Performance Analysis of Electrical Three-Wheel Auto Rickshaw Indigenously Developed using An Electrical Drive Train Retro Fitment Kit

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***Abstract*: Electrification of three wheelers in general and that of passenger auto rickshaw vehicles is vital for an urban transport system under alarming air quality situation of many cities in India. Incentives, concessions and exemptions have been offered for the adoption e-auto rickshaw and target of its electrification is also set by Indian government. In order to organize regular supply of Electrical vehicles (EVs) and extending charging facilities many initiatives viz. Production Link Incentives (PLI), Phased Manufacturing Programme (PMP), reduction in rate of Goods and Service Tax (GST) on EVs, their components and Batteries for Original Equipment Manufacturers (OEMs) and component manufacturers and Model Building laws 2019 and National Energy Policy 2017 for ease of setting up charging stations in place. Despite of all these actions the pace of its adoption is slow. As far as an auto rickshaw adoption is concern it is noted that capital cost of e-auto and possession of a conventional rickshaw in operation as well socio-economic condition of every existing auto driver-operator are the two major factors that are responsible for moderate pace of its adoption. It requires low-cost retro fitment of existing conventional auto rickshaw with an optimal performance. This paper initiates an attempt of designing a retro-kit which is low cost and perform optimally by physically designing it, retrofitting it on the same vehicle and testing the vehicle converted for its performance.**

Keyword: Three-wheel Auto Rickshaw (TAR) C-TAR, E-TAR, Unit in Operation, Total cost of Ownership, Retro-fitment, , NEMMP, FAME.

0. INTRODUCTION

Conventional Three-wheel Auto Rickshaw (C-TAR) represents an Urban Transport System [1] in general and it is a main carriage used in Intermediate Public Transport (IPT). There exist three modes of passenger transport in every Indian city namely private transport using an own vehicle, Public Transport in the form city buses, locals, metros, ferries etc. and the IPT which plays a role of a feeder for a main haul public transport. C-TAR extends front and last connectivity/ delivery. Three-wheel Cycle Rickshaw (TCR), Three-wheel Scooter Rickshaw (TSR), C-TAR, and Taxi are being used in different proportion to extend IPT in majority cities of our country. Among them the C-TAR has been a popular and therefore are large in number in each city. This, a small and narrow three-seater vehicle, usually refereed as "Auto" with a peculiar design makes it convenient and flexible in terms of timings, routes destinations, boarding in, getting down etc. Moreover, it provides door to door services, needs no advance booking, caters to those who do not afford private transport and who are not being served by public transport by virtue of their stay in city sprawls [2] on out skirt of main city.

Despite of all these advantages which make C-TAR an integral part of every growing city and appears indispensable, as per ref. [1] it has been emerged as an origin of many issues that Indian cities are facing. Auto rickshaw has remained equipped with old and outdated Internal Combustion engine (ICE) -based power train using petrol and diesel as fuels. In the beginning it used to be equipped with a two-stroke petrol engine during its entry into Indian market which was changed to a four-stroke engine for the sake of attaining better fuel efficiency and reduce environmental pollution. To sort issues related pollution many big cities like New Delhi, Mumbai, Kolkata, Chennai, Hyderabad, Bangalore and so on Petrol and diesel transport vehicles were banned [3-5] by replacing them with Compressed Natural Gas (CNG) and Liquid Petroleum gas (LPG) fueled transport vehicles. In that case auto rickshaws used were either converted using gas kits on one hand and registration of gas fueled auto rickshaw was allowed in these cities. Due to huge concentration of auto rickshaws in every city and extent to polluting gases viz. carbon monoxide, Carbon dioxide, nitrogen oxides, Unburnt hydrocarbon (UBHC) etc. and Particulate Matter (PM10, PM2.5) emitted by them, six out 10 most polluted cities in the world [12] are from India. Under such circumstances Government of India (GoI) initiated a mission [6] and schemes to adopt electrification [7-8] of transport vehicles at fast pace and three-wheel vehicles in general and auto rickshaws are included prominently in these schemes.

Electrification of any transport vehicle is possible by reducing a percentage of IC vehicles getting registered on one hand and increasing that of electrical vehicles on the other by setting a year-wise target of electrical vehicle registration. As per a news in Economic Times [9] the vehicle-wise electrification target set in our country are as given in **Table 1**

Table 1. Vehicle wise Electrification Target of GoI

Sr No	Vehicle category	Electrification by 2030 in %
1	e-2W	80
2	e-3W	80
3	e-4W	30
4	e-Bus	70

The electrification of auto rickshaws is possible by selling e-auto by OEMs or by converting existing conventional auto rickshaw in e-auto. As per a FAME portal of Department of Heavy Industry (DHI), Ministry of Heavy Industry and Public Enterprises (MHI&PE), Government of India (GoI) there are seven OEMs viz. Mahindra Electric Mobility Ltd. (MEML) , Piaggio Vehicles Pvt. Ltd. (PVPL), Champion Polyplast Ltd. (CPL), Keto Motors Pvt. Ltd. (KMPL), Scooter India Ltd. (SIL), Om Balajee Auto India Pvt. Ltd. (OBAPL) and Mir Auto Pvt. Ltd. (MAPL) who produce models of L5M electric vehicles. Moreover, there are number of OEMs and models as give in **Table 2** of other three three-wheel EV categories viz. e-Rickshaw, e-card and L5N being produced to achieve more and faster adoption of Three-wheel EVs.

Table 2: FAME Approved Three-wheel OEMs and Models

Sr. No	Three-wheel Category	No of OEMs	No of models
1	E-Rickshaw	23	29
2	E-Cart	11	15
3	L5M/E-Auto	07	09
4	L5N	11	27
		Total Models	80

Also, there are 8 retrofitters as per Singh, s. et al [10] who are in the business of retro fitment auto rickshaws into e-auto rickshaw as given in **Table 3**, with varying cost of conversion. They are approved by Automotive Research Association of India (ARAI) and (International Centre for Automotive Technology (iCAT) as retrofitters.

Despite of all these initiatives on the supply side an extent of electrification is moderate, and it is a cause of concern.

Table 3. List of Authorised Retrofitters involved in Auto Rickshaw Conversion

Sr. No.	Name of Retrofitter	Place of Business	Products
1	3 EV Industry Pvt. Ltd.	Karnataka	Retro kit
2	EVCO India	Maharashtra	Retro kits of MVs
3	Enviro Smart	Andhra Pradesh	Retrofit
4	Manatec EV Drive Pvt. Ltd.	Tamil Nadu	retro kit
5	Power Global	New Delhi	Battery Swapping,
6	Race Energy	Telangana	retro kit, Battery Swap
7	Volta Auto. India Pvt. Ltd.	Karnataka	Volta80X/ Cargo/ Retro
8	Velvel Motor India Pvt. Ltd.	Tamil Nadu	E-scooter, E-auto, E-bike

This paper is about development of a low-cost retro-kit with optimal performance for converting a C-TAR into E-TAR. It is possible to get such a kit by physically designing it for a given model, retrofitting it on that model to convert it into E-TAR, testing and analysing its' performance for further improvement and finalize the retro-kit required. It may take 2-3 iterations for the final kit which is low-cost with optimal performance. This project is the first step in achieving it. The paper comprises of six sections among which a second section about a survey of literature undertaken for this work followed by a rationale for conversion of existing Units in Operation (UIO) (conventional auto rickshaw) explained in section 3. A section 4 is about a project methodology in which details of step-by-step execution are provided from a selection of a vehicle model through development of Electrical Drive Train (EDT) as a retro-kit followed by its retro-fitment on the model selected and finally the way it is tested. The last two sections provide data compilation, analysis, results and conclusions related to testing of E-TAR.

1. LITERATURE REVIEW

Thakur, P. and Pal, S. (2019) [1] propose an urgent need of regulatory mechanism for fast-paced adoption of electric auto rickshaw in Indian cities. Regulatory mechanisms suggested by authors are -1) To reduce upfront cost either through incentives, concessions and exemptions or by retrofitting vehicles in operation using a properly designed kit 2) To prepare a Scrapping and transition plan 3) To introduce an open permit system with subsidy in permit fee and exemption on road tax and registration charges for e –auto 4) To remove hurdles in getting finance with a low rate of interest 5) To create e-auto zones to glorify its adoption 6) To establish sufficient number of charging stations across country 7) To enhance awareness about e-auto in auto drivers and people.

Technology Business Incubator Unit (TBIU), Indian Institute of technology (IIT), Delhi (2009) [2] reports on two and three-wheeler in India with reference to driving force of industry, government policies, regulatory framework, traffic issues and conflict with other vehicles and road users. The report specifically emphasizes following in the context of three wheelers- cheap taxis, provide mobility to a class of society who can't afford a personal vehicle to use as a private transport and those not being served by public transport due to location of their stay, neglected by policy makers but important based on data, important part of IPT, feeder for main haul public transport to ensure better load factor for it.

Mulhall, P. et al (2007, 2009 and 2010) write a paper-sequence [3-5] regarding their experience of a project 'Entrepreneurial Interprofessional Project (EnPRO)' offered to them in Illinois Institute of Technology (IIT) Chicago, USA. These three papers are written based on study of contemporary Indian situation for accepting electrification of an Auto rickshaw, designing an e-auto and infrastructure using simulation tools viz. ADVISOR and HUMER and testing its performance through experimentation using a data logger. Many details regarding history of auto rickshaw and Indian transport systems, different architect of EV, motor and battery requirement are given in this paper.It gives systematic procedure in undertaking the EV conversion project.

Department of heavy Industry (DHI), Ministry of Heavy Industry and Public Enterprises (MHI&PE Government of India (GoI)) (2012) prepared a mission plan [6] to initiate electrification of transport in India, popularly known as National Electrical Mobility Mission Plan (NEMMP) 2020 and imposed in this country from year 2013. The vision of this plan is to emerge as a leader in xEV 2-wheeler and 4-wheeler market in the world by 2020 with total sale by 6-7 million units by 2020 and ensure Fuel security to India. It is the first road map for the country to achieve electrification.

DHI, MHI&PE (2015, 2019) [7-8] prepared two documents about Faster Adoption and Manufacturing of Hybrid and Electrical Vehicles in India (FAME) schemes to accelerate electrification of motor vehicles. FAME-I is implemented during FY 2015 – FY2019 while FAME-II is being implemented from FY2019-20 till FY 2024-25. Broadly both the schemes achieve demand promotion through offering demand incentives and extending charging infrastructure to end users. Moreover, there is provision for information dissemination, education, and communication to society for further promotion of EV use. Total fund allocation provided for the schemes was INR 795 crore and INR 10,000 crore among which maximum fund allocated to offer demand incentive to end users in procuring 2-3 wheelers by paying it to OEMs and reduce upfront cost of the vehicle. In the same line 19 states prepared EV Policies to offer incentive, subsidy, and exemptions over Motor tax, registration charges, Permit fee etc.

Economic Times link [9] has details of targets set by GoI to achieve electrification of different category of vehicles by 2030.

Singh, S. et al (2017) [10] stress need of conversion of a Conventional Vehicles (CV) to electrical vehicles (EV) to offer smart public transport for Indian cities under smart city Mission (SCM). The paper highlights that every solution for converting different categories of CVs is smart and sustainable using industry 4 solutions. Authors are of a strong belief that the conversion mitigates concerns of people towards cost and arrive at a kit design which ensures optimization of cost and performance. The statistical data regarding fuel saved, carbon credit acquired per one conversion is supplied in the paper.

AISC, MoRTH, [11] AIS-053 categorizes various types of vehicles into L, M, N categories and places e-auto into L5M category.

Kumar, P. and Chakraborty, S. (2020) [12] explain concept of Total Cost of Vehicle (TCO) in deciding economic viability of various vehicles in their electrification. Based on Annual Km Travel (AKT) and considering Capital Expenditure (CPEX), Operation Expenditure (OPEX) and life of vehicle they calculated TCO of 2 wheelers, 3wheels, 4 wheelers and buses per kilometer. It helps in analyzing how e-auto are financially economical solution by comparing its TCO with that of petrol, diesel and CNG auto rickshaws and give the AKT =110 km/day and 40000km/ day as an economically viable in adopting e-auto. The paper explains the way incentives, subsidy, exemption etc. reduces TCO of EVs and helps in their faster adoption.

Ramachander, A. et al (2015) [13] conducted study of financial well-being of auto rickshaw drivers- owners with Bangalore city as a case. As per them auto rickshaw drivers are either owners or those operate it by taking it on rent. Due to a socio-economic condition majority of them earn just enough to meet needs and savings are insufficient to go for another vehicle. So, for them procuring e-auto is distant dream.

Badami, M. G. et al (2016) [14] provide policy framework by integrating auto rickshaw users and public perspectives with that of driver operators. The framework suggested by them comprises of open permit system, improved access to formal credit sector, timetable for regular fare revision, and phasing out 2-stroke auto rickshaws. Authors highlight many odd things about rickshaw business which keeps drivers handicap and making ownership of auto rickshaw difficult for them.

Hofmann, T. et al (2009) [15] selected Bajaj RE 2 stroke petrol engine Auto rickshaw for a modeling. It helped us in selection of a model in this project. As per authors testing is essential in optimizing performance of any retro fitment kit.

Nambiar, A. V. et al (2019) [16] described criteria for economic conversion of conventional engine auto rickshaw into e-rickshaw. The focus of this paper is to build a retrofit prototype of an e rickshaw and test its performance. As per authors newly designed e-autos are expensive, and drivers must discard old rickshaw and spend money to buy new one. But in conversion they need not spend more money. The paper confirms that retrofitting of the conventional vehicles by keeping all other things as it is and replacing IC engine power train by Electrical power train with 1.5 kW, 48 V, 32 Ah, 3000 rpm BLDC motor as a prime mover within Rs 50000.00 expenditure.

Gawade, S. et al (2019) [17] explain in this paper that tuning Constant variable Transmission (CVT) and any multi speed transmission in general can be of help in optimizing performance and cost of electric power train for an auto. As per the paper electrical powers train with 48 V, 3000 rpm, 1 kW BLDC motor coupled with appropriate transmission is sufficient for Bajaj RE auto rickshaw conversion.

Patter, K. B. et al (2018) [18] explained a methodology for retrofitting electric power train/ drive train in conventional power train based three wheelers. A step-by-step methodology proposed is 1) To develop real world drive cycle for auto rickshaw using micro trip and data logger systems (used VBOX 3i equipped Bajaj 4S CNG RE auto rickshaw) 2) To estimate optimal motor power requirement using simulation software (MATLAB is used) 3) To select a motor, its controller, and a traction battery

Centre for Battery Electric Vehicle (C-BEEV), Indian Institute of Technology, Madras (IITM) [19] offered a method of using of a spreadsheet to calculate energy consumption of three-wheel EV and any EV in general based on a driving cycle recommended by AIS-039.

Warner, J. [20] explains design of a battery pack from knowing energy requirement of a vehicles for a given range.

Dalvi, G. and Pharande, V. (2021) [21] provide procedure for designing and selecting REESS for a conversion kit.

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Loganathan, M. K. et al. [22] provides Multi-criteria Decision Making (MCDM) based procedure in selecting low cost and optimal energy capacity battery for EV conversion.

Santhanagopalan, J. (2015) [23] offers design analysis of large lithium-ion battery systems with mathematically modeling of everything about cells and packs. It is the extensive literature that helped us in designing and revising out battery pack for E-TAR

Sreejith, R. and Rajagopal, K. R. [24] explains procedure for selection of battery and motor based on power, torque and energy requirement of a vehicle.

Vashistha, V. et al. [25] helps in selection of a Brushless Permanent Magnet Direct Current (BLPMDC) motor due to its advantages Mishra, P. et al (2013) [26] provide optimization criteria of power rating of a motor

Gorantla, S. et al. (2018) [27] helps in Modification of drive train for EV conversion

Mehta, R. et al (2014) [28] explain conversion of a CNG powered Auto rickshaw into an electrical rickshaw and insist that modular design, short range, and low speed operation of auto rickshaw makes it ideal candidate for electrification and for use of battery swapping technology. To make it affordable to existing rickshaw driver-operators, authors stress needs of considering constraints viz. cost, sizing and dimension and safety in designing a conversion kit. In the kit a chain drive used between a motor and a differential to transmit drive to wheels.

Automotive Industry Standard Committee (AISC) [29], drafted Automotive Industry Standard (AIS) viz. AIS-123 for designing and testing various motor vehicles being sold by OEMs in India for Ministry of Road Transport and Highways (MoRTH), GoI. This and other associated standards not only help in providing criteria for Type Approval (TA) for new vehicles before their launch but also for analyzing their performance. In general, there are procedures, equipment, range described in them

AVSC, BIS. IS 11825:1986 [30] Method of Weighment of Automotive vehicles. New Delhi: Bureau of Indian Standards, 1986.

AISC, MoRTH, GoI [31] provides procedure for measuring starting gradeability of any motor vehicle in India.

Retro-fitment of auto rickshaw has been studies by various authors and organizations with different objectives and under different circumstances. Many have studied conventional auto rickshaw and their drawbacks and necessity of replacing them by E-autos for achieving energy security and reducing urban issues related to pollution created. The process of designing requisite retro fitment kit in the form of electrical drive train, fitting it on a target auto rickshaw and testing such retrofitted E-auto is explained by different authors. Literature related to different E-three-wheeler manufacturers and assemblers, retrofitter is also studied along with research papers related to auto rickshaw transport and about socio economic conditions of rickshaw drivers.

As per literature surveyed the gap noticed is as follows: -

1. Electrification of auto rickshaw is vital [1] for ensuring energy security and reducing urban pollution and related issues.
2. Despite of providing substantial demand incentives to reduce upfront cost of E-auto over last 6 years e-auto adoption is not up to the targets set.
3. Socio economic condition of drivers is poor to bear TCO of new e-auto and e-rickshaw even under all sorts of incentives, concessions, exemptions, and retro fitment with an optimized kit can further lower TCO to enable existing auto drivers to adopt e-rickshaw.
4. Large number of units in Operation (UIO) with remaining life more than 6 years are 3 million auto rickshaws, that currently operating in country, can be converted in e-auto/ e-rickshaw.
5. Retro fitment kit to convert C-TAR into E-auto/ rickshaw, designed towards performance and cost optimization, shall lower TCO of electrification
6. Fast-paced Electrification of auto rickshaw up to mark is possible through retro fitment.
7. Performance Analysis of a retro-fitment kit essential for its optimal cost and performance

As per gap analysis it is essential to develop low-cost retro kit, fit it to conventional auto rickshaw, test it for optimal performance, refine the kit using few interactions and validating final kit. It will help in faster adoption of e-auto.

2. RATIONALE FOR A PROTOTYPE DEVELOPMENT USING A RETRO-KIT

Prototype is an E-TAR which is an electrical version of a C-TAR and categorized [11] as L5M. This vehicle is designed from scratch by seven OEMs as per Table 2 and is being sold in our country to attain target of adoption of e-three wheelers. Moreover, other types of three-wheel vehicles viz. e-rickshaw, e-card and L5N are being produced and sold to increase share of e-three-wheeler registration as per the table 2. These models, being FAME approved, are eligible for demand incentives [7], concessions and exemptions from national and state governments and therefore upfront cost [6] to procure them is less. Despite of this fact the sale of three wheelers and an E-TARs, also referred as e-autos is less and not as per target set.

In our country C-TAR is being produced from late sixties when Bajaj Auto Ltd. (BAL)- a major OEM producing it, got a permission of producing it in collaboration with Piaggio company of Italy. This vehicle witnessed many transitions over the years and now seven OEMs of Indian origin produce and supply it with similar designs not only to Indian customers but also in many Asian countries around. Indian market witnessed its huge popularity and over last two decades 2-3 lakh units have been sold by all the OEMs every year. At present as per the Vaahan Portal of Ministry of Road Transport and Highways (MoRTH), GoI there are more than 5 million C-TAR are in operation among which 2 million are with age more than ten years and remaining 3 million have a remaining life between 5 years to 15 years based on their year of registration. This many UIOs are the first aspect which slows down process of the electrification and can be used to increase a pace through their conversion using a low-cost but optimally performing retro-kit by developing it systematically.

As per Kumar, P. and Chakrabarty, S. (2020) [12] economic viability of a motor vehicle depends on Capital Expenditure (CAPEX) to procure it and on Operational Expenditure (OPEX) which it requires over its lifetime. In case of ICE vehicles though

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CAPEX is less, expenditure over fueling and maintenance is more, and it further increases with market fluctuation of fuel prices. While Capex of EV is more and OPEX for charging and maintenance is less due less electricity charges and a smaller number of parts in drive train as compared to ICE vehicles. Despite of this fact about EVs, they contain a battery as a Rechargeable Electrical Energy Storage System (REESS) which has almost 40-45% of the cost of EVs and it requires replacement as per its cycle life. Under such background it is required to assess the viability of EVs using a concept called Total cost of Ownership (TCO) - an understanding of true cost of buying goods or services over its useful life.

As per this analysis [12] calculated TCO over useful life and then per km of travel. As per Kumar, P. and Chakraborty, S. the value of TOC/km of electrical L5M remains Rs 1.97 per km which is less as compared to that for petrol, diesel and CNG 3 wheelers for 40,000 Km of Annual Km Travelled (AKT) (110km/day) and over its' useful life of 10 years under certain conditions assumed. The paper emphasizes further that by reducing CAPEX of e-rickshaw and increasing utilization it is possible to enhance economic viability of procuring e-three-wheeler and hence E-TAR for auto rickshaw operator-driver.

As per Ramchander, A. et al (2015) [13] and Badami, M. G. et al (2016) [14] socio-economic conditions of auto rickshaw drivers is not good and further due to other aspects of their profession like blackmailing due to controlled permit policy, traffic cases filed over them, biased perception about an auto rickshaw as mode of transport among Ministry of Urban Development, public, users etc., non- regular and haphazard policy of revision of fares, high cost to revenue ratio of operation, it unlikely to place them and their families above poverty line. Based on this it can be concluded that with existing TCO of new e-auto and e-rickshaw, the existing and prospective rickshaw operators are hardly convinced to procure them. It is required to further lower it by reducing CAPEX of e-auto which is possible by retrofitting their existing rickshaw to EV using a scientifically and systematically designed and developed retro-kit. And for doing so it needs performance analysis of e-auto rickshaw developed using a retro kit.

3. PROJECT METHODOLOGY

3.1 PROBLEM STATEMENT

A fast-paced electrification of an C_TAR as per Thakur [2] is vital for Urban Transport system of India. Despite of huge investment under FAME I and FAME II an adoption of e-auto is relatively slow. Major hurdles in the adoption are- high cost of e-auto, lack of charging infrastructure and lack awareness about alternate charging arrangement, uncertainty about life of a battery and cost of its replacement, High Total Cost of ownership (TCO) in operating new e-auto, and socio economic condition of auto rickshaw driver–operator. Under such circumstances it is essential to offer an affordable solution with minimum TCO. E-rickshaw has emerged as one of the solutions on the basis, but it has some other issues. One more solution is retro fitting an UIO available with auto rickshaw driver- operators with optimally developed retro kit, where CAPEX is further low. It is a sustainable solution which can achieve fast-paced electrification of auto rickshaw by using its body, Chassis, other vehicle systems and replacing an ICE power train with an Electrical power train.

3.2 PROJECT OBJECTIVES

The Project Objectives are as under: -

1) To select a make and a model of auto rickshaw for conversion using a retro kit
2) To design and develop the retro kit considering cost and performance optimization
3) To retrofit the auto rickshaw with the kit developed
4) To analyze the performance of retrofitted e-rickshaw
5) Organization and implementation of the project work

3.3 PROTOTYPE DEVELOPMENT

As per the project title an outcome of the project is a gap between desired and actual performance of e-auto with a given development cost. To get this gap, we need to go backward and test a retrofitted e-auto, for this we need the properly developed retrofitted auto, and it is possible to get a retrofitted e-auto if we have properly designed retro fitment kit to fit in the conventional auto selected. Based on such backward planning the complete project work has been organized in completing this project. The step-by-step execution of the project work is as under: -

3.3.1 Selection of Conventional Unit (auto rickshaw) in Operation:

As stated earlier there are six major OEMs who manufacture conventional auto rickshaw. Among them majority produce an auto rickshaw with D+3 seating capacity and only Scooter India Ltd (SIL) supplies the auto with 1+6 capacity. All of them are producing all the four fuel viz. Petrol, Diesel, CNG and LPG auto rickshaws and with Rear Engine Rear Wheel Drive Layout. The of OEMs is as given below: -

a) Bajaj Auto Ltd. (BAL)
b) Piaggio Vehicles Pvt Ltd. (PVPL)
c) TVS Motors Company Pvt Ltd. (TVMCPL)
d) Mahindra & Mahindra (M&M)
e) Atul Auto Ltd (AAL)
f) Scooter India Ltd. (SIL)

Based on certain criteria given under AIS-123, a standard for retrofitting an auto rickshaw, a model manufactured by Bajaj Auto Ltd Manufacturing Year (MY) 1996 is selected. It is a 2 stroke, air cooled, Naturally Aspirated (NA), petrol, Rear Engine auto rickshaw. The detailed specification of the auto rickshaw (Hofmann, T. et al 2009) [15] selected is given in Table 5.

The vehicle selected is the rear engine rear wheel drive vehicle equipped with a 2 stroke, single cylinder petrol engine mounted on a transaxle. It is possible to dislocate this engine from the transaxle easily and an electrical power train can be fitted to it by making certain modification as per Nambiar A. V. et al (2019) [16]. In replacing engine, we must remove all associated parts viz. parts of Induction, Exhaust, Ignition, cooling, etc. systems along with cylinder head, cylinder block, piston, crank shaft etc. of the engine. There is no need to change other systems of the vehicle selected.

3.3.2 Design and Development of Retro-kit:

Here a retro-kit to be designed and developed is nothing but development of an electrical drive train (EDT). As stated earlier any drive train comprises of a power train and a transmission system connected to supply power and energy to driving wheels. As per Gawade, S. et al (2019) [17] use of multi reduction transmission reduces motor power and torque requirement and helps in optimization of performance of electric power train. Taking it into consideration it is decided to keep entire transmission same in developing the electrical drive train. Therefore, in designing EDT we are required to identify energy requirement for the auto rickshaw for running a km distance and based on range in Kms expected the energy capacity of battery.

Table 4. Detailed Specification of Bajaj RE Auto Rickshaw (MY 1996)

Name of system	Specification	Figures
Engine	Single Cylinder, 2 Stroke, naturally aspirated, Forced draft air cooled Petrol engine	145 CC, 5.15 kW @5000 rpm, 500 Nm @ 5000 rpm
Transmission	Transaxle with Multi plate wet clutch, Gear box, differential, and half shafts	4 forward 1 Reverse Gear Box with ratios 0.2, 0.34, 0.54 and Back axle ratio 0.89
Chassis and Body	Semi-integral construction with a body, soft top	Unladen Weight in kg 277 Payload in kg 333 GVW in kg 610 Coefficient of Drag (Cad) 0.5 Coeff of Rolling Resistance (Cr) 0.0011 Frontal Area (Af) 2.52 Gradeability (%) 12
Electrical	Magneto Electrical system with a manual (lever) start	12 Volt,
Vehicle systems	Hydraulic Drum Brake @ F&R Trailing link front and rear suspension Handle Steering with controls	Suitable and efficient for e-auto also

3.3.3 Identification of Energy Consumption of the Auto Rickshaw: Considering cost and performance optimization as a main criterion following assumptions are made in identification of energy consumption: -

a) Max. speed of auto rickshaw 25 kmph
b) Range of the vehicle 55 Km
c) Velocity of air 5 km/hr.
d) Gradeability 5^0
e) Driving cycle used IDC as per AIS -039

Based on the assumptions made and the specifications of the Chassis and Body of the selected auto rickshaw quoted in Table 5 the power and energy consumption is calculated using Theory of vehicle dynamics [18] (Patter, K. B. et al 2018) and by preparing a spread sheet for 3-wheeler using Indian Driving Cycle (IDC) data [19] are used in it. The values of resistive forces viz. Aerodynamic drag, Force due to rolling resistance, Force due to Gradient resistance, Force for vehicle acceleration which the auto rickshaw experience, power consumed over Indian driving cycle along with energy consumption are as per Table 6.

As we are using a four-speed gearbox with ratios 0.2, 0.34, 0.54 and 0.89 and back axle ratio of 0.24 we consider energy consumption on leveled road in designing battery/ REESS and selecting a traction motor and its controller.

Table 5. Details of Resistive Forces and Calculation of Vehicle Energy Consumption

Sr. No.	Entity	Unit	Value
1	Force due to aerodynamic drag (Fad)	N	4.8323
2	Force due to rolling resistance (Fr)	N	77.79
3	Force due climbing resistance (Fg)	N	625.51
4	Force for vehicle acceleration (Fa)	N	M x a
5	Tractive force (FTract) with zero gradient	N	82.6223
6	Tractive force (FTract) with 12% gradient	N	708.1323
7	Power required Ptract for zero gradient	W/ Nm/s	573.77
8	Power required Ptract for 12% gradient	W/ Nm/s	4917.59
9	Energy consumed over IDC on leveled road	Wh	21.067
10	Energy consumption on leveled road	Wh/Km	32.017
11	Battery Energy Capacity for 55 km range on zero grade	Wh	1760.94
12	Energy consumed over IDC on road with12% grade	Wh	43.7499
13	Energy consumption on road with 12% grade	Wh/Km	66.4829
14	Battery Energy Capacity for 55 km range on road with 12% grade	Wh	3656.55

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3.3.4 Design of Battery: Energy required for getting desired range of vehicle is the basis of deciding energy capacity and designing Rechargeable Electrical Energy Storage System. (Warner, J. 2009) [20, 21] For the selected auto rickshaw with 55 km range and using gearbox reduction (Gr) and Back axle reduction (Ar) a battery capacity can be optimized using multi criteria decision making [22, 23]. As per table energy capacity required is 1760.94 Wh (1.76 kWh). Considering an ideal condition as far as transmission efficiency of 100% and use of battery energy as 100% SOC the battery design is carried out and REESS specification is as per table 7.

Table 6: REESS Specifications

Sr No	Particular	Quantity
A	Requirement of REESS	
1	Energy capacity in kWh	1.76
2	System voltage in Volt	48
3	Current capacity of battery in Ah	36.67
B	Cell Specification	
1	Make	
2	Chemistry	LiFePO4
3	Form Factor	32650 Cylindrical with Φ 32 mm x 65 mm
4	Voltage Nominal/ peak/ Minimum	3.2/3.65/ 2.8
5	Current capacity in mAh	6000
6	Weight in gm	0.141
C	Battery Pack Design	
1	Configuration	6P15S
2	No of cells	90
3	BMS	LiFePO4 15 S 48V with 60 A charging/ discharge current
D	Battery Charger	CCCV 5Ah current and 48 V slow charger
E	Charge & discharge socket	As per amperage
F	Manual Cut out	Two level 60 Ah

3.3.4 Identification Traction motor and controller: After having identified system voltage and knowing torque requirement a traction motor and corresponding motor controller is identified. Among various motor available and their relative advantages and disadvantages (Vashistha, V. et al 2020 and Mishra, P. et al 2013) [24, 25, 26] and further using benchmarking of selection of motor for this operation both from field and quoted in literature surveyed [10, 16, 18] a Brushless Permanent Magnet Direct Current (BLPMDC) motor is selected for the EDT. To achieve cost and performance optimization the BLPMDC motor with the specification given in Table 8 is selected.

Table 7: Specification of Traction motor Selected

Sr. No.	Description	Values
1	Make	Swiss
2	Identification No	SAP-1851AB
3	Nomenclature	BLDC
4	Rated Voltage	48
5	Rated power	1000 W
6	Rated speed	3000 rpm
7	On load max torque	>220 Nm
8	Rated current	26 A
9	No load current	<4.5 A
10	Running current	12-15
11	Operating Temperature	-20^0 to 100^0c
12	Weight	4.9 Kg
13	Wire length	1250

Table 8: Specification of Motor Power Controller

Sr. No.	Description	Values
1	Make	Swiss
2	Identification No	SAP-0985
3	Nomenclature	BLDC Motor Controller
4	Type	1000W 48 V
5	Rated Max. power	1000 W
6	No of MOSFET	24
7	Voltage range	42-60 V
8	Low voltage protection	42 V
9	Braking system	Electronics
10	Current limit	Programmable up to 50 A
11	Motor Angle	120^0
12	Speedometer	Analogue/ Digital
13	Efficiency	>85%

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14	Enclosure	High grade aluminum 220x120x55 mm
15	Weight	1.5 Kg
16	Hole on hole gap	140
17	Operating temperature	0-50^{0}C
18	Protection	Low battery, Throttle error, hall sensor failure, over current & Voltage, Transition Surge, and theft

Table 9: Specification of the e-Throttle selected

Sr. No.	Description	Values
1	Product make	Prakash
2	Identification No	D6
3	Nomenclature	Double switch electronic throttle
4	Operating Voltage	0.8 -4.1 V
5	Technology	Hall sensor

3.3.5 Design and production of Modified clutch shaft and Motor Mounting Bracket: The retro kit which is EDT in which the Electrical Power Train (EPT) comprises (Mulhall, P. et al 2010, Nambiar et al 2019, and Gorantla, S, et al 2018) [27] of a traction motor, a motor controller, a SOC display cum speedometer, an Electronic Throttle, Power key switch and REESS and cables/connectors/ fasteners/ a bracket/ a coupler which put them together to act as an electrical power train. The block diagram of E-DT with a transaxle and an EPT given in Fig. 1

In the given block diagram connections among various units are mechanical, electrical, unidirectional, and bidirectional in nature (Mehta, R. et al 2014) [28] For example TA and TM are connected mechanically using a coupling and a motor locating bracket. TM and MC are connected using cables and connectors to supply electrical power to TM and signals from TM sensors to MC. MC is connected to REESS for receiving DC power to convert it into AC power. Moreover, MC is connected to units viz. Power switch, electronic throttle, SOC Indicator cum speedometer, and Malfunction Indicator Lamp (MLI). Also, REESS is connected to battery charger during charging and to various gadgets like cell phone, vehicle

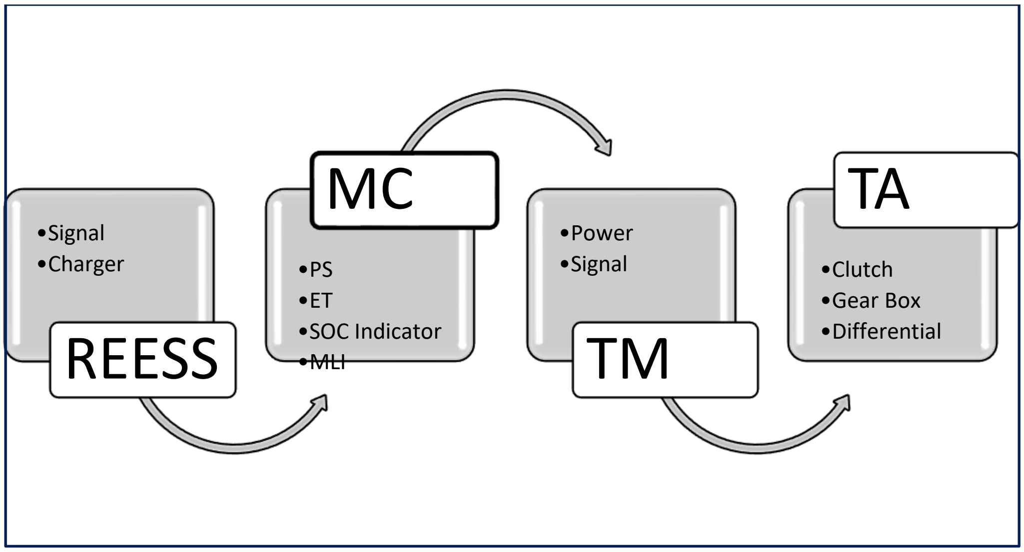

Fig. 1. Block Diagram of Electrical Drive Train

(Legends: MC- Motor Controller, TM – Traction Motor, TA- Transaxle, PS –Power Switch, ET – Electronic Throttle, SOC State of charge, MLI – Malfunctioning Lamp Indicator)

control Unit, and so forth for certain smart functions.

Two parts are designed and manufactured for connecting the traction motor to the transaxle namely a modified coupler cum clutch shaft and a Traction Motor mounting bracket. Other electrical connectors, cables, sockets, MCB, are procured from market as per need.

Retro Fitment of e-Auto: As the kit [28] comprises of many parts among which TA is mounted on its mounting and all are designed and developed systematically a retro fitment of e-auto is easy task. Part wise location given in table 11

Table 10. Code of Practice [29] for Fitment of Electric Power Train Kit

PART	LOCATION	INSTRUCTION IF ANY
Transaxle	Rear side on TA mounting	Engine and TA are mounted on same mounting located on frame of an auto rickshaw
Traction Motor	On Magneto side crankcase using a L shape Bracket	L-shape bracket is located using engine stub 4 tapped holes, Motor is fasted to a vertical bracket arm
Traction Motor Shaft	Inside crank case using RH crankcase bearing and fitted to a coupler of a modified clutch shaft	This is critical assembly which needs to do carefully with respect to balancing
REESS & Motor controller	Behind passenger compartment inside battery casing rigidly fitted to auto rickshaw body portion behind passenger seat.	Battery Box is fixed to a portion of pace available keeping a place for fitting motor controller on one side
E-Throttle, Power switch, SOC indicator cum speedometer	On handlebar and dashboard of auto rickshaw	Using proper gauge cables all three units needs to connect to motor controller terminals and socket and guiding them through conduit for safety and protection.

3.3.6 Testing, Analysis and Result: For testing performance of this newly developed and a unique kind of retrofitted auto rickshaw the best way is to use standards set in our country by Automotive Industry Standard Committee (AISC) and published on Automotive Research Association of India (ARAI) website. The list of standards considered for deciding testing and analysis in this project are as given in Table 12.

Table 11: List of AIS used for testing Electric Power Train Vehicles

Sr. No.	AIS No	Title of the standard	Performance parameter
1	123 (part 3)	CMVR Type Approval of Electrical Propulsion Kit Intended for conversion of vehicle for pure electrical operation	Vehicle Weighment Coast down Gradeability Electrical range and energy consumption
2	003/1999	Automotive vehicle-starting gradeability	% Starting Grade negotiable
3	039 (rev.1):2015	EPT Vehicles- Measurement of Electrical energy consumption	kWh/ Km
4	040 (Rev.1):2015	EPTV- Method of measuring Range	Distance in Km between successive battery charging
5	041(Rev.1) 2015	EPTV- Measurement of net and max 30-minute power	Electrical Motor power testing

As per non-availability of chassis dynamometer/ data logger and tests required as per project design, road tests are conducted with following variables: -

a) Nature of road – Leveled Road and road with slope (0%, 4%, 8%, 12%,16%)
b) Payload – Passenger weight and luggage
c) Throttle -0-Wiide open Throttle (WOT)
d) Performance of vehicle – Cruising/ acceleration/ retardation/ Negotiating grade

Equipment, instruments, and gauges used are
a) Voltmeter
b) Ammeter –clamp-meter
c) Multimeter
d) Vehicle speedometer
e) Stopwatch
f) Tape meter
g) Dummy load -50Kg

The datasheet [1] is prepared for noting down readings. As per all AIS related to EV and that for e-auto retrofitted it is required to prepare retrofitted e-auto rickshaw [26] for any test using certain steps. They are as under and followed before commencement of testing: -
a) To inflate Vehicle tires to the pressure specified by the vehicle manufacturers
b) To lubricate mechanical parts as per manufacturers' specification
c) To put off auxiliary devices
d) To move vehicle for running in before commencement of testing
e) To follow overnight charge procedure at ambient temperature of 20-30 degree centigrade

The test wise criteria and reading taken about vehicle speed (Max), Time taken, Voltmeter (V), Clamp-meter (A), and distance covered as per table 13.

Table 12: Details of testing retrofitted E-TAR

Test No	Payload in Kg	% Grade	Throttle	Phase A/D/C	Reading taken IN	No of reading
1	141	0	1	A	1st, 2nd 3rd and 4th gear	12
2	141	0	¾	A	1st, 2nd 3rd and 4th gear	12
3	141	0	½	A	1st, 2nd 3rd and 4th gear	12
4	141	0	¼	A	1st, 2nd 3rd and 4th gear	12
5	191	0	1	A	1st, 2nd 3rd and 4th gear	12
6	191	<16	1	A	1st, 2nd, and 3rd gear	09
7	191	>16	1	A	1st, 2nd, and 3rd gear	09
8	141	>16	1	A	1st, 2nd, and 3rd gear	09
9	141	<-16	1	C	3rd and 4th gears	06
					Total readings	84

The objective of this project is to reduce Total Cost of Ownership (TCO) [12] of e-auto through refining a retro fitment kit in terms of optimal performance at lower cost. It is not possible to get there in one go but it required more interaction to reach this destination. Analysis of the retrofitted e-rickshaw as described before is a first step towards that and journey may continue till a retro kit with optimized design develop. That juncture will start fast-paced electrification of auto rickshaw and equally fast reduction in urban pollution of many cities.

4. DATA COLLECTION, COMPILATION, ANALYSIS AND RESULTS

All test data collected using data sheets are compiled using spreadsheet and analyzed [29] through comparison and graphs.

4.1 WEIGHMENT TEST [30]

Unladen Weight (ULW) of retrofitted rickshaw 260 kg taken on way-bridge at Anewadi toll plaza with necessary steps suggested under ref. [30].

Comparison with e-three-wheel passenger vehicles from selected Indian OEM - Table 14 shows comparison of retrofitted electrical auto rickshaw with those produced by Piaggio Vehicle Pvt. Ltd. (PVPL), Mahindra Electric Mobility Ltd. (MEML), and Kinetic Green Energy and Power Solutions (KGS&PS)

Table 13: Comparison of Retrofitted E-TAR with Three-wheel EVs of OEMs

ATTRIBUTES/ OEM	PROJECT	PVPL	MEML	KGE&PS
Model	First	Ape City	Treo	Safar
Vehicle category	L5M	L5M	L5M	e-Rickshaw
Seating Capacity	D+3	D+3	D+3	D+4
GVW/ ULW	593/ 333	689/389	/377	679
Transmission	Transaxle	Constant mesh integrated differential	Direct drive,	E-axle
Battery Type	Li Ion	Li Ion	Li Ion	Li Ion
Specification	1.7kWh, 48V,15 kg	7.5 kWh, 51.2 V,	6.5 kWh, 48 V,	4 kWh
Traction Motor				
Type	BLPMDC		BLDC	BLDC
Specification	1 kW, 48 V	5.4 kW,	8kW	1.2 kW
Energy consumption/km	32	110	56.69	
Range in km	55	80	130	100
Top speed in kmph	35	45	55	
% Gradeability	12	19	12.7	10.2
Warranty in months	36	36	36	36
Cost in Lakh	**0.83**	**3.41**	**3.71**	**1.64**

5.2 ACCELERATION TEST

These tests are conducted on leveled surface mostly within college premised. Five tests are conducted under this category where for initial four tests throttle is varied from 0.25 to 1 (WOT) and payload is kept same (141Kg) while last test is conducted by increasing payload to 191Kg and only for WOT. Here in all of them the vehicle is accelerated from zero speed to maximum speed with different throttle opening over 37.6 meters.

Test No 1: This is the first test among five conducted within Institute premises on a pavement. To take readings two persons having total weight of 141 kg boarded on the vehicle. The test is conducted with full throttle.

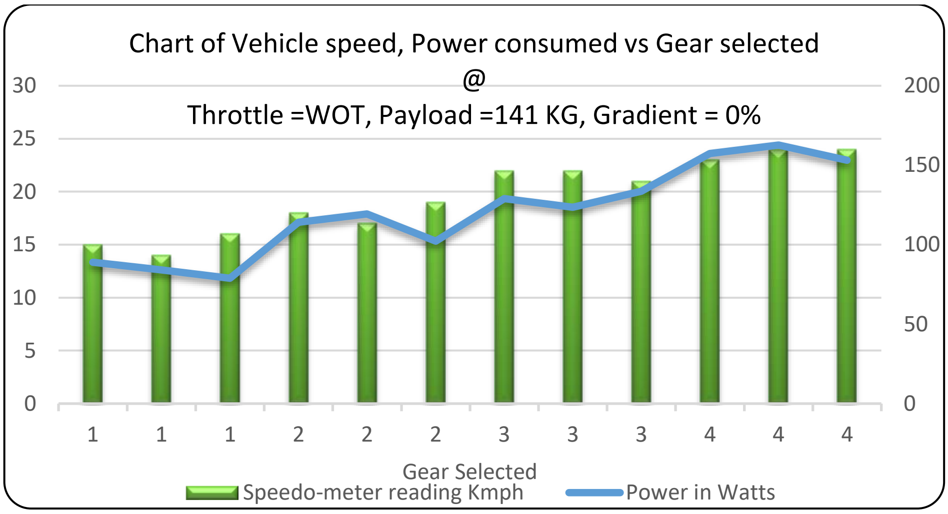

Fig. 2. Chart of Gear selected vs Vehicle speed and power consumed

Analysis as per chart no 1 is -Speed of vehicle increases with the gear charge from 1st gear to 4th gear. There is a positive correlation among the vehicle speed and the power consumed [31]. Average speeds attained in first, second, third and fourth gear are 14, 18, 23 and 24 respectively.

Test No 2: This test is conducted with ¾ throttle keeping other variables same as those in test no 1.

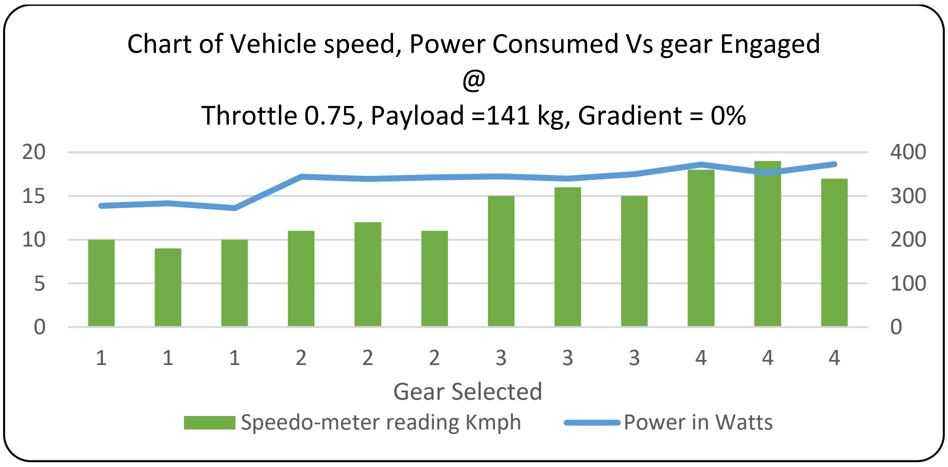

Fig. 3. Chart of Gear selected vs Vehicle speed and power consumed

Analysis as per chart no 2 is -Speed of vehicle increases with gear charge from 1st gear to 4th gear but it is less due to 3/4th throttle. There is a positive correlation among the vehicle speed and the power consumed. Average speeds attained in first, second, third and fourth gear are 10, 12, 16 and 28 respectively.

Test No 3: This test is conducted with 1/2 throttle keeping other variable same as those in test no 1.

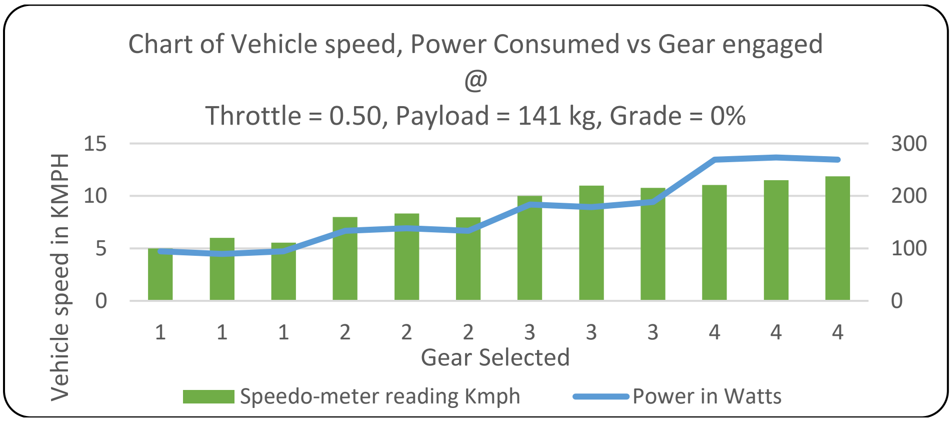

Fig. 4. Chart of Gear selected vs Vehicle speed and power consumed

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Analysis as per chart no 3 is -Speed of vehicle increases with gear charge from 1st gear to 4th gear but it is less due to ½ throttle. There is a positive correlation among the vehicle speed and the power consumed. Average speeds attained in first, second, third and fourth gear are 5.5, 8, 11 and 12 respectively.

Test No 4: This test is conducted with ¼ throttle keeping other variables same as those in test no 1.

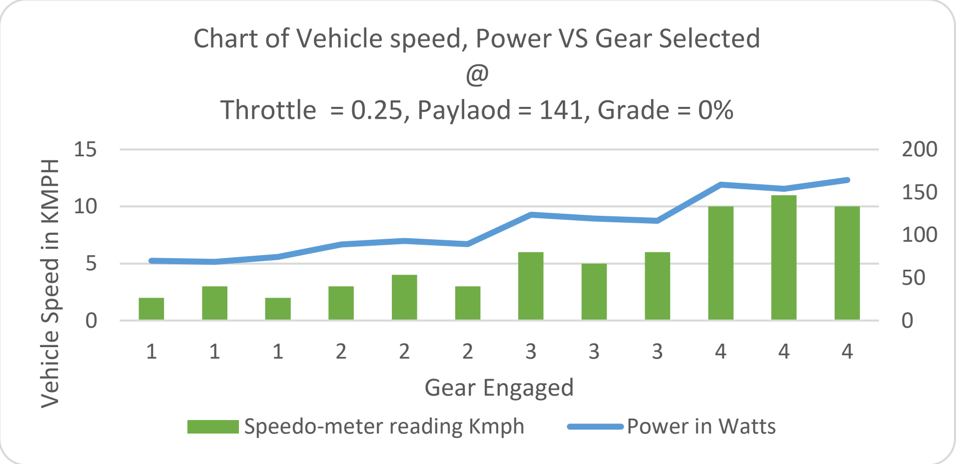

Fig. 5. Chart of Gear selected vs Vehicle speed and power consumed

Analysis as per chart no 4 is -Speed of vehicle increases with gear charge from 1st gear to 4th gear but it is very less due to 1/4 throttle. There is a positive correlation among the vehicle speed and the power consumed. Average speeds attained in first, second, third and fourth gear are 3, 4, 5, and 10.5 respectively.
Test No 5: This test is conducted with WOT and the payload of 191 kgs by putting dummy load on the vehicle keeping gradient 0% as it is.

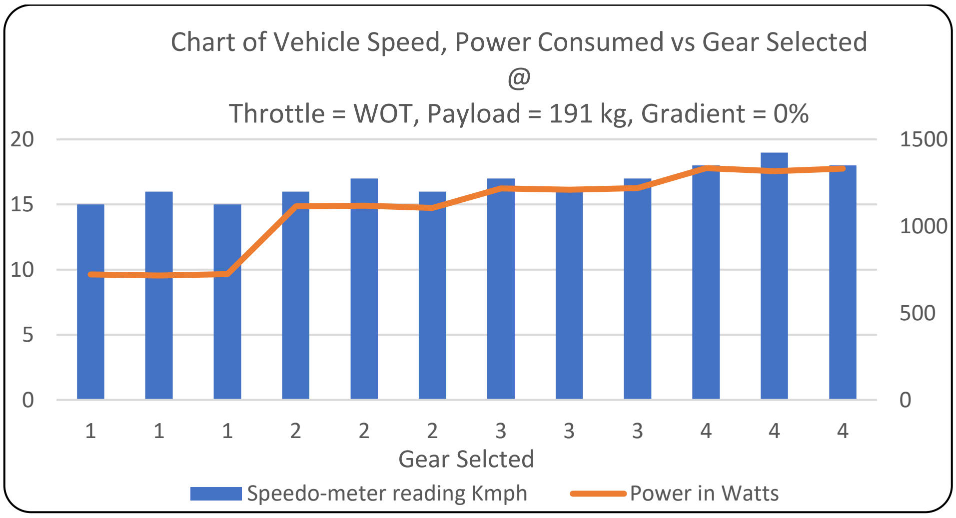

Fig. 6. Chart of Gear selected vs Vehicle speed and power consumed

Analysis of chart No 5-By change in the payload a power consumed in attaining max speed has increased and it is 722 W in first gear and 1332 in fourth gear. Relative of the earlier payload of 141 kg the speed of vehicle decreased with max. speed attained by vehicle is 19 kmph.

5.3 GRADEABILITY TEST

The tests are conducted based on [32]. They are conducted on state highway with positive and negative slopes
Test No 6: This test is conducted with WOT and the payload of 191 kgs on the state highway outside institute premises with the gradient < 16% negotiated for climbing in first gear, for descending in second gear and again ascending in third gear.

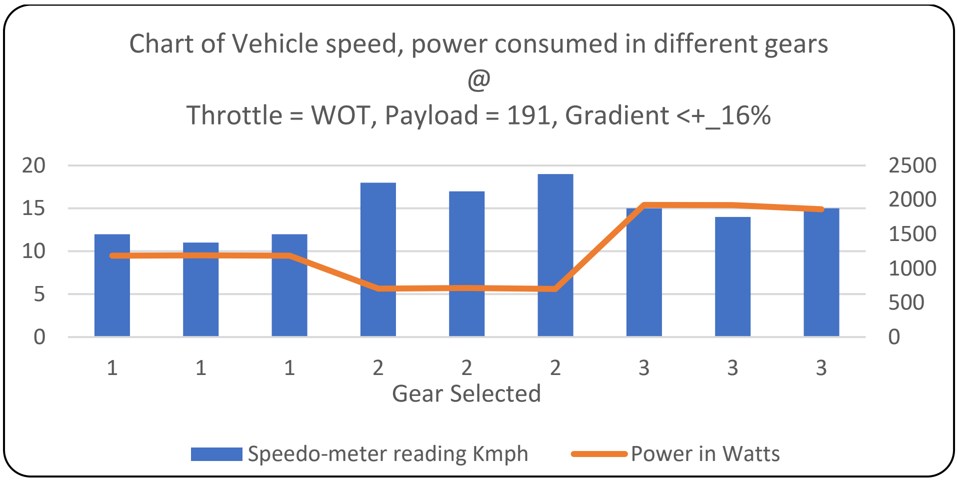

Fig. 7. Chart of Gear selected vs Vehicle speed and power consumed

Analysis of chart no 6-During ascending the grade of < +_16 speed attained by vehicle is less (11 rpm) which has increased with descending the grade. Further for ascending grade speed decreased and power consumed increased

Test No 7: This test is conducted with WOT and the payload of 191 kgs on the state highway outside institute premises with the gradient > 16% negotiated for climbing.

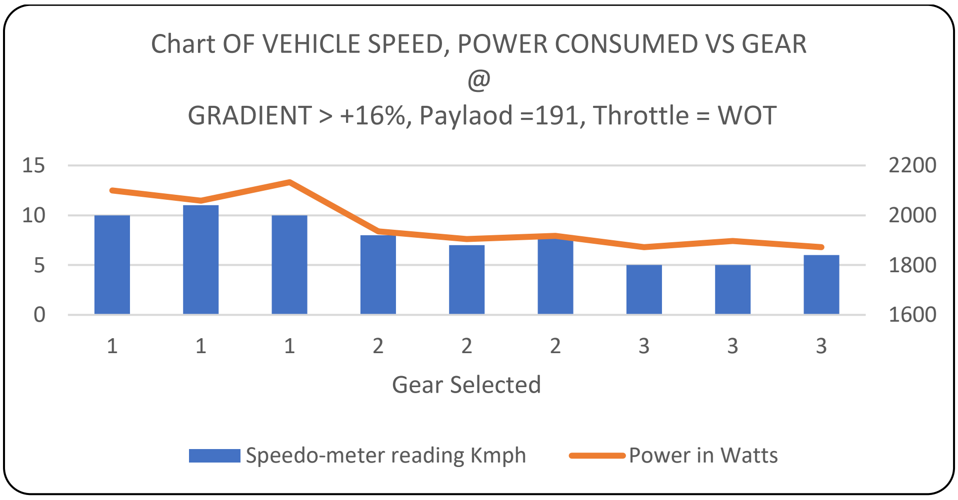

Fig. 8. Chart of Gear selected vs Vehicle speed and power consumed

Analysis of chart 7 -Vehicle did not climb grade in 4th gear due to high payload and greater gradient >16%. Only in first, second and third gear it could climb the grade with higher power 2.1 kW in first gear and minimum power of 1.9kW in third gear.

Test No 8: This test is conducted with WOT and the payload of 141 kgs on the state highway outside institute premises with the gradient >16% negotiated for climbing.

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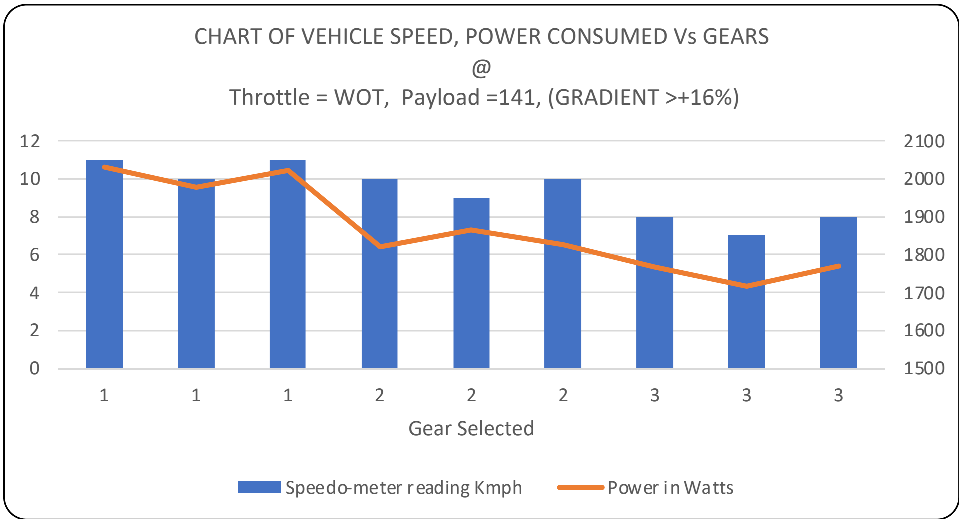

Fig. 9. Chart of Gear selected vs Vehicle speed and power consumed

Analysis of performance based on chart 8- With decrease in the pay load power required to ascend > +16 grade decreased with small increase in the vehicle speed.

5.4 CRUISING TEST

The test conducted down-hill at constant vehicle speed.

Test No 9: This test is conducted while the vehicle going down hill

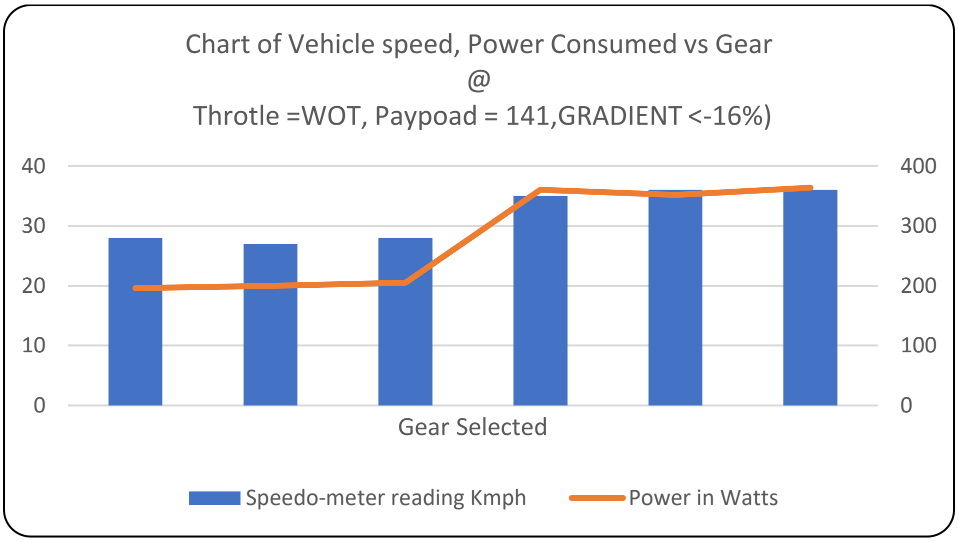

Fig. 10. Chart of Gear selected vs Vehicle speed and power consumed

Performance Analysis of based on the test no 9 as per above chart is -Maximum speed that can be attained while vehicle descending the gradient and speed achieved is 36 kmph. The max. power utilized in this situation is 363.69 watts.

Nine tests are conducted, and data is collected using data sheets. The data then compiled using a spreadsheet and finally results are plotted on charts.

6 CONCLUSION AND FUTURE SCOPE OF WORK

As per the tests conducted, and data collected, compiled, and analyzed following are the conclusions.

1) There is no rise in the retrofitted E-auto vehicle weight, but it has decreased from its ULW by 6.14%.
2) The vehicle converted is like contemporary e-auto rickshaws produced by OEMs. However, cost of conversion including cost of vehicle is 0.83 lac as compared to average on-road cost of 3.20 lakh of e-autos being sold in market. It is 25% of the average cost of OEM e-auto

3) Maximum speed of the converted vehicle is 35 kmph than that of e-auto, due to use of optimization in designing it.
4) Gradeability is 12% and is less than newly designed e-autos and with the motor of 1 kW power and use of 31kWh/km it is appreciable. Use of 4 speed gearbox has overcome the issue.
5) It is required to go for higher energy capacity REESS by increasing its current capacity from 36 Ah to 60 Ah keeping system voltage as 48 V
6) The testing and analyzing E_TAR with its upgradation for little higher motor power and enhancing battery capacity can be analyzed further in the direction of finalizing a retro-kit
7) There are 5 OEMs that produce ICE auto rickshaw and average greenhouse emission from them is 112 gm/km. Due to conversion then into e-auto it will reduce to zero.

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