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Technical analysis and performance evaluation of retrofitted electric Auto Rickshaws (E-TAR) in rural India

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Abstract India needs to electrify rickshaws because of the emissions produced by modern cars running on fossil fuels like gasoline and diesel. There are incentives, discounts, and exemptions available for the use of e-auto rickshaws. The production of electric vehicles has also been given a target by the Indian government. The Indian government has taken a number of steps to increase the availability of charging stations and a steady supply of electric cars (EVs). Even after taking all of these measures, there has been little adoption. For Indian auto drivers, the capital cost of purchasing an e-auto is expensive. To attain ideal performance, it is important to modify the present generation of traditional auto rickshaws using low-cost retrofitting. Retro-kit is created and evaluated for performance in this study by changing parameters.

Keywords: conventional three-wheel Auto Rickshaw (C-TAR), electric three-wheel Auto Rickshaw (E-TAR), retro-fitment

1. Introduction

The conventional 3-wheel auto-rickshaw (C-TAR) is a primary vehicle utilized in intermediate public transport (IPT) and generally symbolizes an urban transport system. In any Indian city, there are three different ways to go around: privately, publicly, and through intermediate public transport (IPT). C-TAR is used in every region of India, from villages to metro cities. In various ratios, taxis, three-wheel scooter rickshaws (TSRs), and C-TARs are employed to expand the incidence of IPT in most of our nation's cities. The C-TAR, also known as "Auto," has been one such tool and is hence popular and known as "Auto" in each city. For various routes, destinations, boarding in, exiting, etc., this approach is practical and adaptable. Additionally, it offers door-to-door services, does not require advanced reservations, and helps individuals without access to private transportation.

Despite all these benefits, which make C-TAR a crucial component of every developing metropolis and seem vital, according to Singh et al. (2017), C-TAR has come to light as the cause of the problems Indian cities are currently experiencing. Auto rickshaws continue to have an internal combustion engine (ICE) that uses both petrol and diesel as fuels, which pollutes the environment. To solve this environmental problem, many metro cities in India banned vehicles from running on diesel. Therefore, the Indian government is permitted to convert IC engines into compatible E-Rickshaws. Due to the extensive pollution and high density of auto-rickshaws in every metropolis, six out of the top ten most contaminated cities in the globe are located in India. In response, the Government of India (GoI) started a mission and a set of programs to quickly electrify vehicles, with a focus on three-wheelers in general and auto-rickshaws in particular.

Only 8 retrofitters have received approval from the International Centre for Automotive Technology (iCAT) and the Automotive Research Association of India (ARAI), according to Singh et al. (2017). Despite all of these measures, only a limited number of automobiles are electrified.

To accelerate the electrification of motor vehicles, DHI, MHI&PE (GoI, 2015) developed materials for the Faster Adoption and Manufacturing of Hybrid and Electrical Vehicles in India (FAME) initiatives. The notion of the total cost of a vehicle (TCO) has been discussed by Kumar and Chakraborty (2020) in determining the economic viability of the electrification of various vehicles.

Hofmann et al. (2009) used Bajaj RE Indian manufacturer's auto for modeling. A Bajaj RE 2-stroke petrol engine was also used in this study. The process for economically converting a conventional engine auto-rickshaw into an e-rickshaw was described by Nambiar et al. (2019). How to change a continuously variable transmission (CVT) or any other multispeed gearbox was discussed by Gawade et al. (2019). According to the paper, converting a Bajaj RE auto rickshaw requires only an electrical powertrain combined through suitable transmission.

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A method for retrofitting an electric power train in three-wheelers with conventional power trains was described by Patar et al. (2018). The author estimates the ideal motor power need and explains how to choose various parts for the modification of C-Tars into E-Tars. They create a real-world drive cycle for an auto rickshaw. A study by Warner (2015) explained how to design a battery pack by understanding the energy requirements of a vehicle for a particular range. The methods for planning and choosing a rechargeable electrical energy storage system (REESS) for kit conversion from a conventional vehicle to an E vehicle were provided by Dalvi and Pharande (2021). The Loganathan et al. (2021) paper offers a multicriteria decision-making (MCDM)--based method for choosing an affordable battery with the best energy capacity for an EV conversion. A large lithium-ion battery system design analysis was provided by Santhanagopalan et al. (2014). This approach was useful in this project when developing and upgrading our E-TAR battery pack. The method for choosing various parts of an E-TAR was described by Sreejith and Rajagopal (2016). The work of Dhar et al. (2021) aids in choosing a motor.

The study by Mishra et al. (2013) offered details on the motor power rating optimization criteria. The study by Gorantla et al. (2018) describes how the drive train must be modified for EV conversion. According to Mehta et al. (2014), who explains how a CNG-powered rickshaw was converted into an E-TAR, auto-rickshaws are ideal candidates for electrification and the application of battery-exchanging technology.

Ramchander et al. (2015) and Harding et al. (2016) studied the socioeconomic circumstances of autorickshaw drivers. The socioeconomic situation of autorickshaw drivers was demonstrated in the paper to be poor. It is necessary to further reduce this risk by lowering the CAPEX of the E-TAR, which is practical because of the need to convert the current CTAR to an ETAR utilizing a retrofit kit that has been carefully and methodically designed and created.

According to the literature review, the adoption of E-auto during the past six years has not met the stated goals. To ensure energy security and lower urban pollution and associated problems, autorickshaws must be electrified. To encourage more low-income vehicle drivers to use e-rickshaws, retrofitting costs must be optimized even further. For a retrofit kit to be most cost-effective, a reduced total cost of ownership (TCO) of electrification and performance analysis are needed. Retrofit kits for converting C-TAR into E-autos or rickshaws. The purpose of this study is to create an affordable retro-kit that performs optimally for transforming a C-TAR into an E-TAR. The performance of the created kit was evaluated by varying various parameters.

2. Methodology

All four fuels, namely, gasoline, diesel, compressed natural gas, and liquefied petroleum gas, are produced by all manufacturers of rear-wheel-drive autorickshaws. For this experiment, a model from Bajaj Auto Limited is chosen, and retrofitting is performed according to the AIS 123 regulations. It is a rear-engine, 2-stroke, single-cylinder, naturally aspirated (NA), gasoline autorinker. When the engine is changed from conventional auto to E-Tars, all the assembled parts need to be removed. The other systems of the chosen vehicle do not require changing.

To create the electrical drive train, the entire transmission of the chosen model is the same. As a result, to construct an EDT, it is necessary to determine how much energy the autorickshaw needs to run over a km distance and to estimate the battery's energy capacity based on that distance. The maximum autorickshaw speed is 25 km/h, with a 55 km range, a 5 km/h air velocity, a gradability of 50, and an IDC driving cycle according to the AIS-039 standard. The specifications of the chosen auto-rickshaw body and chassis are listed in Table 1.

Table 1 Elements of the Resistive Forces and Vehicle Energy Consumption Calculations.

Entity	Value	Unit
Aerodynamic drag force	4.8323	N
Rolling resistance force	77.79	N
Climbing resistance force	625.51	N
Tractive force (0% gradient)	82.6223	N
Tractive force (12% gradient)	708.1323	N
Power needed (0% gradient)	573.77	W/Nm/s
Power needed (12% gradient)	4917.59	W/Nm/s
Energy spent over IDC on leveled road	21.067	Wh
Energy consumed on a straight road	32.017	Wh/km
Battery Energy Capacity for 55 km (0% grade)	1760.94	Wh
Energy spent over IDC on the road (12% grade)	43.7499	Wh
Energy consumed on road with (12% grade)	66.4829	Wh/km
Battery Energy for 55 km range on road with 12% grade	3656.55	Wh

The theory of vehicle dynamics is used to calculate power and energy consumption (Patar et al., 2018). Table 2 lists the forces experienced by the auto rickshaw during vehicle acceleration, including aerodynamic drag, rolling resistance, gradient resistance, and force, as well as the power used during the Indian driving cycle and energy consumption. A four-speed gearbox with ratios of 0.2, 0.34, 0.54, and 0.89 as well as a back axle ratio of 0.24 are chosen for this model, as are the energy utilization on the straight path during the battery and traction motor and its controller's design.

Table 2 Specifications of the Rechargeable Electrical Energy Storage System.

Num.	Specifications required for the project	
A	*Requirement of REESS*	
1	Energy capacity	1.76 kWH
2	System voltage	48 V
3	The current capacity of a battery	36.67 Ah
B	*Cell Description*	
1	Chemistry	LiFePO4
2	Form Factor	32650 Cylindrical with Φ 32 mm x 65 mm
3	Voltage	2.8-3.2
4	Current	6000 mAh
5	Mass	0.000141 kg
C	*Battery Pack Design*	
1	Configuration	6P15S
2	Cells	90
D	Charge and discharge socket	As per electrical current flowing through a circuit (amperage)

Rechargeable electrical energy storage system design and energy capacity decisions are based on the amount of energy required to achieve the desired vehicle range. Using multicriteria decision-making, the battery capacity for the chosen rickshaw with a 55 km running capacity and gearbox drop (Gr) and back axle drop (Ar) may be optimized. The battery is designed, and the REESS specification is as per Table 3, taking into account an ideal state where the transmission efficiency is 100% and the battery energy is used at 100% SOC.

Table 3 Specific specifications of the traction motor chosen.

Sr. no.	Description	Value
1	Make	Swiss
2	Identification No	SAP-1851AB
3	Nomenclature	BLDC
4	On-load maximum torque	> 220 Nm
5	Rated power	1000 W
6	Rated speed	3000 rpm
7	Rated voltage	48
8	Rated current	26 A
9	No load current	< 4.5 A
10	Running current	12 – 15
11	Operating Temperature	-200 to 1000C
12	Weight	4.9 kg
13	Wire length	1250

After determining the system voltage and understanding the required torque, the appropriate traction motor and motor controller were chosen. The EDT motor is ultimately chosen as a BLPMDC motor. Table 4 provides information on the Motor along with its specifications.

The following components make up the EDT kit's electrical power train (EPT): These devices consist of an electronic throttle, a SOC display/speedometer, a motor controller, and a traction motor. (made by Prakash and operating between 0.8 and 4.1 volts using Hall sensor technology), a power key switch, a resistor, wires, and a coupler. The devices were connected by a coupler to form an electrical power train (Gorantla, 2018). Figure 1 shows a block schematic of an E-DT with a transaxle and an EPT. The two parts that have been created and manufactured to attach the traction motor to the transaxle are a modified coupler/clutch shaft and a mounting bracket.

The Retro Fitment Kit contains various components, among which the tether anchor (TA) is fitted on its mounting componentwise location, as shown in Table 5 (Mehta et al., 2014).

3. Results and discussion

The performance of a modified E-rickshaw was compared to that of the standard model after it was created. Table 6 shows the various parameters of the vehicle's test. The performance of the E-rickshaw roof was evaluated on leveled roads and those with varying slopes. Different parameters, such as the e-rickshaw payload variation and throttle opening, were analysed. The vehicle's acceleration, cruising, and retardation periods were also evaluated.

Table 4 Description of the controller system.

Sr. no.	Description	Value
1	Brand	Swiss
2	Identification No.	SAP-0985
3	Nomenclature	BLDC motor control
4	Operating Temperature	00C-500C
5	Rated maximum power	1000 W
6	Current Limit	Programmable up to 50A
7	Voltage range	42-60 V
8	Low voltage protection	42 V
9	Braking system	Electronics
10	No. of MOSFET	24
11	Motor angle	1200
12	Speedometer	Analogue/Digital
13	Efficiency	> 85%
14	Enclosure	High-grade aluminum
		220x120x55 mm
15	Weight	1.5 kg
16	Hole-on-hole gap	140
17	Type	1000 W 48 V
18	No. of MOSFET	24

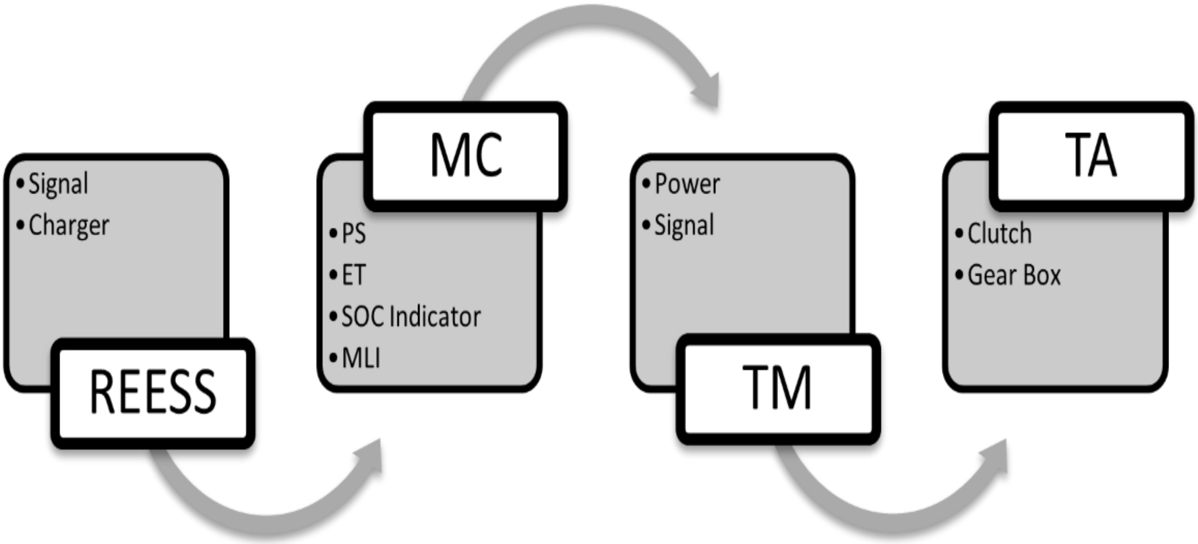

Figure 1 Electric drive train diagram.

Table 5 List of automotive industry standards (AISs) applied for analysing electric vehicles.

AIS no.	Name	Performance consideration
123 (Part3)	CMVR Type Approval of Electrical Propulsion Kit Proposed for alteration of rickshaw for pure electrical operation	Vehicle Weighing Coast down Gradeability Electrical range and energy consumption
003/1999	Automotive vehicle starting grade-ability	%
039 (rev.1) : 2015	EPT Vehicles- Checking of Electrical energy utilization	kWh/km
040 (rev.1) : 2015	EPTV- Method of determining range	Distance in km between consecutive battery charging
041 (rev.1) : 2015	EPTV- Measurement of net and max 30-minute power	Electrical Motor

Table 6 Description of the experiments with the retrofitted E-TAR.

Test Number	Weight in kg	% Grade	Throttle	Phase A/D/C	Reading	No. of reading
1	141	0	1	A	1st to 4th gear	11
2	141	0	¾	A		11
3	141	0	½	A		11
4	141	0	¼	A		11
5	191	0	1	A		11
6	191	<16	1	A	1st, 2nd, and 3rd	10
7	191	>16	1	A	gear	10
8	141	>16	1	A		10
9	141	<-16	1	C	3rd and 4th gears	06

Before an e-rickshaw can be operated, it must be ready to test. This includes moving the device into position and following an overnight charging procedure. Ensure that the tires are properly inflated and greased. A comparison of the three different models is presented in Table 7. These include an ETAR and a retrofit auto rickshaw.

Table 7 Evaluation of Retrofitted E-TAR with Three-wheel Electric Vehicles.

Original Equipment Manufacturer	Current Work	Piaggio Vehicles, Pvt. Ltd (Ape City)	Mahindra Electric Mobility Limited (Treo)	KGE&PS (Kinetic Green Energy and Power Solutions)-Safar
Vehicle class	L5M	L5M	L5M	e-Rickshaw
GVW/ULW	593/333	689/389	/377	679
Battery Type	lithium-ion	lithium-ion	lithium-ion	lithium-ion
Requirement	1.7kWh, 48 V, 15000 g	7.5 kWh, 51.2 V,	6.5 kWh, 48 V	4 kWh
Range in km	55	80	130	100
% Gradeability	12	19	12.7	10.2
Approximate Cost (INR)	85000	341000	372000	165000

A spreadsheet was used to analyze and aggregate the data collected during the testing process. The weight of the e-rickshaw was measured at a toll plaza in Maharashtra. The acceleration tests were carried out inside the institute's campus on flat surfaces. Two individuals, who weighed more than 140 kilograms each, boarded the vehicle to collect readings. The data collected during the tests revealed that the e-rickshaw speed increased as the e-rickshaw moved from the first to fourth gear. In addition, the electric vehicle consumption and the average speeds of the different gear changes were positively correlated (Figure 2).

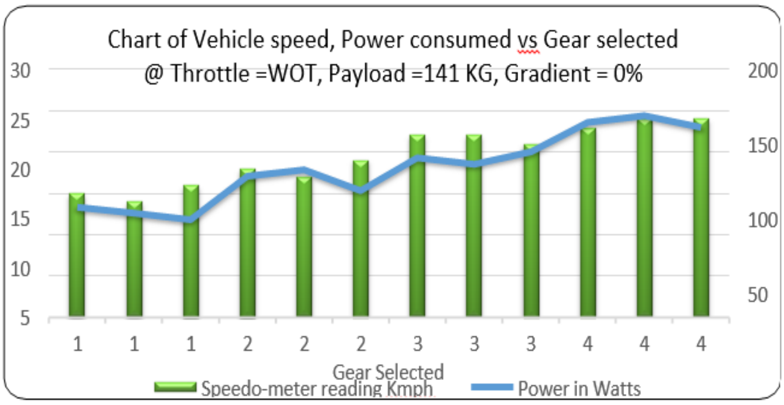

Figure 2 Graph of the variation in parameters at the wide open throttle.

The second test was conducted at the 3/4 throttle. The results of the second test are shown in Figure 3. The vehicle's speed increases as the gear changes from first to fourth, but the vehicle has a low power consumption because of this change. The relationship between the vehicle's speed and the electricity used is also positive. The average speeds of the first, second, third, fourth, and fifth gears are 10, 12, 16, 25, and 28 kmph, respectively. The third test was conducted with half-throttle gear changes and the results of the third test are shown in Figure 4. The other parameters of the test were the same as before. The results of the third test show that the vehicle's speed increases when it shifts gears from the first to fourth gear. On the other hand, it decreases when it returns to the half-throttle mode. The relationship between speed and electric usage is also positive. The average speeds of the first, second, third, and fourth gears are 5.5, 8, 11, and 12 kmph, respectively.

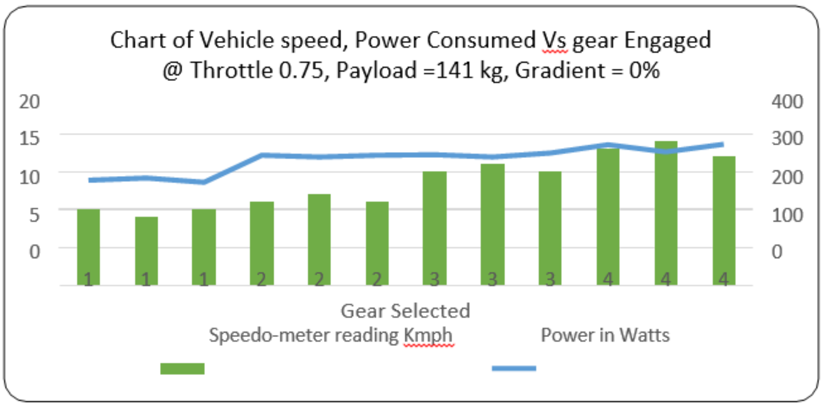

Figure 3 Graph of the variation in the parameter at the 0.75 throttle.

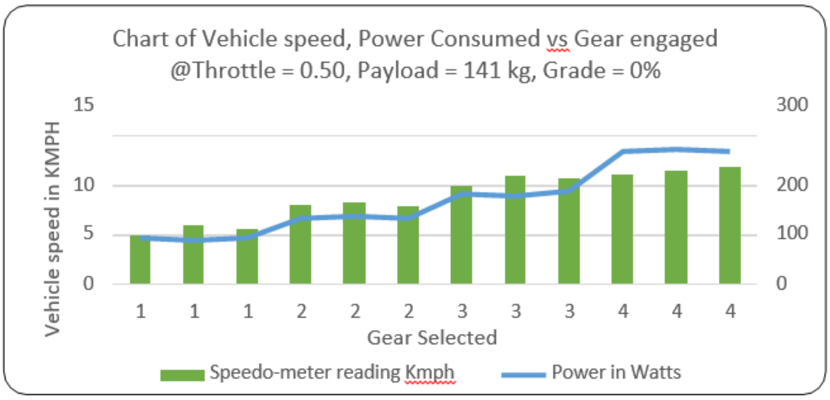

Figure 4 Graph of the variation in parameters at the 0.50 throttle.

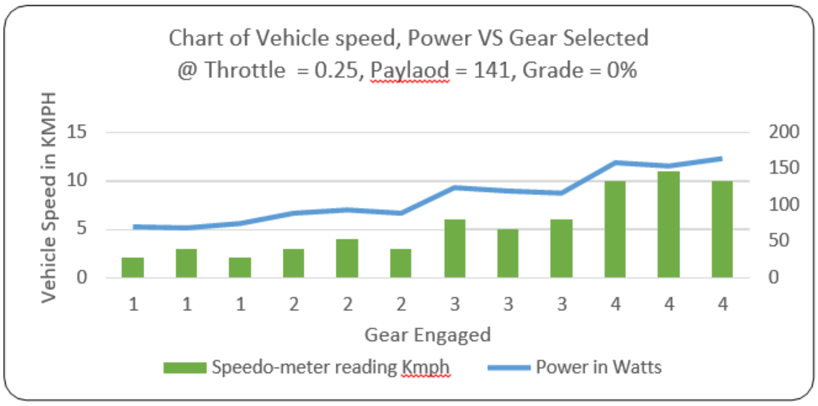

Figure 5 Graph of the variation in parameters at the 0.25 throttle.

The fourth test was performed using the same parameters and 1/4 throttles as the previous test the results are shown in Figure 5. The vehicle's speed increased with gear changes but decreased significantly with the use of 1/4 of the throttle. The relationship between power consumption and vehicle speed is positive.

The fifth test was carried out with a weight of 191 kg and a wide open throttle as shown in below Figure 6. To maintain a gradient of 0%, a dummy was placed on the rickshaw. The results of the test revealed that the power needed to reach a maximum speed of 19 kilometers per hour increased as the payload changed. The tests were carried out according to the American Society of Cardiology (AIS) guidelines. They were transported across a state route with gradients of either negative or positive. Test 6 was carried out on a highway near Satara, Maharashtra, using a vehicle with a payload of 191 kg and a WOT of 19. In addition to negotiating a moderate gradient of less than 16%, the vehicle also climbed in the 1st, 2nd, and 3rd gears before reaching its destination. The results of the test are shown in Figure 7, showing that the speed at which the vehicle reached its destination was lower than that of the chosen model, while its power consumption increased. On a state highway near the Satara district of Maharashtra, Test No. 7 was carried out with WOT and a weight of 191 kgs, climbing a gradient of more than 16%.

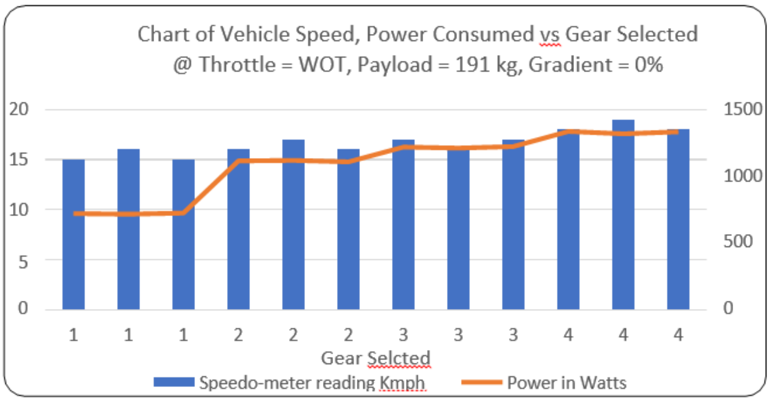

Figure 6 Graph of the variation in parameters at a zero% gradient.

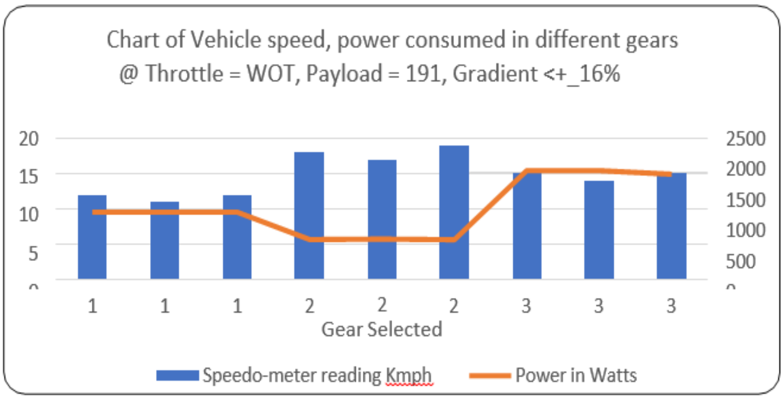

Figure 7 Graph of the variation in parameters at less than a 16% gradient.

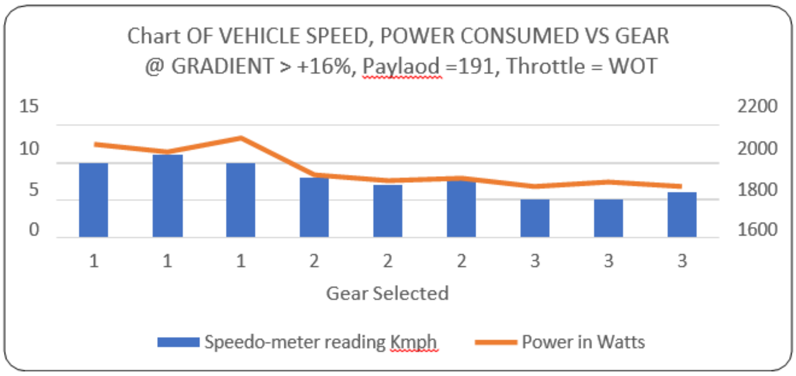

Figure 8 Graph of the variation in the speed and power consumed from gears 1 to 3 at a load of 191 kg.

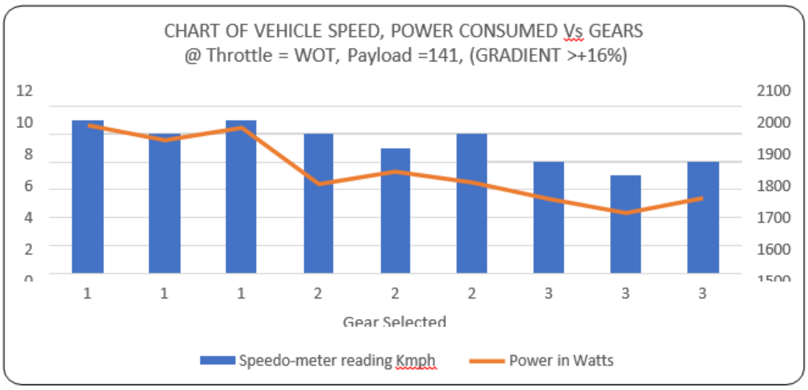

Figure 9 Graph of the variation in the speed and power consumed from gears 1 to 3 at a load of 141 kg.

The results of the seventh test in Figure 8 show that the vehicle did not climb the grade in the fourth gear due to the steeper gradient and heavy load. Only the chosen model was able to do so for the first, second, third, and fourth gears. The vehicle required more power in the 1st and 3rd gears. The eighth test was carried out at the same location as the previous test, as shown in Figure 9. The payload of the vehicle was 141 kg, and a gradient of more than 16% was analyzed. The results of the test showed that the vehicle's speed could be maintained with less power as its payload decreased. The goal of the downhill cruising test was to determine the vehicle's ability to maintain a steady speed while traveling down a slope. The 9th test was performed as the vehicle descended a slope. The preceding chart is shown in Figure 10. The maximum speed at which a car can travel while descending is 35 kilometers per hour. The total power that the vehicle used during this test was 359 kilowatts. The ninth test's results were documented by sheets of data. These data are then gathered and analyzed using a spreadsheet, and the results are subsequently plotted on charts.

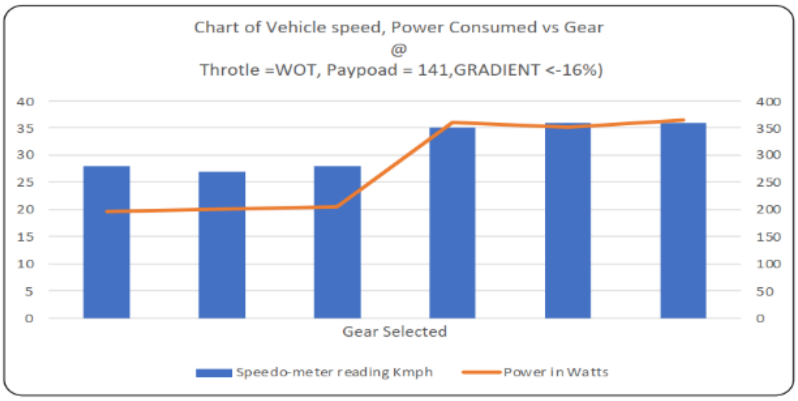

Figure 10 Graph of the variation in the speed and power consumed with gear change.

The proposed work is beneficial in terms of reducing emissions and ensuring cost-effectiveness, as follows.

1. Reduced Emissions.

- Environmental Impact: The implementation of hybrid electric vehicles has led to a substantial reduction in emissions, aligning with environmental sustainability goals.

  Emission Emits Hydrocarbon Gases No Tail-pipe Emission Power 7.5 KW 1 KW 1 KW 1 KW Top Speed 70 km/h 40 km/h 40 km/h 40 km/h Max Torque 19.2 Nm 38 Nm 38 Nm 38 Nm Capital Cost (Rs) 2,27,000/- 58,115/- 65000/- 83,115/- Running Cost 2.85 Rs Per km 0.48 Rs Per km (Household) 0.40 Rs Per km (Household) 0.40 Rs Per km (Household) Range 35 km in 1 Liter 70-80 km in 1 Charge 85-90 km in 1 Charge 95-100 km in 1 Charge

  Vehicles significantly decrease their reliance on traditional fuel sources, contributing to lower greenhouse gas emissions.
- Quantitative analysis: Our findings reveal a noticeable decrease in carbon emissions when a hybrid electric vehicle is used. A comparison of conventional vehicles and nonrenewable energy sources revealed a significant reduction in the overall environmental impact.
- Reducing the vehicle's dependence on fossil fuels This shift toward sustainable energy contributes positively to environmental conservation and promotes a greener transportation ecosystem.
- Long-Term Environmental Benefits: Over the lifespan of a vehicle, the reduction in emissions persists, providing long-term environmental benefits. Hybrid electric vehicles contribute to mitigating climate change and fostering a cleaner atmosphere.

2. Cost effectiveness.

- Initial Investment and Long-Term Savings: Despite the initial investment, our analysis demonstrates compelling long-term cost savings. Fuel consumption is significantly reduced, leading to lower operational costs and demonstrating the financial viability of the solar-powered hybrid electric vehicle.
- Return on Investment (ROI): The calculations indicate a positive return on investment over the lifespan of the hybrid electric vehicle. Factors such as fuel savings, reduced maintenance costs, and potential government incentives contribute to a favorable ROI.
- Government Incentives and Policies: The proposed work identified and leveraged various government incentives and policies supporting the adoption of clean energy solutions in vehicles. These incentives enhance the cost-effectiveness of the project, providing additional financial benefits.
- Lifecycle Cost Analysis: A comprehensive lifecycle cost analysis reveals economic advantages. Considering the installation, maintenance, and operational costs, the overall cost-effectiveness of the hybrid electric vehicle is evident.

4. Conclusions

In this research, it was determined that the vehicle's unladen weight (ULW) decreased by 6.14% after being retrofitted with an E-auto vehicle based on the tests that were conducted and the data that were gathered, processed, and analysed. The Retofitted E-auto resembles modern e-auto rickshaws made by several e-auto manufacturers. However, the cost of converting a C-TAR to an E-TAR, which includes the price of the rickshaw, is approximately 85000 Indian rupees, while the e-auto price in the Indian market is approximately 3.20 lakh. This cost is 25% less than the typical OEM e-auto price. The adapted car's top speed is 35 kmph slower than that of an electric vehicle. Compared to recently developed e-autos, gradability is lower at 12%. This study used a four-speed gearbox to address this issue. To transition to a REESS with greater energy capacity, its current capacity must be increased from 36 to 60 Ah while the voltage is kept at 48 V. The examination and analysis of the E-TAR, which has been upgraded to have somewhat more motor power and increased battery capability, can be performed to finalize a retro-kit. Currently, cars emit an average of 112 gm/km of greenhouse gases. The reduction will reach zero as a result of the conversion to e-auto. The observed reduction in emissions achieved through the integration underscores the project's commitment to environmental conservation. The decreased reliance of vehicles on traditional fuel sources aligns with global efforts to mitigate climate change and transition toward cleaner energy alternatives. Carbon emissions are also reduced significantly. The proposed work serves as a model for environmentally conscious design, encouraging the adoption of battery-powered systems in mainstream vehicles. Moreover, the economic benefits highlighted in the project findings underscore the potential for widespread adoption of battery-powered vehicles, mitigating concerns related to fuel dependency and fostering a paradigm shift toward more sustainable transportation solutions. As governments and industries globally prioritize sustainable practices, the proposed work provides a practical and feasible blueprint for reducing the environmental impact of vehicular emissions while addressing economic considerations.

Ethical considerations

Not applicable.

Conflict of interest

The authors declare no conflicts of interest.

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