cycle, a model is required to calculate the required wheel torque. It consists of a PI controller having the reference driving cycle, actual speed of the vehicle and reference speed as inputs. It produces the output torque command which vehicle system to work accordingly with the given drive cycle. In order to increase the functionality of the PI controller a feed forward loop is used. This loop based on the reference speed and actual speed, calculates the traction torque needed for tracing the reference drive cycle. The error between the reference speed and the actual speed is compensated by adding another torque calculated by the PI controller. In order to prevent integrator windup, the integrator is reset each time the speed falls down to zero.

D. Modeling and Sizing of Fuel

The conventional modeling has to incorporate all the dynamic variation inside the PEM Fuel Cell system due to the electrochemical and thermodynamic reactions and polarization dynamics during the model development. Developing precise model with the consideration of all these physical phenomena and empirical nonlinear relationship is a highly challenging task. The complexity emerged with the conventional modeling of Fuel cell could be easily resolved using one of the intelligent computation technique called Artificial Neural Network. An Artificial Neural Network technique is a substantially distributed parallel processor composite of simple processing units termed as neurons which has natural tendency for saving exponential knowledge and make it available for use . Once the network is properly trained with appropriate input-output parameter, it provide good mapping between the nonlinear parameters involved in the PEM fuel cell system. Since the power required to drive the vehicle is more, it is necessary to size the fuel cell stack in such a way that it should meet the requirements. Fuel cell Pack of 25kW with a nominal voltage of 129.5V modeled in which 5 fuel cell stack connected in series and the simplified model is shown in figure 7.

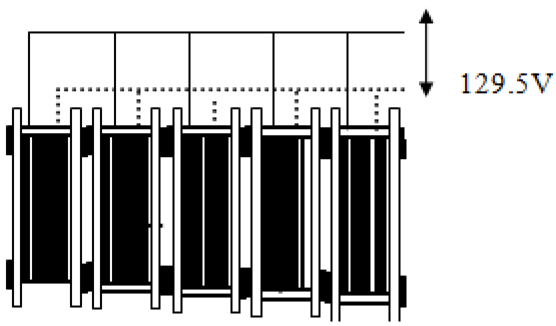

Fig. 7. Stacks of fuel cell.

IV. RESULTS

A driving cycle is a standardized driving pattern that described by means of a speed time table. Therefore, the speed and the acceleration are known for each point of time and the required mechanical power as a function of time can be determined for the proposed vehicle. Driving cycles are produced by different countries and organizations to assess the performance of vehicles in various ways, as for example energy storage module life span and energy sources sizing. In this work, two different drive cycles such as NEDC (New European Driving Cycle) and UDDS (Urban Dynamometer Driving Schedule) is presented for investigating the performance of the proposed electric vehicle model.

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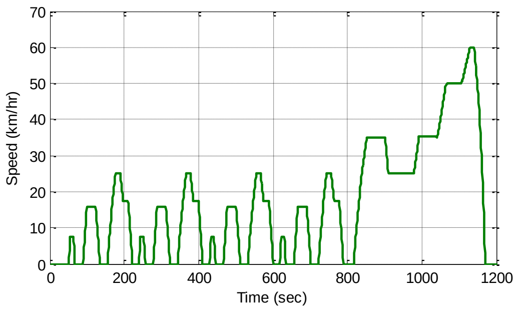

Fig. 8. Speed profile of New European driving cycle.

On the other hand, the next drive cycle used to assess the performance of the proposed vehicle model is the UDDS drive cycle which is derived from actual urban driving data which exhibits continuously varying speed over the entire driving cycle with the maximum range of 45km/hr. The UDDS drive cycle is used to simulate the urban/city driving of a vehicle that providing frequent start and stops.

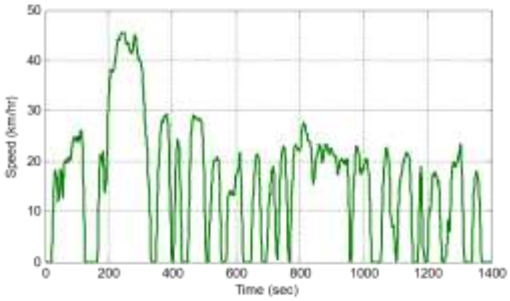

Fig. 9. Speed profile of urban dynamometer driving schedule.

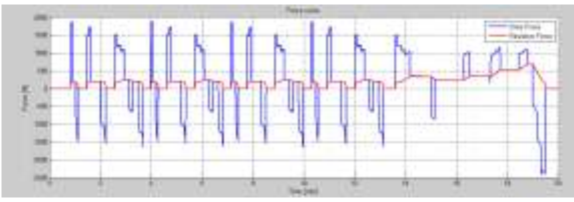
Fig. 10. Force required to drive the vehicle system.

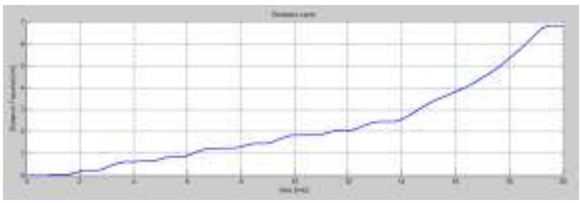
Fig. 11. Vehicle distance profile for NEDC drive cycle.

Once the vehicle accelerates, the torque of the motor is maximum as the speed reaches the maximum speed. In the cycle, the acceleration is zero so the motor power suddenly decreases because it does not have to overcome the inertia of the vehicle and accelerate the total weight of it. It can also be seen that during the deceleration the power is negative which indicates that energy is being fed back to the motor to charge the batteries.

V. Conclusion

Even though the Battery powered electric vehicle is advantageous over conventional IC vehicle in several aspects such as zero fossil fuel consumption, zero emission, etc., it bagged its own downside also such as the requirement of large package sizing for storing sufficient energy that predominantly increases the initial installation cost, applicable only for the low range applications and limitation on operational period. The shortcoming arises with the Battery powered electric vehicle is effectively sort out with the discovery of hybrid electric vehicle. The objective behind the hybridization of the energy sources is to combine the fruitfulness of the energy sources in a conservative manner that provides unanimous solution for the fuel depletion and energy conservation. The control or management over the power sharing between the multiple energy sources is a mandatory issue in hybrid electric vehicle. Hence this project work is spotlighted on the design and development of the Hybrid Electric Vehicle with no tail pipe emission gases. Zero emission vehicle, no tail pipe emission of gases. Emits 121 grams of carbon-dioxide/mile, which is very low when compared to conventional vehicle. Uses 40-60% of fuel's energy. The proposed system's overall efficiency is 64%.

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