Design and development of an affordable plug in/solar assisted electric auto rickshaw

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ABSTRACT

The three wheeled auto rickshaws are most extensively used in India for transporting people and cargo. Even though the existing vehicle design is robust in the operating environment, but the emission control is minimal owing to the use of inefficient internal combustion engines. The best way to revamp the existing auto rickshaw is to develop a solar assisted auto rickshaw with efficient electric drive train to minimize the emissions at the tail pipe. This paper presents the development of solar assisted three wheeler auto rickshaw and also to implement an energy management strategy suitable for Indian city-driving pattern and driving requirements setup. The proposed auto rickshaw is modeled in Simulink software, fabricated and tested at different traffic conditions. From the test results it is concluded that the fabricated solar assisted auto rickshaw mimic the existing conventional auto rickshaw.

1. INTRODUCTION

The main source of fuel consumption and emission of abundant quantity of Green House Gases (GHGs) into atmosphere is Transportation sector. So fossil fuel consumption and pollution level in air are two severe problems faced by automobile industry, which bring forward an immediate need in the development of advanced technologies for vehicle propulsion architectures systems [1]. A three wheeled conventional Auto Rickshaw (AR) as shown in Figure.1 is one of the affordable and easily access form of private transportation in India and a few other Asian countries [2]. The popularity of AR is mainly due its low cost, reasonable oil consumption efficiency, small size and a narrow body, making it perfectly suited for operation in the narrow and thickly populated roads of Indian cities. Unfortunately most of the conventional Auto Rickshaws are operating at very low speeds (25–30 Kmph) due to heavy traffic conditions and causes increased consumption of oil, intense air pollution and emit abundant quantity of GHGs.

If an AR runs 50–60 Km per day with a petroleum consumption of 25–30 Km per liter (Kmpl), and then fuel required is approximately 2 liters per day. The corresponding CO_2 emission is 5 Kg per day [3]. The total amount of CO_2 emission for 1 million auto rickshaws will be 50 Lakh Kg per day. If the CO_2 emission is traded on Indian market for 1 million auto rickshaws, it would worth INR 1 Crore (against INR 2 per 1Kg), and annually INR 300 Crores (assume 300 days in navigation per year). At present approximately 3 million auto rickshaws are offering taxi services in India. They cost CO_2 emission of INR 900 Crores and fuel consumption of 1800 million liters per annum. Therefore fuel consumption and pollution levels in the atmosphere are the major concerns in using the AR. In all major cities and towns of India, air pollution due to AR have improved considerably over the years and pose a risk to people health those who have access to urban roads regular and who live

very close to highways [4].

Figure 1. Conventional auto rickshaw in India

In all major cities and towns of India, air pollution due to AR have improved considerably over the years and pose a risk to people health those who have access to urban roads regular and who live very close to highways [4]. About 40 - 55 % of Indian population is living within 500 -1000 meters of such roads and highway suffers with variety of diseases due to vehicle pollution. It has been observed that the number of vehicles registered has been tripling every 10 years, from close to 10 million in 1986 to nearly 30 million in 1996 and further to over 100 million in 2017. The Figure 2 illustrates that three wheelers occupies a significant place in Indian transportation sector and thus account for a major part of the pollution produced. A large growth in number of registered vehicles demand more energy and causes increased emission of CO_2 and GHGs which effect the environment considerably. One of the objectives of urban transportation is reduction of air pollution and to find ways to improve energy consumption efficiency of AR. In order to realize that objective, technology is needed which promises us to make availability of abundant quantity of renewable energy sources for powering vehicles and considerably reduce demand for fossil fuels. The primary requirements for the next generation urban vehicle must be having low fuel consumption, low or zero emissions and compact design to operate in narrow and

thickly populated roads of Indian cities [5]. "It is becoming increasingly clear that the future is biased towards small, beautiful, drivable and affordable vehicles". In recent years, Compressed Natural Gas (CNG) and Liquefied Petroleum Gas (LPG) auto rickshaws are introduced in the market to reduce noise and air pollution. These models have not become popular because of scarcity of CNG and LPG. World is progressing towards Electric Vehicle (EV) and Hybrid Electric Vehicle (HEV) [6]. A pure Electric Auto Rickshaw (EAR) would be the best in terms of emissions and energy use, but commercialization of it is constrained by the energy storage capabilities of batteries available in the market. Lead-acid batteries are very cheap and heavy but they are not able to provide sufficient energy to meet long journey requirements due to that EV driving range is restricted to 60-80 km .The Nickel-Metal Hydride or Lithium ion batteries available in the market are quite expensive when compared to the existing Lead acid battery.
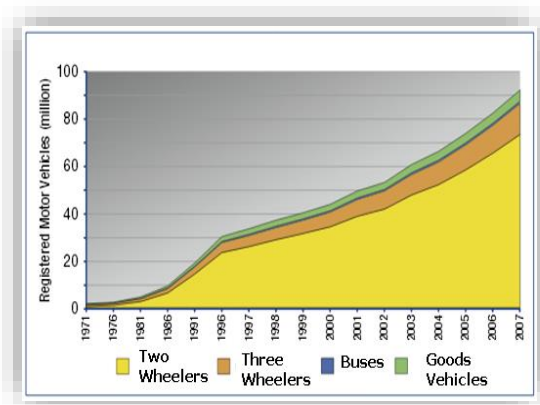

Figure 2. Motor vehicles registered per year in India

2. PROPOSED CAR MODELING AND LAYOUT

The first stage of the design process involved in measuring the tractive force requirement of the 3 wheeler is mentioned below: The formulae for calculating tractive efforts are given from Equation (1) to Equation (8) respectively.

$$F_{total} = F_{aero} + F_{roll} + F_{la} + F_{grad}(N) \tag{1}$$

$$F_{aero} = C_d.A.\rho.V^2.0.5 \ (N) \tag{2}$$

$$F_{roll} = m.g.C_{rr}(N) \tag{3}$$

$$F_{la} = m.a(N) \tag{4}$$

$$F_{grad} = m.g.sine(\theta)(N) \tag{5}$$

Tractive effort required at the wheels to accelerate the vehicle to the maximum velocity is given by:

$$F_{tr} = F_{res} + F_{la} \tag{6}$$

Total tractive force needed

$$F_{tr} = F_{total} + F_{al} \tag{7}$$

$$F_{res} = F_{aero} + F_{roll} + F_{grad} \tag{8}$$

The gradient resistance and the linear acceleration components are not included in the tractive force calculations because doing so would increase the size of the motor to unreasonable proportions. The required linear acceleration can be supplied by the motor because electric motors can handle significantly more power (2 to 3 times) for a short period of time.
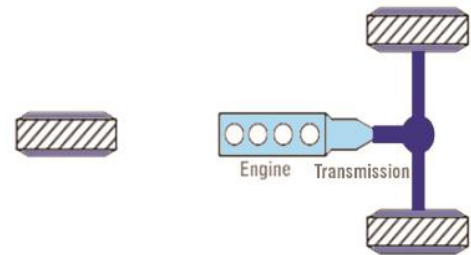

Figure 3. Drive train of a convectional auto rickshaw

To build a solar/electric vehicle using a conventional three wheeler auto rickshaw platform as shown in Figure. 3, electric wheel hub motors are to be used at the wheels to provide the power and traction at the rear wheels. Figure 4 shows a layout of proposed electric auto rickshaw model.
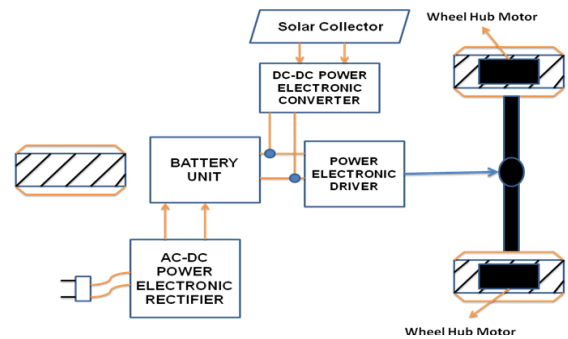

Figure 4. Drive train of the Electric Auto Rickshaw

3. SELECTION OF POWER TRAIN COMPONENTS

Appropriate selection of power train components is very much required for designing the affordable solar assisted /plug in auto rickshaw.

3.1 Selection of electric motor

BLDC Motors has got several advantages over other types of motors as shown in the Table 1. Also, the BLDC motors do not require any air flow inside for cooling purpose [7].

Table 1. Comparison of different motors

Parameter	DC Brush	Brushless Permanent Magnet	Induction Motor	Switched Reluctance Motor
Efficiency %	85	95	90	<90
Efficiency@ 10% load	80	85	70	78
Cost $/KW	10	15	7.5	10
Max. rpm	<600	1000	>1500	>1500
Ruggedness	Good	Good	Excellent	Excellent
Reliability	Fair	Good	Excellent	Good

Typically brushless motors have 5 to 10 % better efficiency than induction motors and 8 to 12 % better efficiency than brushed DC motors [8]. Based on the availability, literature survey data and considering the advantages two Permanent Magnet Brushless DC motors have been selected for use as shown in Figure.5 and the specifications are given in Table 2.

Figure 5. Permanent magnet brushless DC wheel hub motor with accelerator unit

Table 2. Specifications of permanent magnet brushless DC wheel hub motor

S.No	Parameter	Specifications
1	Rated power	1500 W (2HP)
2	Rated voltage	48V
3	Efficiency	84%
4	Number of Wheel Hub Motors	2
5	Max speed	650 rpm
6	Max Torque	98.36 N-m
7	Rated Torque	83.46 N-m
8	Brake	Drum
9	Wheel Size	10"

3.2 Controlling of electric motor using DC Chopper

The performance of electric motor is governed by a chopper controller which controls currents in an armature and a field winding in accordance with a command from an accelerator pedal. The labeled diagram of the chopper controller used is given in Figure.6.
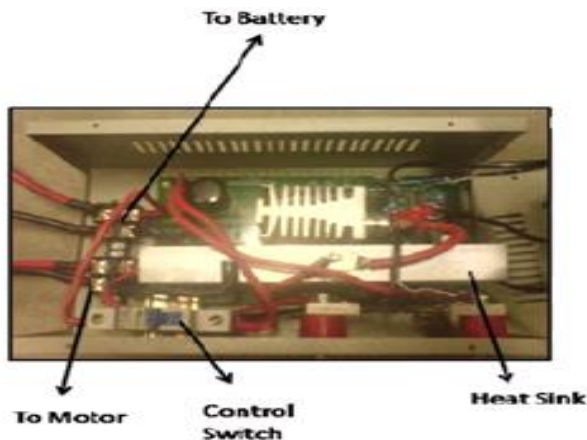

Figure 6. DC chopper controller

3.3 Choice of battery

The battery chosen for this electric auto rickshaw is a sealed lead acid battery specially designed for traction applications. Traction batteries (Motive Power Batteries) are specially designed to meet the demands of, electric vehicles and many other industrial traction applications [9-11]. The choice of this battery has its own advantages and disadvantages. The advantage being the elimination of heavy cost involved in going for the Nickel metal hydride or Lithium ion batteries although they provide better performance than the battery chosen. Taking into consideration the availability of technology and cost constraints lead-acid traction batteries were chosen as shown in Figure.7 and the specifications are tabulated in Table 3.

Figure 7. Traction Batteries – 4 x 12V 20Ah

Table 3. Specifications of traction batteries

S.No	Parameter	Specifications
1	Make	HBL Traction Batteries of type G-Ride
2	Battery Capacity	12 V, 20 Ah, C5 rating (5 hr discharge rate)
3	Quantity	16
4	Cell voltage	2 V
5	No: of cells	6
6	Total Battery pack rating	48 , 80 Ah

3.4 Battery charge and discharge test

A test was performed on the traction battery selected to find out the variations in the following parameters during actual discharge viz., voltage, specific gravity of electrolyte and temperature. Both open circuit voltage (OCV) and closed circuit voltage (CCV) were monitored in the process and the results are tabulated in Figure.8, Figure.9 and Figure.10 for a constant current withdrawal of 5 A.
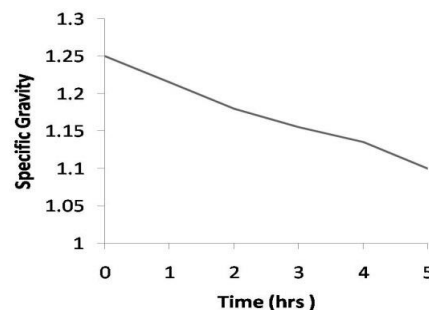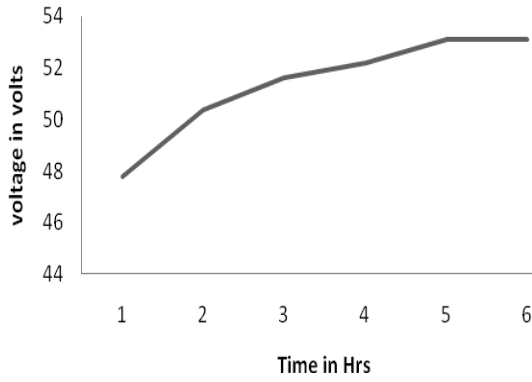

Figure 8. Time vs specific gravity

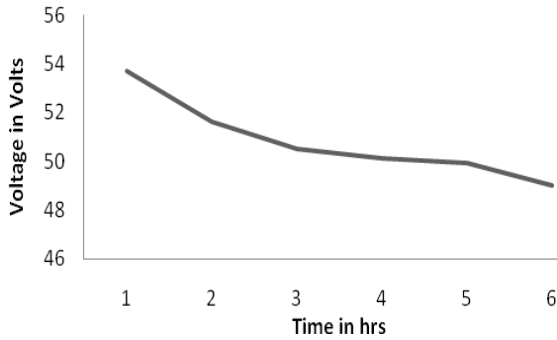**Figure 9.** Charge test for constant current of 5°

Figure 10. Discharge test: Time Vs voltage (5A)

4. PROPOSED PLUG IN/SOLAR ASSISTED AUTO RICKSHAW

Block diagram of existing auto rickshaw, proposed electric rickshaw and proposed solar assisted electric rickshaw are shown in Figure.11, Figure.12 and Figure.13 respectively.
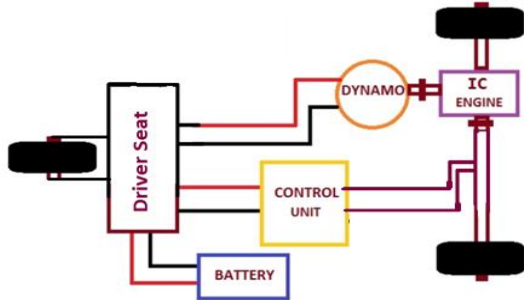

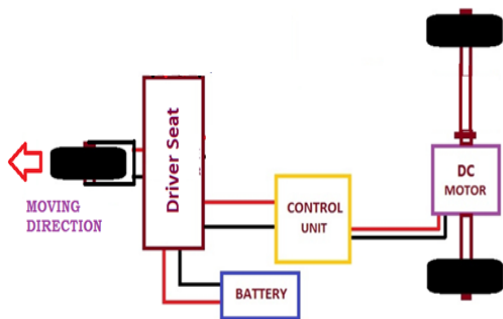**Figure 11.** Block diagram of existing auto rickshaw

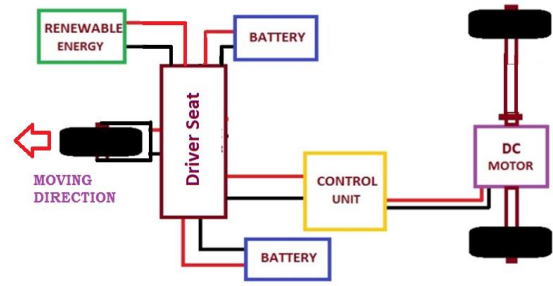**Figure 12.** Block diagram of proposed electric rickshaw

Figure 13. Block diagram of proposed solar assisted electric rickshaw

Based on the dimensions of existing auto rickshaw [3], parameters of proposed electric rickshaw and solar assisted electric rickshaw are shown in Table 4 and Table 5 respectively.

Table 4. Specifications of proposed electric rickshaw

Sl. No	Description	Value
	Weights & Measures	
1	Kerb weight	272 Kg
2	No.of Persons	5
3	Pay load	338 kg (68Kg per passenger)
4	Gross vehicle weight (W)	610 Kg
	Dimensions	
5	Overall length	2625 mm
6	Overall width	1300 mm
7	Overall height	1710 mm
8	Wheel base	2000 mm
9	Ground clearance	180 mm
10	Wheel radius (r)	19cm
	Fuel Economy	
11	Acceleration (a)	0.5m/sec^2
12	Mileage within a city	60-80Km per single charge
13	Maximum speed (V_{max})	30Kmph or 8.33m/s
14	Average trip/day	40 to 60 Km/day
15	Braking System	Rear Braking system
16	Air Resistance (K)	5mN/kg
17	Speed of Electric Drive= (V_{max} in m/s)/(r × 0.10472)	418 Rpm
18	Tractive Force F = W(a+g*G+K) where g=9.8 m/sec^2	314N
19	Torque (T)= F×r	59.66Nm
20	Power output (P)	2.61kW
21	Efficiency of Motor(η)	85%
22	Power Input= P/ η	3.070kW
23	System voltage	48 V
24	Electric motor	48V, 3kW, PMDC motor
25	No of Batteries	4 (12×4=48V)
26	Battery Capacity	12×4=48V, 140 Ah each Lead Acid Battery
27	Charger Input Voltage	220V A.C
28	Charger output Voltage	48/24/12V
29	Depth of Discharge	60%
30	Transmission	1 forward and 1 reverse

Specifications of Plug in charger and Solar panels required for charging the battery in Plug in ER and Solar assisted ER are given in Table.5 and Table.6 respectively.

Table 5. Design of solar PV system for proposed electric rickshaw

Sl. No	Description	Value
1	Solar radiation (E)	1000 W/m^2
2	Efficiency (η)	15%
3	Battery Capacity	12×4=48V, 140 Ah each Lead Acid Battery
4	Power output of panel (P)	500W
5	No. of Panels	2
6	Voltage Rating of Each Panel	24V
7	Output Current	20.83A
8	Area required =P/(E×η)	3.33 m^2

Table 6. Design of plug in supply for proposed electric rickshaw

Sl. No	Description	Rating
1	Source Voltage (V_S)	220 A.C
2	Output Voltage (V_o)	48/24/12V D.C
3	Transformer Rating	220V/48V
4	VA rating of Transformer	3KVA
5	Full Bridge Rectifier	48V A.C to 48V D.C
6	Voltage Regulator (IC 7812)	12V
7	Smoothing Capacitor	10nF

Simulated model of electric rickshaw and corresponding output wave forms are shown respectively from Figure 14 – Figure 17 and fabricated model of electric rickshaw with solar panels and charger is shown in Figure 18.
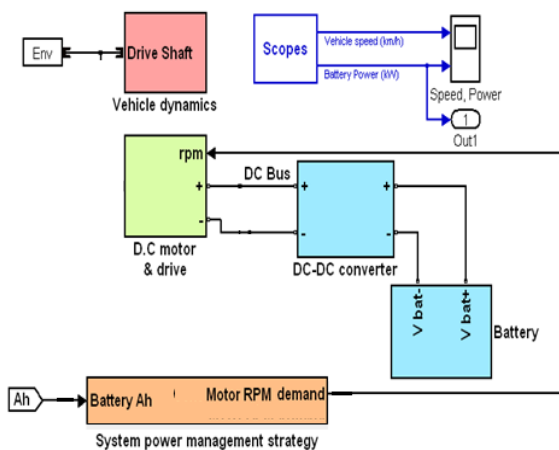

Figure 14. Simulated model of proposed electric rickshaw

Variation of vehicle speed, battery power and motor RPM demand with respect to time are shown from Figure.15 - Figure.17 respectively. From the simulated results, it is noted that the Electrical power required for speed of 50 Kmph. But urban speeds are about 25-30 kmph, the above estimates are appears to overestimation. Based on the above simulated results, a permanent magnet DC motor capable of supplying power 3 KW is chosen for two rear wheels.
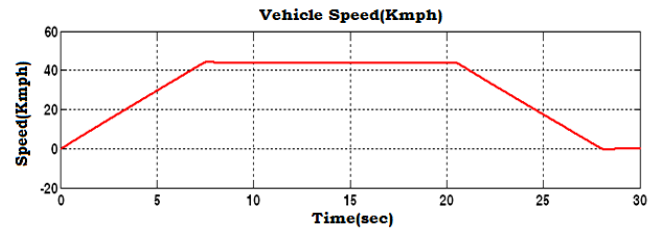
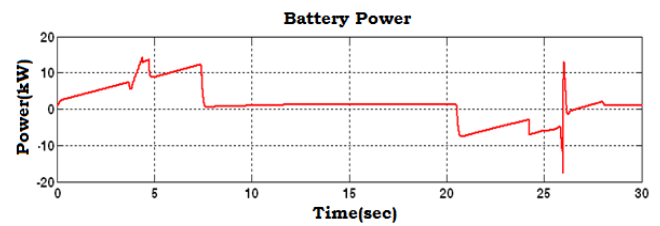

Figure 15. Variation of vehicle speed with time

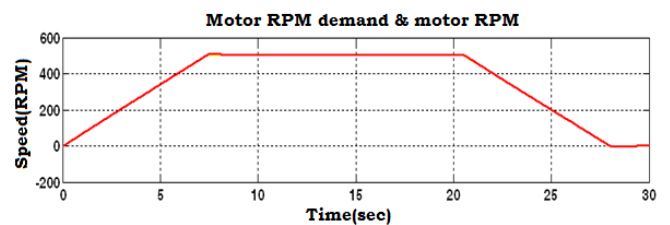**Figure 16.** Variation of battery power with time

Figure 17. Variation of motor RPM demand and motor RPM curve with time

Figure 18. Fabricated model of proposed solar assisted ER

Comparison between existing and fabricated solar assisted electric rickshaw are given in Table.7.

Table 7. Comparison between existing and fabricated electric auto rickshaw

S. No	Description	Existing Electric Rickshaw [3]	Fabricated Solar assisted Electric Rickshaw
1	Transmission	1 forward and 1 reverse	1 forward and 1 reverse
2	Wheel radius (r)	19cm	14cm
3	Efficiency	80%	85%
4	Mileage within a city	150 km per single charge	80km per single charge
5	Maximum Speed (N)	40Kmph	30kmph
6	Average traveled distance	80-100km per day	40-60km per day
7	No. of Persons	4	5
8	Kerb Weight	205kg	272kg
9	Pay load	280Kg	338 Kg
10	Total weight (W)	485Kg	610 Kg
11	Acceleration (a)	0.5 m/sec^2	0.5 m/sec^2
12	Power Input =Power Output/Efficiency	3kW	2 kW
13	Rating	PMDC, 60V, 3kW Electric Motor	PMDC, 48V, 2kW Electric Motor
14	Charger Output Voltage	60V	12/24/48V
15	No.of Batteries	5	4
16	A set of Storage Batteries	60V(12V×5), 140Ah each Lead Acid Battery each	48V (12×4),120 Ah each, Lead Acid Battery
17	Depth of Discharge	60%	60%

5. TESTING OF SOLAR ASSISTED ELECTRIC RICKSHAW

Based on the operation of solar assisted electric auto rickshaw in Tenali (small town in Andhra Pradesh, India) morning and evening load curves (collected and tested) are depicted and are shown from Figure.19 - Figure. 22 respectively. From the load curves, it has been observed that an average speed range of 25-30 Km will be required for urban driving scenario in India. Often high speeds are observed. The solar assisted electric auto rickshaw is operated in such a way that it runs most of the time in electrical mode and on high speed requirement with IC engine. Hence it has high fuel efficiency and has very low potential for emissions. Test results of the solar assisted electric auto rickshaw are tabulated in Table.8 and it is concluded that the fabricated solar assisted auto rickshaw mimic the existing conventional auto rickshaws.
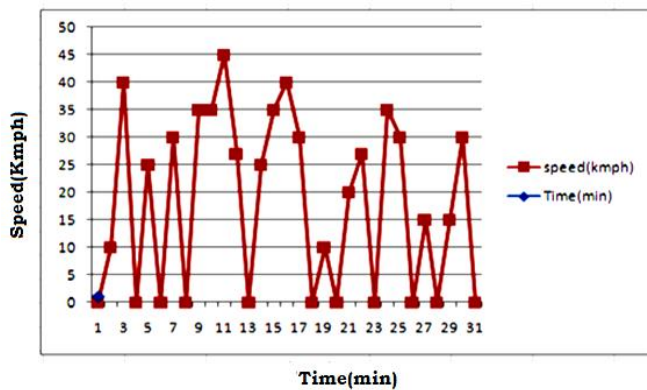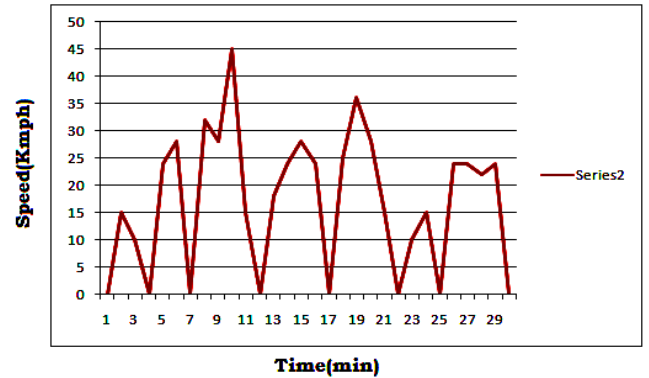

Figure 20. Typical 30 min Morning driving cycle (tested with solar assisted electric auto

Figure 21. Typical 30 min Evening driving cycle (collected)

Figure 19. Typical 30 min morning driving cycle (collected)

Figure 22. Typical 30 min evening driving cycle (tested with solar assisted electric auto rickshaw)
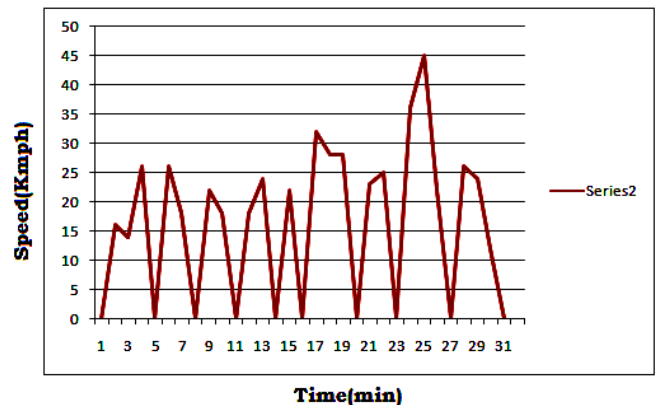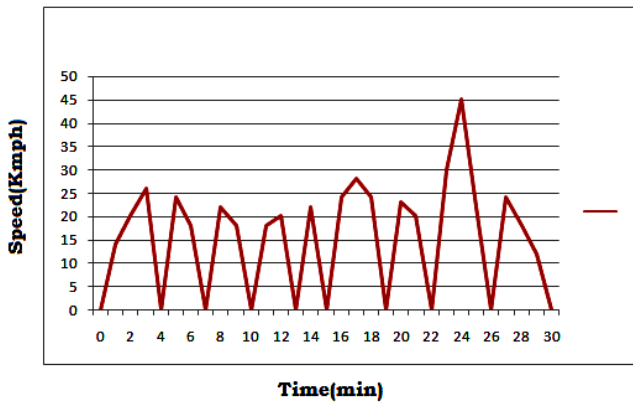
Table 8. Test results of electric auto rickshaw

Variable	Day time	Evening
Time (Hours)	2.5 (8.00-10.30A.M)	2.5 (6.00-8.30P.M)
Distance (Km)	35	23
Max.speed (Kmph)	45	45
Average Speed(Kmph)	27	22
No. of stops	20	32
Stoppage Time (min)	30	42

6. CONCLUSION

The paper has been taken up with the motive of bringing about a radical change in the way auto rickshaws contribute towards urban pollution and providing a feasible solution for the same. The primary objective is to have zero tail pipe emissions and replace the fossil fuel dependency. This helps in moving towards greener society. This benefits the people who make a living out of auto rickshaws as they can save more in the long run though capital costs are on the higher side. The prototype is to prove practically that this concept can be implemented in an auto rickshaw which has a massive role to play in public transportation in most of the Asian countries. The prototype developed had a zero emission at the tail pipe with the usage of renewable solar energy. From the test results it is concluded that the fabricated solar assisted auto rickshaw mimic the existing conventional auto rickshaws.

REFERENCES

[1] Vezzini A, Sharan H, Umanand L. (2013). Low-pollution three-wheeler autorickshaw with power-assist series hybrid and novel variable DC-link voltage system. Journal of the Indian Institute of Science 85(2): 105.

[2] Miller JM. (2006). Hybrid electric vehicle propulsion system architectures of the e-CVT type. IEEE Transactions on power Electronics 21(3): 756-767. http://doi.org/10.1109/TPEL.2006.872372

[3] Hofman T, Van Der Tas SG, Ooms W, Van Meijl EWP, Laugeman BM. (2009). Development of a micro-hybrid system for a three-wheeled motor taxi. World Electric Vehicle Journal 3(3): 572-580.

[4] Gonder J, Simpson A. (2007). Measuring and reporting fuel economy of plug-in hybrid electric vehicles. World Electric Vehicle Journal 1(1): 134-141.

[5] Williamson SS, Emadi A, Rajashekara K. (2007). Comprehensive efficiency modeling of electric traction motor drives for hybrid electric vehicle propulsion applications. IEEE Transactions on Vehicular Technology 56(4): 1561-1572. https://doi.org/10.1109/TVT.2007.896967

[6] Road Transport Year Book (2011-12). Transport Research Wing Ministry of Road Transport & Highways Government of India New Delhi, from http://in.toolalfa.com/LinkClick.aspx?fileticket=RhX00 HSiIT4%3D&tabid=72&mid=486

[7] Minami S. (2011). Reality and virtuality of electric vehicles. Journal of Asian Electric Vehicles 9(1): 1447-1451. https://doi.org/10.4130/jaev.9.1447

[8] Mulhall P, Naviwala M, Lukic SM, Braband J, Emadi A. (2007). Entrepreneurial projects program at Illinois Institute of Technology: solar/battery hybrid three-wheel auto rickshaw for India. In Vehicle Power and Propulsion Conference,2007. VPPC 2007. IEEE pp. 682-689. https://doi.org/10.1109/VPPC.2007.4544210

[9] Lebeau K, Van Mierlo J, Lebeau P, Mairesse O, Macharis C. (2013). Consumer attitudes towards battery electric vehicles: A large-scale survey. International Journal of Electric and Hybrid Vehicles 5(1): 28-41. https://doi.org/10.1504/IJEHV.2013.053466

[10] Faria R, Moura P, Delgado J, De Almeida AT. (2012). A sustainability assessment of electric vehicles as a personal mobility system. Energy Conversion and Management 61: 19-30. https://doi.org/10.1016/j.enconman.2012.02.023

[11] Caricchi F, Ferraro LD, Capponi FG, Honorati O, Santini E. (2003). Three-wheeled electric maxi-scooter for improved driving performance in large urban areas. Proceedings of the IEEE Electric Machines and Drives Conference 3: 1363–136. https://doi.org/10.1109/IEMDC.2003.1210629