ISSN 2347 - 3983
Volume 9. No. 8, August 2021
International Journal of Emerging Trends in Engineering Research
Available Online at http://www.warse.org/IJETER/static/pdf/file/ijeter14982021.pdf
https://doi.org/10.30534/ijeter/2021/14982021

Study and Assessment of Propulsion Systems of Three-Wheeled Electric Powered Rickshaw in India

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ABSTRACT

India is one of the prominent manufacturers in the automobile industry with 30 Million of vehicles production rate. Most of vehicles manufactured in India utilize internal combustion power drive methodology. Additionally, pollutions, global warming, conventional fuels exhaustion and loss of building materials are the major concerns associated with IC engine technology. Electric drive technology has the potential to mitigate these issues. Three-wheeled (3-W) battery powered rickshaws/vehicles are primarily employed for public conveyance in the metropolitan cities of India. The motor (propulsion) is a vital component of 3-W battery powered rickshaw. But, selection of appropriate propulsion system for 3-W rickshaw is crucial step. In the present study, an exertion has been prepared to assess the correct propulsion system for 3-W battery powered vehicle in Indian contest.

Key words: Propulsion system, Hybrid electric vehicles, battery system, three-wheeled rickshaw.

1. INTRODUCTION

The internal combustion (IC) engine technology, established for fossil energy, is extensively employed for private and civil service purposes according to work presented in the literature [1]–[6]. The IC engine-based vehicles are the major contributor to the following serious difficulties for the environment and human beings such as: air, water and land pollutions, global warming, depletion of the ozone layer, fossil fuels exhaustion, road congestion, loss of building materials and accidental issues [7]–[10] Therefore, alternative technology is needed to cope up the issues arising from conventional engine technology across the globe such as cleaner electric/hybrid vehicles [11]–[14].

In India, two types "three-wheeled" vehicles are currently in practice for the conveyance of passengers as well luggage. These popular "three-wheeler" vehicles are conventional fuel powered "auto-rickshaw" and electrically powered "battery or electric-rickshaw". Delta type architecture having one wheel at front axle and two wheels at back axle is extensively employed in these vehicles due to less radii of turning [15], [16].

The necessary tractive torque for three-wheeled e-vehicle is provided by the e-propulsion system [17]. E-propulsion system converts the electric energy of batteries into mechanical power [18]. Electric propulsion functions like a heart for EVs and provides the traction power to propel the vehicle in the forward as well as reverse direction [19]–[22]. The propulsion system of the EVs works on bidirectional modes i.e. discharging and charging of batteries. Power converter and electronic controller are the sub-functional units for smooth as well as control operation of the propulsion system [20]. In the modern EVs four types of traction motors i.e. DC motor, Induction Machine (IM), Switch Reluctance (SR) Motor and Brushless DC motor are employed [21], [23]

The most vital powerful system of an electric vehicle is its propulsion (motor) also known as "core" [9]. It imparts required tractive force against moving resistance of the vehicle in forward as well as in backward direction [24]. Electric rickshaws are getting more attention due to its eco-friendly nature, lightweight, less costly and many other operating characteristics over conventional auto rickshaws [25]. Battery rickshaws have the potential to decarbonize the environment and other associated pollution issues for developing country like India [23], [26].

Work related to electric vehicle, hybrid vehicles, pure electric vehicles technology have been published in the literature. However, so far, no effort has been prepared to assemble and modernize the work interrelated to the propulsion system of three-wheeled (3-W) battery/electric rickshaws for Indian prospective. In the present study, an exertion has been prepared to assess the correct propulsion system for 3-W battery powered vehicle in Indian contest.

2. METHODLOGY

The conversation initiates thru the current production rate of conventional vehicles in India including two-wheeler, three-wheeler and four-wheeler vehicles. It is monitored via lessons of various configurations of electric drive technology such as series and parallel hybrid vehicles. Longitudinal and transverse configuration of pure electric motor drive technology is studied. Next, study of mechanical and physical significance for three-wheeled battery powered rickshaw/vehicle has been carried out. Finally, analysis of accurate propulsion system for 3-W battery rickshaw through technical assessments has been performed. In the reference section list of associated documents has been assigned for additional evidence.

3. OVERVIEW OF CONVETIONAL AND ELECTRIC VEHICLES

According to the Society of Indian Automotive Manufacturers (SIAM), the Indian auto industry is one of the largest in the world with a production rate of 30.915 Million vehicles in the year 2018-19. The total production rate of passenger, commercial, three and two-wheelers vehicles for the financial year 2012-13 to 2018-19 is shown in figure 1 [27]. Hence, there is a need to utilize alternative power system technology for the road transportation sector.

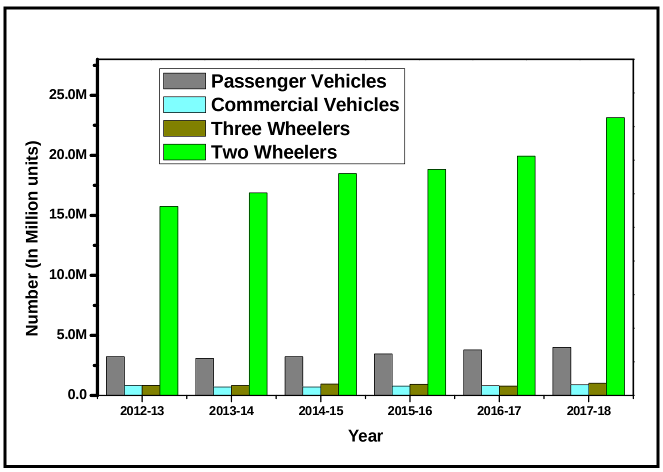

Figure 1. Total Indian automobile production trends

3.1 Electric Vehicles

The concept of an electric vehicle is given by Gustave Trouvé in 1881. In 1900, total 4200 vehicles were sold globally, out of which 38% were electric powered automobiles. In the year the 1990s, General Motors launched EV1, a realistic electric vehicle in the competitive market of the conventional engine vehicle. An electric propulsion system is utilized either partially or completely to provide the necessary traction force in EVs. Battery, ultracapacitors, fuel cell and hybrid system are employed in EVs as an energy storage medium in place of the fuel tank of conventional vehicles. Figure 2 shows the basic layout of the EVs drive with a portable energy resource system.

Hybrid electrical vehicles (HEVs) and Pure electric vehicles or battery electric vehicles (BEVs) are the different classifications of electric vehicles.

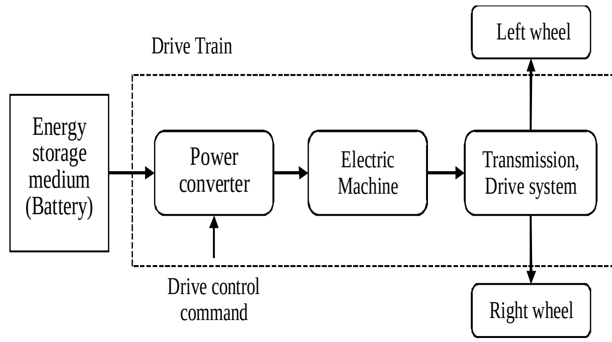

Figure 2. EVs drive system layout

3.2 Hybrid Electric vehicles

A vehicle that has two or more power train is known as a hybrid vehicle, a further hybrid vehicle that has an electric drive train is defined as "Hybrid Electric vehicles". The drive train of HEVs has IC engine drive as primary power train and electric machine drive as secondary power train. Usually, one bidirectional power train is employed with hybrid vehicles to store the regenerative braking energy. Figure 3 shows the energy flow concept for the drive train of a HEVs [28].

There are various operational modes of a hybrid drive train to supply its power to encounter the load requirement:

i) Only power train I supply power to the load.
ii) Only power train II supply power to the load.
iii) Both power train I and II supply power to the load simultaneously.
iv) Power train II receives power from load during regenerative.

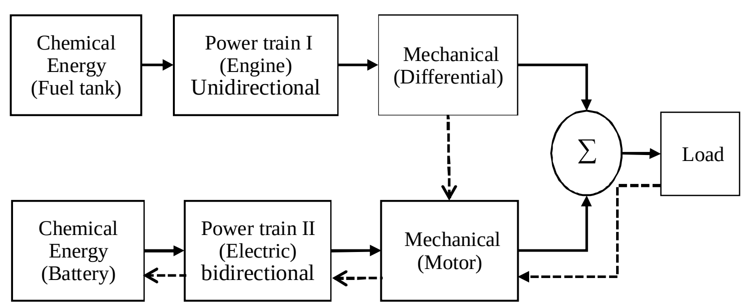

Figure 3. HEVs energy flow concept [28]

3.2.1 Series Hybrid Electric Drive Trains

When mechanical power train I and electrical power train II are coupled into a single electrical drive-train at the merging point, series hybrid drive train or electrical coupling drive train architecture is formed. The fundamental characteristics of a series hybrid drive train are that power converter adds two electrical energy together. The power converter acts as an electrical power coupler in a series hybrid configuration to govern the power flows from the batteries and generator to the electric machine. The electric propulsion system is obtained power from power sources such as battery packs, IC engine and electric generator. Driving range of vehicle can be enhanced by employing engine/dynamo system to charge the batteries.

In the architecture of a typical series hybrid drive train, the engine and generator are mechanically decoupled from driven wheels. Unidirectional power source, the IC engine is connected to the bidirectional traction motor power source. The speed of the vehicle is independent of engine speed and torque. Full electric power mode, full engine power mode, hybrid power mode, battery charging mode etc. are the different operating modes of the hybrid drive train.

3.2.2 Parallel Hybrid Electric Drive Trains

In parallel drive train, both engine power train and electric motor power train supply their mechanical power in parallel directly to wheels through a mechanical coupler. The battery and motor constitute a bidirectional flow of energy like series power train except for the output of the motor is connected to a mechanical torque coupler.

The battery-motor system is employed to improve the fuel economy of the engine in the parallel drive train system. The unique characteristics of the parallel hybrid drive train are that a mechanical coupler combines the two mechanical power sources. Usually, torque coupling is employed in a parallel configuration that combines the IC engine torque and traction machine. After that, total torque is transferred to the driving wheels by the torque coupler [29]. The vehicle controller, motor control, engine control, battery, IC engine, electric motor and mechanical torque converter are the different components of the parallel hybrid drive system. The general's benefit of parallel architecture over the series configuration is given as follows:

i) No need for a generator
ii) Smaller motor compares to series architecture.
iii) Higher efficiency compared to series hybrid configuration.

3.2.3 Series-Parallel Hybrid Electric Drive Trains

Series-parallel hybrid drive trains are also known as electrical-mechanical coupling hybrid power trains. Mechanical and electrical coupling either individually or simultaneously impart traction power to the vehicle. This configuration has torque as well as speed coupling features to overcome the disadvantages of series and parallel electric drive trains [28].

The series-parallel configuration is used in Toyota Prius to minimize the size of the needed IC engine compared to conventional drive trains while providing the optimal performance. Following are the operational modes of the Series-parallel drive train:

i) Speed coupling mode
ii) Torque-coupling mode
iii) Regenerative mode

3.3 Pure Electric vehicles

Pure electric vehicles are advanced and forthcoming technology to eliminate the emissions and pollution of hybrid and conventional vehicles. Electric vehicles refer to vehicles which utilize only the electric motors as a propulsion system and electric machine is driven from electrical power sources. Figure 4 shows the modern architecture of electric drive train with electric propulsion, energy storage and auxiliary as primary subsystem unit [29].

Traction motor, mechanical transmission and power electronics are the different elements of the propulsion system. Energy storage unit consists of a storage medium, refuelling system and management unit for energy supply. The auxiliary subsystem includes a temperature control unit and a power steering unit. Mechanical links are represented by two lines together and electrical by thick dark arrows.

EVs have longitudinal and transverse configurations based on the motor arrangement as shown in figure 5 [29], where M is the traction motor, G is the fixed gearing and D is the mechanical differential.

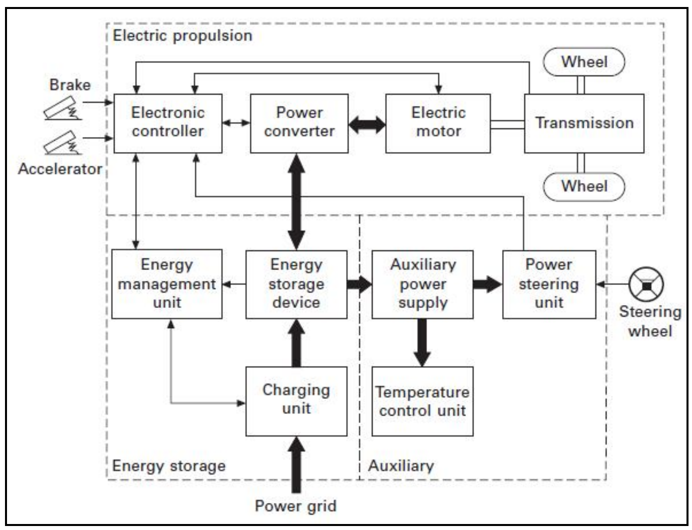

Figure 4. Configuration of modern electric drive train

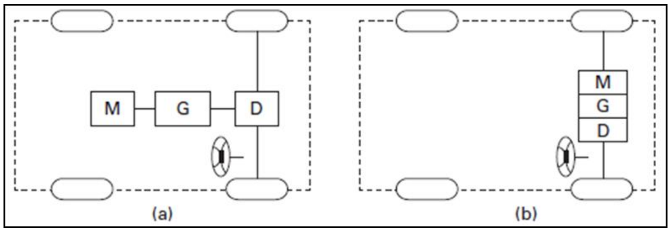

Figure 5. Configuration of the electric propulsion system (a) Longitudinal and (b) Transverse

4. THREE-WHEELED VEHICLES IN INDIA

Currently, approximately 200 registered production divisions are involved for developing industrialized battery operated rickshaw in India as per (ICAT) [30]. The current production rate of three-wheeled vehicles in India is 611171 [31].

Figure 6. 3-W battery powered vehicle (Mahindra Treo) [32]

Top manufacturing brands of three-wheeled (3-W) for conventional fuel powered and electric mobility is shown in table 1. Mechanical body structure of three wheeled (3-W) electric vehicle or battery powered (Mahindra Treo, Lithium-Ion battery powered) vehicle is illustrated in figure 6 [32]. Table 2 shows the mechanical, electrical, electronic and physical constraints of battery powered (Mahindra Treo, Lithium-Ion battery powered) 3-W vehicle. This is the electrical version of conventional fuel powered vehicles which replace IC engine by electric propulsion system. Hence, electric 3-W rickshaws have low carbon emissions at tail point and reduced greenhouse effect. Additionally, 3-W battery powered rickshaws are light in weight and having 100 km driving range per charging.

Table 1. Different manufactures of three-wheeled vehicle in India

S.N.	Brand/Manufacturers of fuel powered 3-W vehicles	Brand/Manufacturers of battery powered 3-W vehicles
1.	Bajaj Auto Limited	Bajaj Auto Limited
2.	Piaggio Vehicles Private Limited	Piaggio Vehicles Private Limited
3.	Mahindra & Mahindra Ltd.	Mahindra Electric Mobility Limited
4.	TVS Motor Company	Goenka Electric Motor Vehicles Pvt. Ltd
5.	Atul Auto Limited	Atul Auto Limited
6.	Lohia Auto Industries	Lohia Auto Industries
7.	Force Motors Ltd.	Kerala Automobiles Limited (KAL)

Table 2. Operating parameters of 3-W vehicle (Mahindra Treo, Lithium-Ion battery powered) [32]

S.N.	3-W vehicle's Parameter	Design value
1.	Battery type	Lithium-Ion
2.	Battery capacity	7.37 kWh
3.	Motor Power	8 kW
4.	Motor Torque	42 Nm
5.	Seating capacity	3+1(Driver)
6.	Driving range	130 km
7.	Wheel base	2.007 m
8.	Overall width	1.35 m
9.	Overall length	2.769 m
10.	Overall height	1.75 m
11.	Turning radius	2.9 m
12.	Kerb weight	377 kg
13.	Max. Speed of vehicle	55 km/h
14.	Gradeability	12 degree

5. PROPULSION SYSTEM OF 3-W RICKSHAWS

Power system of battery powered 3-W rickshaws includes battery, propulsion machine and microcontroller. Therefore, in the present study, an effort has been prepared to summarize the power system employed in the literature for 3-W battery powered rickshaws. Table 3 shows the various power system components such as battery type, No. of batteries, capacity of batteries, machine type and motor power for battery powered 3-W rickshaws.

Table 3. Power system components of 3-W battery rickshaw

Reference/ source	Type of Vehicle	Battery types & quantity	Battery capacity	Motor Types	Motor Power
[33]	3-W	Li-Ion, 12V, 4	5 kWh	SRM	11.19 kW
[34]	3-W	Lead-acid, 12V, 2	2.4 kWh	BLDC	1 kW
[23]	3-W	Li-Ion, 12V, 4	4.8 kWh	BLDC	2 kW
[35]	3-W	Pb-Acid, 12V, 2	0.720 kWh	DC Motor	500 W
[36]	3-W	Pb-Acid, 12V, 4	4.8 kWh	BLDC	500 W
[37]	3-W	Pb-Acid, 12V, 5	6.0 kWh	DC Series	1000 W
[38]	3-W	Pb-Acid, 12V, 4	4.8 kWh	BLDC	1000 W
[39]	3-W	Pb-Acid, 12V, 4	5.72 kWh	BLDC	1000 W

Generally Pb-Acid batteries are widely used in 3-W electric rickshaws for short distance convenience across metropolitan cities in India. While top manufactures of 3-W rickshaw across India as discussed in table 1, are offering Li-Ion batteries pack for 3-W rickshaws. The weight of one Pb-Acid battery is 27 kg as per ICAT AIS-048 while Li-Ion battery is 14 kg. Therefore, Li-Ion powered 3-W rickshaws have comparatively lower weight.

DC, SR, BLDC propulsion systems are extensively employed in battery powered 3-W rickshaws as per literature survey carried out in table 3. In the present study, an attempted has been prepared to identify the suitable motor among DC, SR, and BLDC for 3-W battery vehicles. A selection criteria has been employed based on rating scheme starting from one (1) to five (5) where 1 specifies poorest and 5 specifies superb performance of DC machine, SRM, Brushless DC machine [40], [41]. Scientific assessment and estimation between DC machine, SRM and Brushless DC propulsion system for battery powered 3-W rickshaw is illustrated in Table 4. Total grades gained via respectively propulsion system are assessed based on the performance. The performance of the brushless DC motor is best among all with 44 total grades.

Table 4. Assessment and estimation of 3-W rickshaw motor [40], [41]

Assessment Constraints	DCM	SRM	BLDC
Proficiency	3	5	5
Torque	2	3	5
Controllability	4	3	4
Trustworthiness	4	3	4
Power density	4	3	4
Active response	3	4	5
Preservation	3	4	5
Price	5	4	4
Noise liability	4	5	4
Heaviness	3	4	4
Total	**35**	**38**	**44**

6. CONCLUSION

Electric power technology has the potential to mitigate the pollutions, global warming, conventional fuels exhaustion and loss of building materials concerns associated with IC engine vehicles. Various configuration of electric power technology and their benefits have been studied in the current study. Three-wheeled (3-W) battery powered rickshaws/vehicles are primarily employed for public conveyance in the metropolitan cities of India. Next, study of mechanical and physical significance for three-wheeled battery powered rickshaw/vehicle has been carried out. Finally, analysis of accurate propulsion system for 3-W battery rickshaw through technical assessments has been performed.

ACKNOWLEDGEMENT

The authors would like to acknowledge the University Polytechnic, UGC and CAD laboratory in Department of Mechanical Engineering for an assistant to support this research.

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