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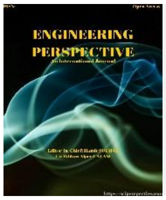

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Research Paper

Evaluation of Electrification of 4W Light Commercial Vehicle

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ABSTRACT

Road transport is a prime contributor to CO_2 emissions in the Indian transportation sector. The motor vehicle fleet in India is responsible for 90% of the total energy consumption in the transport industry and of this, 45% is consumed for freight transport. Currently, petroleum is used primarily to generate energy for road transport and most of it is imported. With the increase in environmental issues and oil prices, it has become necessary to switch to alternative propulsion systems. Current ICE vehicles can be adopted for Electric vehicle retrofitting which aids in reducing the transport sector emissions. In this paper, the process of conversion of a 4W Light Commercial Vehicle into an Electric Vehicle adhering to the vehicle conversion norms in India is discussed. A numerical analysis of the vehicle was done to evaluate its performance. A cost comparison of the ICE vehicle, a Retrofitted Electric vehicle, and a New Electric vehicle was carried out. The results showed that the converted vehicle has better performance than that of an ICE vehicle and costs lower than the new electric vehicle.

Keywords: Conversion; Electric Vehicle; Internal Combustion Engine Vehicle; Light Commercial Vehicle; Regenerative Braking; Retrofit

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1. Introduction

Globally, India is the third largest emitter of Greenhouse gases (GHG) [1]. After joining the Paris agreement, India aims to reduce the intensity of emissions by 33 – 35% when compared to the levels in 2005. For the transportation sector to align with the Paris agreement's and India's goals, the GHG emission levels should be substantially lower than the current emissions. On the other hand, the demand for transportation increased significantly due to population and economic growth. To reduce GHG emissions, the fuel efficiency of conventional vehicles has to be improved and Electric Vehicles (EV)/Alternative propulsions should be adopted. India has set the norms for fuel efficiency/emission standards by limiting CO_2 emissions. Approximately 12 Gt of CO_2 is emitted into the air per year worldwide due to the production and combustion of the fuels used for transportation [2].

The EVs have zero tailpipe emissions but are still associated with the emissions produced while manufacturing, charging, and recycling. The life-cycle GHG emission of a Passenger EV is approximately 19-49 % lower compared to that of gasoline cars in India, and in the future, EVs may emit around 30 - 63% lesser throughout their life cycle than their counterparts [2-3]. The adoption pace of EVs in India can be improved potentially by ICE to EV retrofitting. The Ministry of Road Transport and Highways of India, made amendments to the Central Motor Vehicle Rules 1989, legalising the retrofitting of ICE vehicles to EVs. Retrofitting will extend the useful life span of the existing vehicles based on their structural integrity by at least 5 - 7 years and will prevent the vehicle from falling into the new scrappage policy in India .

1.1 Urban Freight

Urban freight contributes a major share to the social and economic development of cities. Globally, it accounts for 10% to 15% of the vehicle equivalent miles travelled in the city and provides employment to 2% – 5% of the urban population. Two-wheelers, Light commercial vehicles (LCVs), and Heavy commercial vehicles (HCVs) are generally used for freight transportation in urban areas. The accelerated urbanisation in India in recent times has raised the demand for the movement of freight remarkably. As a result, the freight vehicle traffic is rising thereby increasing the total energy consumption for the movement of these goods and services by road [4] which contributes to GHG emissions, traffic congestion, and noise pollution. To curb these adverse impacts, decarbonization of urban freight is necessary, and based on the comparison of life-cycle GHG emissions of ICE vehicles and an EV, the EVs are substantial as they emit lower.

1.2 Light Commercial Vehicle

The Light commercial vehicles segment comprising trucks, vans, and three-wheelers are the most common modes of freight transportation in India. These vehicles are generally used for the carriage of goods and their GVW doesn't exceed 3.5 tons. According to the Road Transport yearbook 2018-19, out of the total newly registered transport vehicles, LCVs account for a share of 24.1 %, out of which 67.7.% are Four-wheeler LCVs [5]. The emissions due to vehicular movement for urban freight cause a severe impact on the environment. To decarbonize the environment, the conventional vehicles used for urban freight have to be switched to electric vehicles as their operation is clean compared to the ICE vehicles. Electric vehicles are more efficient than their counterparts in the cities because of regenerative braking which converts most of the kinetic energy lost while deceleration by using the electric motor as a generator and stores it in the battery which in turn improves the range. However, this efficiency depends on how the vehicle responds to the stop-go traffic in the cities. On the contrary, fuel-based cars convert the kinetic energy while braking into waste heat.

1.3 Vehicle Retrofitting

Electric retrofits involve converting an ICE vehicle to an electric drivetrain, aiding the transition to zero-emission vehicles while operating by adapting current vehicles and, thus, reducing the transport sector emissions. Electric vehicles offer lower operating costs but their high initial cost and range anxiety are influencing the shift toward widespread adoption of EVs in India. The high initial cost issue can be resolved by converting the existing ICE vehicles into electric vehicles. This process is both cost-effective and eco-friendly in operation [6].

The conversion process presented in this paper had the following objectives:

- Compliance with Indian Legislation: The retrofitted vehicle should comply with the Central Motor Vehicle Rules (CMVR), 1989 in India, and also should conform to the requirements mentioned in AIS 123 standard [7]. Based on the AIS 123, the vehicles selected for retrofitting into pure electric are manufactured on or after 01 January 1990, and should not be provided with permits to carry dangerous or hazardous goods as mentioned in the CMVR [8].
- The range of at least 100 km/day for urban freight transport.
- To integrate the technology with proper design and sizing.

2. Vehicle Conversion Process

2.1 Selecting the vehicle

Various parameters have to be inspected while selecting a vehicle for conversion into an electric vehicle. According to Indian Road transport office norms, a commercial vehicle aged more than 15 years should be scrapped if the vehicle doesn't pass the fitness and emission tests [9]. Almost all the vehicles in India come with a warranty of 1,00,000 km and the average life of a vehicle is 15 years or 3,00,000 kilometres [10]. Therefore, the life expectancy of the selected vehicle should be at least 5 more years or 1,00,000 kilometres and the chassis must be inspected for structural integrity else the conversion will not be beneficial. Above all, the Vehicle must comply with Indian Legislation. The complexity of the conversion process increases with the increase in the number of electrical and electronic components in the vehicle. The number of auxiliary electrical and electronic components also affects the range of the vehicle [11]. The following are the specifications of the conventional 4-wheeler LCV – N1 category chosen for retrofitting to an Electric vehicle.

Table 1. Specifications of Light Commercial Vehicle [12].

Parameter	Specification
Make and Model	TATA and ACE HT+
Engine	2-cylinder, 800 CC Common Rail Engine
Max. Power output	26 kW @3750 rpm
Max. Torque	85 Nm @ 1750 – 2750 rpm
Suspension	Leaf spring suspension with shock absorbers
Tires	155R13 LT 8PR
Wheelbase	2250 mm
Max Gradeability	36 %
Gross Vehicle Weight	1950 kg
Payload	900 kg
Gearbox type	GBS 65-5/5.07
Frontal Area	2.37 m^2

Figure 1. Selected ICE vehicle for conversion into Electric Vehicle

2.2 Removal of the Powertrain

The next step in the conversion process is the removal of the ICE powertrain and related components. The powertrain components that have to be removed depend on the method of conversion i.e., an ICE vehicle can be converted into an electric vehicle by either replacing the engine and clutch with the motor and operating the vehicle with the existing gearbox in a fixed reduction or by replacing the entire ICE powertrain unit with the Electric powertrain unit. The aforementioned process is more cost-effective than the latter. The stripped vehicle has to be observed or studied for possibilities of mounting the Electric powertrain unit, and electrical and electronic components of the vehicle.

2.3 Sizing of Motor, Controller, and Battery

This paper deals with the electric LCV in urban driving conditions. The speed of the vehicle is limited to 50 kmph. Numerical analysis was performed to calculate the power required by the vehicle to achieve the speed of 50 kmph with its GVW (1950 kg) at a ruling gradient of 3.3 % in a plain rolling area [13].

The total driving resistance (in N) of the vehicle is calculated as follows:

$$F_{resistance} = F_r + F_w + F_g \quad (1)$$

Where F_r = Rolling resistance force (in N).

$$F_r = mgC_{rr}(\cos\alpha) \quad (2)$$

Where m is the mass of the vehicle (in kg), g is the acceleration due to gravity (9.81 m/s^2), C_{rr} is the coefficient of rolling resistance, which is 0.01 in this case, and α is the slope of the road (in radians).

F_w = Aerodynamic drag force (in N)

$$F_w = \frac{1}{2}\rho A C_d V^2 \quad (3)$$

Where ρ is the density of air (1.2 kg/m^3), A is the frontal area of the vehicle, which is 2.37 m^2 in this case, C_d is the drag coefficient of the vehicle, and V is the velocity of the vehicle (in m/s).

F_g = Gradient climbing force (in N)

$$F_g = mg(\cos\alpha) \quad (4)$$

Let P (in Watts) be the power required to propel the vehicle. The power required by the vehicle can be calculated as follows:

$$P = VF_{resistance} \quad (5)$$

Let T_w be the torque (in Nm) at the wheels and r be the tire rolling radius (in m). Let $\eta_{powertrain}$ be the efficiency of the powertrain which is operating with the overall gear ratio of i_t. Therefore, for N_w wheel speed (in rpm) and T_w torque, N_m will be the required motor speed (in rpm) with T_m torque. The actual power required by the motor P_m (in kW) to propel the vehicle in the drive cycle can be calculated as follows:

$$T_w = F_{resistance} r \quad (6)$$

$$N_m = N_w i_t \quad (7)$$

$$T_m = \frac{T_w}{i_t \eta_{powertrain}} \quad (8)$$

$$P_m = \frac{2\pi N_m T_m}{60000} \quad (9)$$

The motor power required in the drive cycle can also be determined by interpolating the Speed, Torque, and Power values provided by the manufacturer of the motor.

By substituting the corresponding values in Eq. (1), Eq. (2), Eq. (3), and Eq. (4), $F_{resistance}$ is obtained as 1063.8 N, and from Eq. (5), the power required as 14.7 kW, which is 15 kW approximately.

There are several types of motors, at different operating voltages, available in the market. A 96 V PMSM motor with a rated power of 15 kW is considered in this study. The specifications of the motor and the controller are listed in the tables 2 and 3 respectively.

Table 2. Specifications of the Motor.

Parameter	Specification
Motor type	Permanent Magnet Synchronous motor
Rated power	15 kW
Rated Torque	47.7 Nm
Rated speed	3000 rpm
Peak power	30 kW
Peak torque	115 Nm
Peak speed	8000 rpm
Rated current	150 A
Peak current	380 A
Protection level	IP67
Weight	34 kg

Table 3. Specifications of the Controller.

Parameter	Specification
Control Method	PG Vector Control
Rated capacity	18.5 kVA
Peak capacity	40 kVA
Rated current	150 A
Peak current	400 A
Peak torque	115 Nm
Peak speed	8000 rpm
Operating voltage	12 V
Input voltage range	72 – 120 VDC
Protection level	IP67
Weight	6.8 kg

There are various types of cells with different cell chemistries and capacities available for electric vehicle propulsion. Each one has its advantages and disadvantages [14]. Lithium Ion and Lithium Polymer are the most commonly used batteries in electric vehicles due to their high energy density and life span [15]. The battery capacity depends on the range requirement and auxiliaries power consumption of the vehicle. The range of an electric vehicle depends on many factors such as vehicle design, the load of the auxiliaries, driving, environment, etc. [16].

Taking into consideration of the required vehicle power, average ancillary power, and the design limits of the motor and inverter, the battery pack with a configuration of 30 series and 1 parallel (30s1p) cells was designed which gave a nominal voltage of 96 Volt and a total energy capacity of 22.08 kWh (the total energy capacity of the battery can be obtained by the multiplying the cell's nominal voltage, nominal capacity, number of cells in series and number of cells in parallel). The specifications of the cell and the battery pack were listed in the tables 4 and 5 respectively.

Table 4. Specifications of the Cell.

Item	Parameter	Specification
Voltage	Charge voltage	3.65 V
	Nominal voltage	3.2 V
	Discharge voltage	2.5 V
Capacity	Nominal capacity	230 Ah
Current	Max Continuous charge/discharge current	0.5 C/1 C
Energy	Maximum energy	736 Wh
Size	Dimension (Width x Thickness x Height)	173.9 mm x 53.9 mm x 207.2 mm
	Weight	4.14 kg

Table 5. Specifications of the Battery Pack.

Parameter	Specification
Battery pack voltage	96 V
Pack Capacity	230 Ah
Battery energy capacity	22.08 kWh
Battery pack configuration	30 series x 1 parallel
Battery pack weight	124.2 kg
Total enveloping space	80 litres

The mass of the conventional IC engine vehicle is 1050 kg. The mass of the engine is approximately 90 kg and the mass of the fuel tank, radiator and other components collectively is 40 kg. Therefore, the mass of the vehicle without the engine and other components is 920 kg. On the other hand, the mass of the motor is 34 kg, the mass of the Inverter is 6.8 kg, the mass of the battery pack is 124.2 kg, and the mass of the battery envelope and other electric accessories collectively is 40 kg. Therefore, the mass of the retrofitted vehicle is 1125 kg.

2.1 Selecting the vehicle

There are 4 types of charging methods/modes established for electrical vehicles and 4 types of charging ports standardized [15]. The charging method of type 1 (240V 50Hz, Maximum output current of 32A) and charger port of type 1 (SAE-J1772-2009) was selected in this case. The charging time of the battery is 7.2 hours approximately. The charging time of the battery can be calculated in the following way:

$$T_{ch} = \frac{V_{cb} A_{nc}}{V_{ch} A_{maxch}} \quad (10)$$

Where T_{ch} is the Charging time (in hours), V_{cb} is the Charge voltage of the battery (in V), A_{nc} is the nominal capacity of the battery (in Ah), V_{ch} is the output voltage (in V) of the charger and A_{maxch} is the maximum output current (in A) of the charger.

3. Integration

The variation in the weight distribution before and after conversion into an electric vehicle has to be minimum so that there will be minimal changes in the vehicle dynamics. As the selected vehicle is a light commercial vehicle with the payload at the rear, the battery pack has to be placed forward biased on a rigid frame and fully constrained in all directions, by making necessary alterations to the vehicle's frame.

In this case, the wheels are to be driven by the motor through the existing gearbox, propeller shaft, and differential. Both the gearbox input shaft and the motor output shaft have external spline shafts. Therefore, a flange coupling, with a hub with the tooth profile of the gearbox input shaft at one end and the tooth profile of the motor output shaft at the other end should be designed and installed. To keep the performance better and driving convenient, the gearbox has to be locked in the 2nd gear, which offers suitable reduction as per the chosen motor, and eliminates the hassle of gear changing, making the transmission fixed reduction. Though the rest of the gears and components such as the gear shifter, synchronizers, dog clutch, etc. in the gearbox are now made idle, it is advised not to remove them as it could affect the balance of the shafts. The gear selector of an EV replaces the gear shifting lever in an ICE vehicle.

In this Electric vehicle, the clutch is eliminated and so is the clutch pedal. The conventional accelerator pedal of the ICE vehicle has to be replaced with an Electric vehicle accelerator pedal i.e., a pedal with a rotary potentiometer. Since the converted vehicle doesn't have an engine, a vacuum booster for the brakes can be driven by a compressor. The cluster should provide information such as Battery SoC, Range, Battery/Motor temperature, vehicle speed, etc. has to be displayed on the cluster. All the electrical systems and their connections should be adhering to the safety norms and regulations of electric vehicles in India.

4. Evaluation of Vehicle performance

The following are the key parameters of the retrofitted vehicle:

Table 6. Specifications of the vehicle after retrofitting.

Parameter	Specification
Gross Vehicle Weight	1950 kg
Payload	825 kg
Kerb Weight	1125 kg
Gear ratio	11.712:1
Frontal Area	2.37 m2
Tires	155R13 LT 8PR
Max Speed	50 kmph (Limited)
Motor Max power	30 kW
Motor Rated power	15 kW
Battery pack voltage	96 V
Battery pack capacity	230 Ah

4.1 Electrical energy consumption of the vehicle

Generally, Modified Indian Drive Cycle (MIDC) is used to assess the engine emission levels and passenger car fuel economy. The cycle consists of Urban and Extra Urban drive cycles each lasting for 780 and 400 seconds respectively. The Urban drive cycle represents city driving conditions, generally characterised by low vehicle speed. Assuming that the road is straight, flat, and dry, the Urban drive cycle was used to calculate the electrical energy consumption/km, State of Charge (SoC), and an electric range of the vehicle without and with regenerative braking. The distance travelled by the vehicle in the cycle is 3.98 km. Considering the intermittent, continuous, and prolonged loads, the average power required for the auxiliaries in the vehicle is 0.5 kW.

4.1 Energy Consumption of the vehicle with regenerative braking

Regenerative braking in electric vehicles converts most of the kinetic energy of the vehicle while deceleration into electrical energy and charges the battery.

The energy regenerated into the battery is calculated as follows:

The vehicle acceleration/deceleration power (in kW).

$$P_{dec} = \frac{maV}{1000} \quad (10)$$

Where a is the deceleration of the vehicle (in m/s^2).

Braking power (in kW) applied to generate the deceleration,

$$P_{braking} = P_{dec} - P_{roadload} \quad (11)$$

Where $P_{roadload}$ is the deceleration power (in kW) produced due to the road loads.

The energy dissipated (in kWh) due to the applied braking power $P_{braking}$ is:

$$E_{braking} = \frac{P_{braking}}{3600} \quad (12)$$

$P_{braking}$ is considered to be zero when P_{dec} is less than or equal to $P_{roadload}$.

The net regenerative braking energy returned to the battery in the city is 32% [18] and this estimation may vary depending on the different vehicles and different drive cycles [19].

The analysis is carried out initially with a payload of 70 kg only, i.e., the weight of the driver. The energy required to power the auxiliaries is consumed from the battery. So, during the driving conditions, the battery energy is utilised for vehicle propulsion and auxiliaries and during braking, the braking energy recaptured by the electric motor would charge the battery which can compensate for the energy required by the auxiliaries.

The propulsion energy consumed by the vehicle in the drive cycle, E_1, is 0.473 (kWh).

E_2 be the energy consumed by the auxiliaries in the drive cycle (in kWh).

$$E_2 = \frac{P_{aux} T_{dc}}{3600} \quad (14)$$

Where P_{aux} is the average power required by the auxiliaries (in kW), and T_{dc} is the Drive Cycle duration (in seconds).

Therefore, from Eq. (14), E_2 is 0.108 kWh.

The electrical energy recovered from regenerative braking in each cycle, E_3, is 0.129 kWh.

The total energy consumed from the battery per drive cycle with regeneration is:

$$E_b = E_1 + E_2 - E_3 \quad (16)$$

By substituting the corresponding values in Eq. (16), E_b is 0.453 kWh.

Let E be the total electrical energy consumed from the battery per km (in kWh/km) per drive cycle.

$$E = \frac{E_b}{T_{dc}} \quad (15)$$

From Eq. (15), the total electrical energy consumed from the battery in a drive cycle with regenerative braking is 0.113 kWh/km

4.2 Energy consumption of the vehicle without regenerative braking

The analysis is carried out initially with a payload of 70 kg only, i.e., the weight of the driver. The energy required to power the auxiliaries is consumed from the battery. So, during the driving conditions, the battery energy is utilised for vehicle propulsion and auxiliaries and during braking, energy is utilised for auxiliaries.

The propulsion energy consumed by the vehicle in the drive cycle E_1, is 0.473 (kWh).

From Eq. (14), E_2 is 0.108 kWh.

The total energy consumed from the battery per cycle without regeneration is, E_b is the sum of E_1 and E_2, i.e., 0.582 kWh.

Therefore, from Eq. (15), the total electrical energy consumed from the battery in a drive cycle without regenerative braking is 0.146 kWh/km.

Table 7. Electrical energy consumption at various payloads without regenerative braking.

Payload (kg)	Propulsion Energy Requirement/Cycle (kWh)	Battery Energy Consumed/Cycle (kWh)	Electrical Energy Consumption (kWh/km)
70	0.473	0.582	0.146
300	0.518	0.626	0.157
500	0.556	0.665	0.167
700	0.595	0.704	0.177
825	0.619	0.728	0.183

Table 8. Electrical energy consumption at various payloads with regenerative braking.

Payload (kg)	Propulsion Energy Requirement/Cycle (kWh)	Energy recovered/Cycle (kWh)	Battery Energy Consumed/Cycle (kWh)	Electrical Energy Consumption (kWh/km)
70	0.473	0.129	0.453	0.113
300	0.518	0.159	0.467	0.117
500	0.556	0.184	0.481	0.120
700	0.595	0.210	0.494	0.124
825	0.619	0.226	0.502	0.126

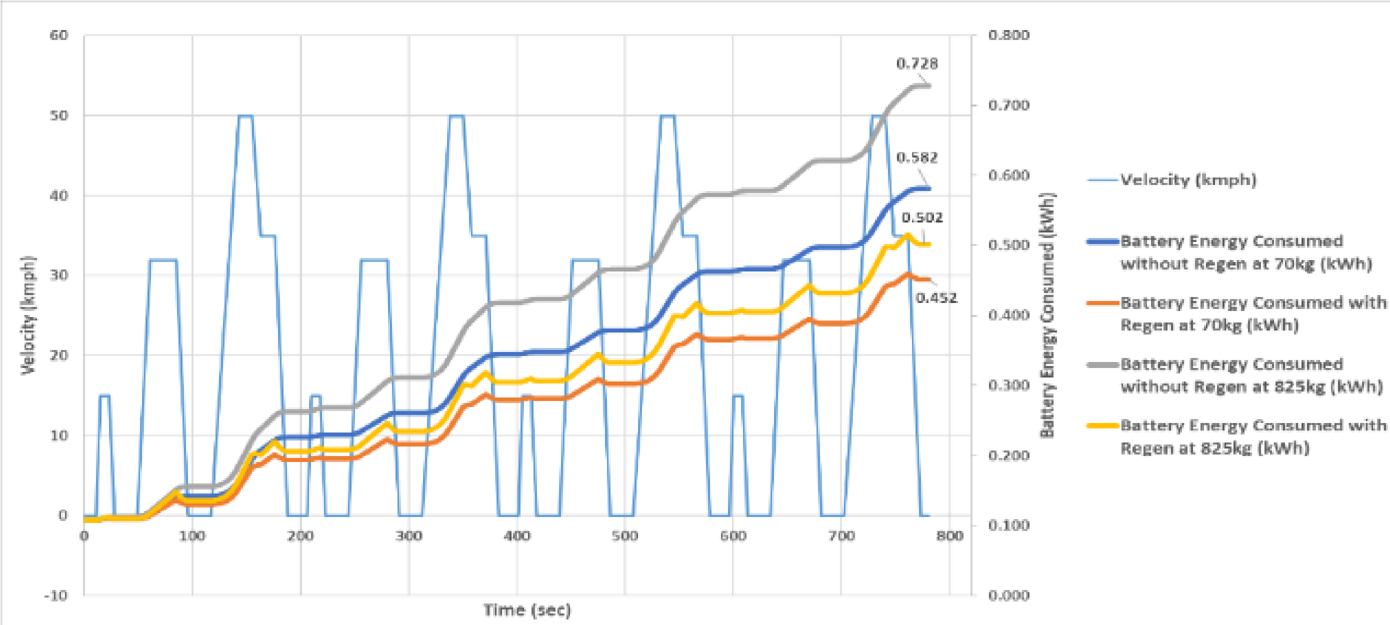

Figure 2. Battery energy consumption in the Drive Cycle

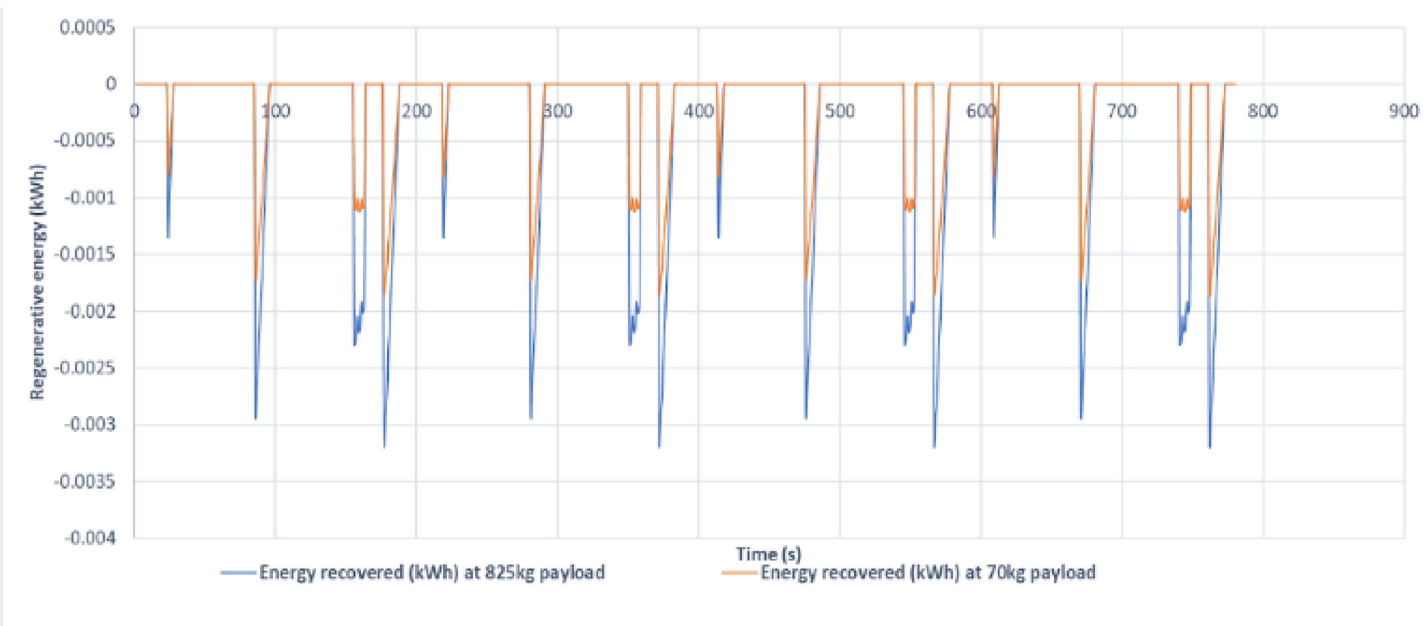

Figure 3. Comparison of Regeneration energy at 70 kg and 825 kg payload

4.3 Range of the vehicle

The range of an electric vehicle can be calculated by dividing the available electrical energy in the battery (in kWh) by the electrical energy consumption of the vehicle per km Eq. (15). Only 10 – 90 % of the battery capacity is used to maximise the battery life. The range of the vehicle without and with regenerative braking at various payloads was calculated and tabulated as follows:

Table 9. Range of the vehicle at various payloads without and with regenerative braking.

Payload (kg)	Theoretical Range without Regenerative braking (km)	Theoretical Range with Regenerative braking (km)
70	120.7	155.3
300	112.1	150.2
500	105.65	146.1
700	99.8	142.2
825	96.5	139.9

4.4 Maximum gradeability of the vehicle

The gradeability of the vehicle is determined using Eq. (17).

$$Gradeability\ \% = 100\left(\frac{F_t}{g \times GVW} - C_{rr}\right) \quad (17)$$

Where F_t is the Tractive force, which can be calculated in the following way:

$$F_t = \frac{T_m \eta_{powertrain} i_t}{r} \quad (18)$$

By substituting the corresponding values in Eq. (17), the gradeability of the vehicle is 22.1%.

4.5 Cost comparison of ICE and Retrofitted EV

The cost of owning and operating an ICE vehicle and an Electric vehicle can be compared directly. The owing cost of the selected ICE vehicle is approximately ₹6,50,000.

Approximately 10 kWh of energy is available in 1 litre of diesel. The mileage of the selected ICE vehicle is approximately 18 kmpl.

Assuming the usage of 100,000 km in 5 years, the fuel consumption can be calculated in the following way:

$$Fuel\ Consumed = \frac{Distance\ travelled}{Mileage} \quad (19)$$

By substituting the corresponding values in Eq. (19), the fuel consumption of the selected vehicle for 5 years is 5,555.5 litres.

The diesel price for one litre in India is ₹90, therefore the total fuel expenses for 5 years will be ₹5,00,000. And the total service and maintenance costs, and costs of spares for 5 years account for approximately ₹1,50,000, under normal operating conditions.

Therefore, the total owning and operating cost of an ICE vehicle for five years is the sum of owning cost, fuel expenses, and maintenance cost, i.e., ₹13,00,000.

The energy consumption of the ICE vehicle can be calculated by using Eq. (20).

$$Energy\ consumption = E_f F_c \eta_E \quad (20)$$

Where E_f is the energy available per litre of fuel (in kWh), F_c is the fuel consumption per kilometre (in litre/km) by the vehicle, and η_E (=30%) is the efficiency of the vehicle's engine. By substituting the corresponding values in Eq. (20), the energy consumption of the ICE vehicle is 0.167 kWh/km.

The resale value of the selected ICE vehicle after 10 years is ₹250,000 approximately.

The total cost incurred for converting, (i.e., the sum of costs of the old vehicle, battery pack, motor, controller, supporting electrical and electronic equipment, and miscellaneous), the selected vehicle into a pure Electric vehicle is approximately ₹8,50,000. And the maintenance cost, i.e., brakes, lubrication, cost of spares, etc. of the Electric vehicle for 5 years will be ₹80,000 approximately under normal operating conditions.

The cost of electrical energy is ₹8.24/kWh [20]. Then the total cost incurred in charging the vehicle over 5 years i.e., 1,00,000 km with a charging efficiency of 80% is:

$$Cost\ of\ Charging = \frac{E \times Cost\ electrical\ energy \times Distance\ travelled}{Charging\ efficiency} \quad (21)$$

By substituting the corresponding values in Eq. (21), the cost of charging the vehicle for 5 years is ₹1,17,000.

Therefore, the total cost of owning and operating a converted or retrofitted Electric vehicle for 5 years is the sum of conversion cost, cost of charging or operating cost, and maintenance cost, i.e., ₹10,47,000.

The cost of owning the new similar Electric Vehicle, as per the market at the time of writing this paper, is approximately ₹14,00,000.

Therefore, the total cost of owning and operating a new Electric vehicle for 5 years is the sum of owing cost, cost of charging or operating cost, and maintenance cost, i.e., ₹16,00,000.

From the above calculations, we can observe that the operating and maintenance cost of an Electric vehicle are less than that of an ICE vehicle, though the initial cost of an Electric vehicle is high. And the total cost of a converted Electric vehicle for five years is 20% less than the total cost of a new ICE vehicle and 35% less than a new Electric vehicle for 5 years.

5. Results and discussion

The Evaluation of the conversion of the ICE 4-Wheeler Light commercial vehicle was carried out. The electrical energy consumption/km, SoC, and range of the vehicle were determined using Modified Indian Drive Cycle- Part 1 at various payloads without and with regenerative braking.

At 70 kg payload, the electrical energy consumed was 0.113 kWh/km and at the payload of 825 kg, the energy consumed was 0.126 kWh/km with regenerative braking. The calculations showed that the range of the vehicle with Regenerative braking was 155.3 km and 139.9 km at 70 kg and 825 kg payload respectively. On the other hand, the energy consumed by the ICE vehicle was 0.167 kWh/km, and to achieve a similar range as the retrofitted vehicle at 70 kg payload, i.e. 155.3 km, the fuel required was 8.62 litres and the CO_2 emissions were 146.5 gm/km. Electric vehicles don't produce any CO_2 emissions while operating.

The maximum gradeability of the vehicle was 22.10%. A cost comparison study of both vehicles was carried out. The cost of operation of the retrofitted EV and ICE vehicle for 5 years is ₹1,97,000 and ₹6,50,000 respectively. The total cost incurred for conversion was ₹8,50,000 and the total cost for 5 years was approximately ₹10,47,000.

7. Conclusions

The conversion process of an ICE vehicle into a pure electric vehicle is presented in this paper. Though the conversion process discussed was for a Light Commercial Vehicle, the conversion procedure remains more or less the same for any vehicle. Sizing of the motor, controller, and battery pack was done. The mathematical model of the retrofitted EV in the Modified Indian Drive Cycle- Part 1 was developed and numerical analysis was carried out at various payloads with and without regenerative braking to evaluate the performance of the vehicle. The total cost i.e. sum of owing cost, operating cost, and maintenance cost of a converted Electric vehicle for 5 years is approximately 20% less than that of a new ICE vehicle and 35% less than that of a new Electric vehicle. The higher initial cost, charging infrastructure, and range anxiety are the major reasons for people stepping back to buy an Electric vehicle. This study shows that one of the ways to overcome the higher initial cost is by converting the existing ICE vehicles into Electric vehicles. The Government of India should also provide subsidies for EV retrofitting with which the cost parity with new ICE and electric vehicles can be achieved. Electric vehicles don't emit particulates while in operation. But, are still associated with the emissions produced while manufacturing, charging, and recycling. The charging infrastructures which use renewable resources of energy such as solar, wind, etc. have to be developed to reduce the emissions associated with EV charging and also to lower the costs incurred for charging the battery of the vehicle.

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Nomenclature

$F_{resistance}$	The total driving resistance of the vehicle (N)
F_r	Rolling resistance force (N)
F_g	Gradient climbing force (N)
F_w	Aerodynamic drag force (N)
m	Mass of the vehicle (kg)
g	Acceleration due to gravity (m/s^2)
C_{rr}	Coefficient of rolling resistance
α	Slope of the road (rad)
ρ	Density of air (kg/m^3)
A	Frontal area of the vehicle (m^2)
C_d	Drag coefficient of the vehicle
V	Velocity of the vehicle (m/s)
P	Power required to propel the vehicle (W)
T_w	Torque at the wheels (Nm)
r	Tire rolling radius (m)
$\eta_{powertrain}$	Efficiency of the powertrain
i_t	Overall gear ratio of the drivetrain
N_w	Speed of the wheel (rpm)
N_m	Speed of the motor (rpm)
T_m	Torque of the motor (Nm)
P_m	Power of the motor (kW)
P_{dec}	Power required to decelerate the vehicle (kW)
a	Deceleration of the vehicle (m/s^2)
$P_{roadload}$	Deceleration power due to road load (kW)
$P_{braking}$	Applied braking power (kW)
$E_{braking}$	Energy dissipated due to applied braking powe r (kWh)
T_{ch}	Charging time (h)
V_{ch}	Charge voltage of the battery (V)
A_{nc}	Nominal capacity of the battery (Ah)
V_{ch}	Output voltage of the charger (V)
A_{maxch}	Maximum output current of the charger (A)
E_1	Propulsion energy consumed by the vehicle in the drive cycle (kWh)
E_2	Energy consumed by the auxiliaries in the drive cycle (kWh)
P_{aux}	Average power required by the auxiliaries (kW)
T_{dc}	Drive cycle duration (s)
E_b	Total energy consumed from the battery per drive cycle (kWh)
E	Total electrical energy consumed from the battery per km (kWh/km)
E_3	Electrical energy recovered from regenerative b ra king in each cycle (kWh)
F_t	Tractive force (N)
E_f	Energy available per litre of fuel (kWh)
F_c	Fuel consumption per kilometer (litre/km)
η_E	Efficiency of the vehicle's engine

Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

CRediT Author Statement

P. Vijay Sai Goud: Conceptualization, Data curation, Writing-original draft, Investigation.

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