Solar/Battery Electric Auto Rickshaw Three-Wheeler

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***Abstract*–Auto rickshaws are three-wheeled vehicles used extensively in many Asian countries as taxis of people and goods. Although the vehicle design is well-suited to the environment in which it operates, it is a crude, inefficient design. Due to poor vehicle maintenance and the use of inefficient 2 or 4 stroke engines with very little pollution control, auto rickshaws present a huge pollution problem in major Indian cities.**

Illinois Institute of Technology's (IIT) rickshaw project is aimed at developing an advanced solar-based electric auto rickshaw. This paper presents research on the conventional auto rickshaw, future conceptual infrastructure designs for electric rickshaws, and the recent design research and simulations of the next auto rickshaw. IIT's solar/battery electric three-wheeler is meant to match and exceed the conventional vehicle's performance, but with a more intelligent and efficient design. We introduce the next overall design of the rickshaw in this paper as the Auto Rickshaw 2.0, where the conventional vehicle is version 1.0. IIT's technical development aim for Auto Rickshaw 2.0 is to decrease the total electric power needed for propulsion with an optimized battery system and a more efficient motor. Four system drive train options are covered, and the selected configuration is simulated and analyzed in ADVISOR software. Additionally, conceptual infrastructure designs are modeled and optimized in HOMER software.

Index terms*–*Batteries, drive trains, energy storage systems, India, land transportation, plug-in vehicles, photovoltaics, pollution, pollution control, rickshaw, road vehicle electric propulsion.

I. Introduction

India's roads are becoming more congested each year with not only cars and buses, but especially two- and three-wheelers. India is home to over 2.5 million auto rickshaws (three-wheelers), and this number is growing, with over 250,000 new rickshaws sold in India each year. Research has shown that motorization is increasing even more rapidly than urbanization, and the increased traffic worsens India's already prevalent pollution problem [1], [2]. Many major cities are beginning to prohibit the use of petrol-powered rickshaws, and due to this, major rickshaw manufacturers such as Bajaj Auto are seeing increases in sales of alternate fuel powered rickshaws, such as Compressed Natural Gas (CNG) and Liquefied Petroleum Gas (LPG) models [3], [4].

With the factors of pollution and increased traffic in mind, the best way to revamp the rickshaw is to develop a more efficient design that will be powered by a non-polluting energy source, which can be achieved with an electric drive train since there are zero pollutants at the tailpipe. A renewable source would make it a better solution compared to the current alternative fuel-powered rickshaws. One way to do this is to use an energy system that can take advantage of several sources of renewable energy—namely, an electric system. The electricity may be provided by solar, wind, hydro, or other renewable sources. Rickshaws are great candidates for electrification due to their low speeds and a relatively little distance covered in a day [1]. In this paper, a new solar/battery electric auto rickshaw is presented. The new rickshaw design characteristics are defined and presented, and the new vehicle layout is modeled and simulated in ADVISOR [5]. Results show that the modeled vehicle is close to the desired performance of 50 miles of daily range and it is meeting the drive cycle.

This paper will first give a brief history of India's conventional auto rickshaw and transportation industry with a focus on the auto rickshaw, as well as efforts by the government to reduce pollution and promote less-polluting technologies (Sections II, III). Section IV highlights the rickshaw's inefficiencies in an industry comparison of Indian vehicles. In Section V, the research on the rickshaw driving cycle gathered via GPS and surveys will be covered, followed by recharging infrastructure research in Section VI. Section VII defines the Auto Rickshaw 2.0, such as technical targets and design description. Section VIII presents the drive train options for Auto Rickshaw 2.0. The selected configuration and simulations of the next design are covered in Section IX. Conclusions and future work on the rickshaw and its components are presented in Section X.

II. Conventional Auto Rickshaw (Auto Rickshaw 1.0)

Conventional auto rickshaws are suited to the Indian environment: they are small and narrow, allowing maneuverability on congested roads. They have a top speed of 55km/h, or 34 mph, and generally carry 1-4 passengers and their cargo. Despite apparent advantages in the vehicle design, auto rickshaws present a huge pollution problem in major Indian cities. This is due to poor vehicle maintenance and the use of an inefficient engine with very little pollution control.

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The drive train shown in Figure 1 usually includes an air-cooled 2-stroke or 4-stroke gasoline engine and a transmission (a 4-speed gearbox), although many newer vehicles are powered by diesel, LPG, or CNG. Typical engine models have capacities ranging from 145 to 175 cc, and maximum engine power ranging from 6.3 hp to 8.5 hp. An 8-liter or 9-liter fuel tank supplies the vehicle for a typical 2 or 3 days. The electrical system includes a conventional 12 V lead-acid battery for lighting and engine control and ignition. Vehicle weight varies from 277 kg to 470 kg for larger models.

Tables I-III give many of the conventional auto rickshaw parameters and performance criteria [7].

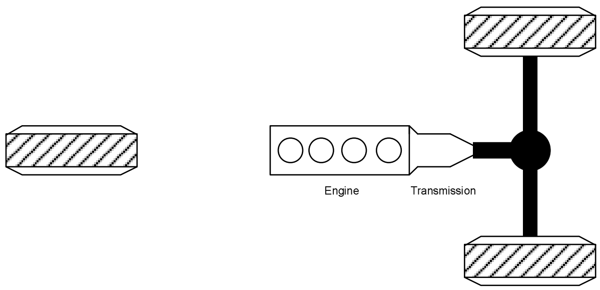

Fig. 1. Drive train of a conventional auto rickshaw three-wheeler.

TABLE I
PHYSICAL DIMENSIONS OF THE AUTO RICKSHAW 1.0

Parameter	Value
Length	2675 mm
Width	1300 mm
Height	1700 mm
Clearance	180 mm
Frontal Area	2.09 m^2
Coeff of drag	0.5
Center of veh mass	0.4 m
Wheel Base	2000 mm
Kerb Weight	280 kg
Daily Distance Driven	70-120 km

TABLE II
PHYSICAL SPECIFICATIONS OF THE ENGINE BLOCK OF RICKSHAW 1.0

Parameter	Value
Type	Four Stroke, SI, Forced air Cooled
Weight	45kg
Displacement	175cc
Max. Power	6kW @ 5000 rpm
Max. Torque	12.7Nm @ 4000 rpm
Payload	310kg (max), 100 kg (avg)

TABLE III
LOAD CHARACTERISTICS OF THE AUTO RICKSHAW 1.0

Variable	Value	
Top Speed	55 kph	
Gradeability	16% @10kph and 334kg payload	
Acceleration	0 to 20 kph	4.4 sec
	0 to 30 kph	6.6 sec
	0 to 40 kph	10 sec
	0 to 55 kph	19.6 sec

III. INDIA'S TRANSPORTATION INDUSTRY DEVELOPMENT

India has taken many steps to promote alternative sources of energy in the past few decades. Particularly in the transportation sector of energy use, much attention and effort has been focused on CNG and LPG technologies. According to the Ministry of Non-conventional Energy Sources (MNES), part of this is due to India's desire to depend less on energy imports. Another part of this initiative was driven by the citizens, however. Sparked by a public interest litigation filed in the Supreme Court in 1985 about the failure of the government to protect Delhi's environment, attention was given to pollution caused by vehicle emissions (an estimated 70% of total pollution). This led to many policies and initiatives eventually culminating in replacement of the entire Delhi bus fleet with CNG buses in 2001. To this day, some major Indian cities are stipulating that only zero-emissions vehicles be allowed to operate in the city, and some have even banned petrol-powered rickshaws [3].

Three main disadvantages exist with incorporating CNG and LPG technologies on rickshaws: (a) oil is still added to the chamber in the two-stroke configurations, which adds to the pollution, (b) the addition of these does nothing to lessen India's dependence on foreign oil, which is another significant issue for the country, and (c) CNG and LPG are non-renewable energy sources [3], [7].

India also has one of the world's largest programs for renewable energy. The MNES has many initiatives and targets for increasing wind power, solar and solar thermal power, hydro power, and other sustainable projects. In fact, renewables account for 32.0% of India's total electricity generation capacity; compare this to a mere 11.5% in the US, and approximately 21.0% and 20.0% for China and Japan. Especially for solar power, a large increase in capacity is expected since India experiences 250-300 clear sunny days a year in most parts of the country. India receives an estimated 5,000 trillion kWh of solar radiation per year, so solar power offers great potential to meet a part of the country's fast growing energy requirements [8]. As far as incorporating renewable energies into transportation, according to the MNES website, new initiatives by MNES include research and development of new and renewable systems for transportation, portable and stationary applications for rural, urban, industrial and commercial areas.

Unlike India's major successes in the area of CNG, electric vehicles have seen limited applications, such as shuttling tourists from their parked vehicles to historical sites and monuments. One example of this for rickshaws was the India Zero Emissions Transportation (IZET) Program which launched a small group of rickshaws to be field tested in Agra from 1999 to 2003. In the consumer market, REVA electric car company has seen increasing sales of its three door hatchback model since it began production in 2001. In addition, the major Indian automaker Tata just introduced a concept electric car, which will be brought to market in 2011. The trend of electrification is now slowly beginning to catch on with two and three-wheelers by the company Indus-Electrans and other companies [3].

IV. Industry Comparison

It is important to compare the rickshaw to similar vehicles in the industry to see where it stands on its capabilities and efficiency. Many cars in India are small, and so it is easy to find comparable cars in both engine power and weight. Table IV shows this comparison and presents the respective miles per gallon ratings (highway ratings). The Maruti Suzuki and Tata Indica are both passenger cars, the Honda Eterno is a scooter, and the Bajaj Pulsar is a motorcycle.

TABLE IV
Indian Vehicle Comparison

Vehicle	Engine Power (hp)	Curb Weight (kg)	Miles per U.S. Gallon
Bajaj 4S Rickshaw	8.5	280	80
Maruti Suzuki 800	37	650	47
Tata Indica	70	995	30
Honda Eterno	8.2	125	152
Bajaj Pulsar 150	14	145	127

Analyzing the table, we find that the conventional rickshaw is inefficient relative to other Indian cars and motorcycles. For example, since the Maruti Suzuki 800 weighs more than twice as much as the rickshaw, and has more than 4 times the horsepower, one might expect that the rickshaw would achieve at least twice the 800’s fuel economy, but it does not. However, the Honda scooter does not seem to be more efficient than the rickshaw. This may show that there is a point at which the efficiency of small vehicles cannot be improved much by decreasing the vehicle weight and power of the engine. This gives even more reason for electrification of small vehicles like the rickshaw.

V. Usage Pattern Development and Defining Driving Cycles

Usage patterns are especially important when considering converting a conventional vehicle to an electric one. A usage pattern, or driving cycle, is a plot of speed versus time, but more than that, it is a sequence of vehicle operating points and conditions that represent the way a vehicle is driven in a certain environment. To redesign the rickshaw and its components in a cost-effective way and to ensure the correct vehicle performance, a vehicle driving cycle or usage pattern must be found. The first data we considered for driving cycles for the rickshaw were the existing driving cycles that Indian organizations use. There are two: (1) the Indian driving cycle developed by Gandhi et al and later with input from the Automotive Research Association of India; and (2) the modified Indian driving cycle based on the European Urban Driving Cycle (EUDC) with speed limited at 90 kmph [7].

It is seen in simulations and looking at the top speeds of the rickshaw that the driving cycles cannot apply to the rickshaw. Therefore, to collect accurate data to use in creating a new rickshaw driving cycle, we used a GPS tracking system on an auto rickshaw in India as it was taxiing. Twenty six hours of data was collected in both heavy traffic and light traffic conditions [7].

For the process of creating a representative driving cycle for the rickshaw, the actual raw data was used. The section of raw data including the statistical extremities (maximum speed, acceleration and deceleration) was the starting point. We expanded the data set until the speed distribution of the data set approached that of the average. The statistics and the speed distributions along with the deviations from the goal are given in Tables V and VI, and this data shows that the averages and the actual data are quite similar. In addition, by comparing the statistical results of the two representative driving cycles (Table V) to the defined goal (Table VI), we see that the averaged and extreme dynamics are also similar. Our representative driving cycles are shown in Figures 2 and 3 [7].

TABLE V
Statistics of the Representative Driving Cycles [7]

Variable	Daytime	Evening
Time (sec)	5650	4849
Distance (km)	9	17
Max Speed (km/h)	35	50
Ave Speed (km/h)	5.5	12.9
Accel (m/s^2)	6.34 (max), 1.66 (avg)	6.36 (max), 1.83 (avg)
Decel (m/s^2)	-6.34 (max), -1.66 (avg)	-6.42 (max), -1.87 (avg)
Idle Time (sec)	405	222
No. of Stops	104	61

TABLE VI
Speed Distributions and Deviation from the Average for the Developed Driving Cycles [7]

Speed Range	Day Average	Day Actual	Evening Average	Evening Actual
0 ~ 5	27.8%	27.8%	50.8%	50.4%
5~10	22.4%	22.9%	37.5%	37.8%
10~15	12.5%	12.4%	8.9%	9.0%
15~20	13.5%	12.7%	2.2%	2.2%
20~25	10.2%	9.7%	0.4%	0.4%
25~30	5.5%	6.0%	0.1%	0.1%
30~35	4.5%	4.8%	0.1%	0.1%
35~40	2.4%	2.6%	0.0%	0.0%
40~45	0.7%	0.8%	0.0%	0.0%

The daytime driving cycle is a great picture of the rickshaw driven in heavy traffic and/or with heavy loads, whereas the evening driving cycle shows a picture of light traffic and/or light loads. Together, these driving cycles allow us to simulate the rickshaw and its new designs much more accurately. They will also allow a study of the electric range and battery life given both average and worst case driving routines. Driving cycles provide demand and performance characteristics and help in the development of a model of the actual vehicle in ADVISOR, short for Advanced Vehicle Simulator software [5]. ADVISOR is a set of model, data, and script text files for used with Matlab and Simulink and is used to analyze performance, fuel economy, and emissions of conventional, electric, hybrid electric, and fuel cell vehicles. The power of ADVISOR is in that it predicts the performance of a vehicle without the need to actually assemble a test vehicle.

Going back and simulating the conventional vehicle with these driving cycles, we see the rickshaw fuel efficiency range from 34 km/L (80 mpg) in light traffic to as low as 28 km/L (66 mpg) in heavy traffic conditions, which matches the fuel efficiency ranges documented in literature on the rickshaw.

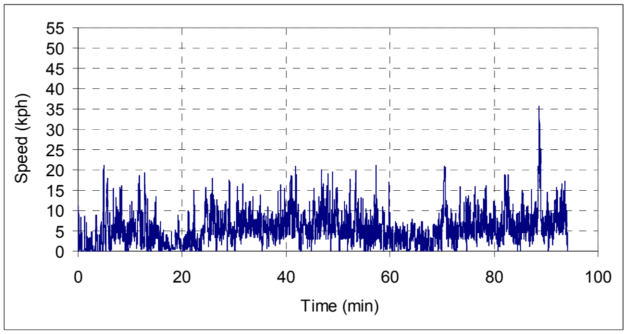

Fig. 2. Representative daytime driving cycle [7].

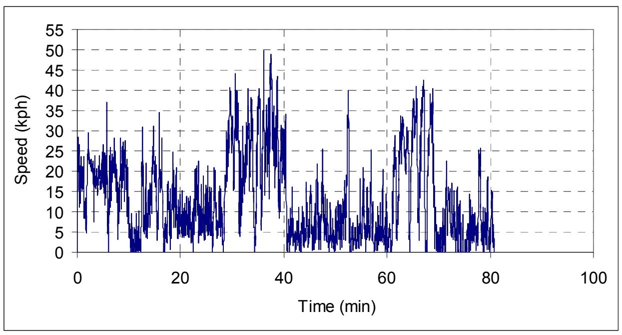

Fig. 3. Representative evening driving cycle [7].

VI. Recharging Infrastructure

In addition to the work done on developing the driving cycles and vehicle model, the conceptual recharge infrastructure was considered in detail. We used the Hybrid Optimization Model for Electric Renewables (HOMER) software from the U.S. National Renewable Energy Laboratory (NREL) for this investigation. HOMER simplifies the task of evaluating both conventional and renewable energy technology design options for off-grid and grid-connected power systems by evaluating the economic and technical feasibility of a large number of both renewable and non-renewable technology options and accounting for variation in technology costs and energy resource availability [6].

With the help of the HOMER software, a range of designs for a large solar and wind-powered battery recharge stations were developed with the option of an assisting LPG generator located in the vicinity of Mumbai, India. The method of transporting the batteries to and from the customer was also investigated: it was decided to transport the batteries to and from the customer via all-electric converted trucks to further minimize pollution on the system level. The effect on the system efficiency of transporting the batteries was also considered in the design of the mother recharging station [1].

In this scenario, a rickshaw operator would go to local service stations (possibly existing gas stations) where his discharged batteries would be swapped with fully charged batteries. The fully charged batteries would be brought from an off-site recharging station to the service stations by all electric trucks as shown in Figure 4. Figure 5 shows research done on actual potential locations for a recharging station supplying gas stations located in Mumbai, India.

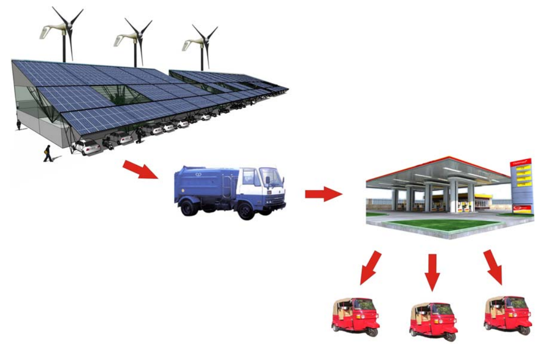

Fig. 4. Recharging infrastructure diagram [1].

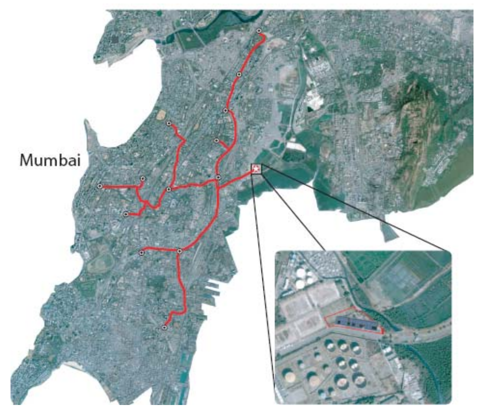

Fig. 5. Proposed locations of mother and daughter stations in Mumbai, India [1].

There are several goals set for the design of the recharging station: (a) the battery swapping process should appear to the rickshaw driver to be as quick as filling up a gas tank, and should be efficient and effective, requiring training for the battery swap servicers. (b) The fraction of renewable energy sources used to charge the batteries should be maximized while minimizing the time to recover financial investments. (c) To eliminate additional stress on the grid, we want to operate the recharge infrastructure with minimal or no grid interaction, especially since the grid is weak or non-existent in rural areas of India.

First the load of the charging station, in terms of daily energy demand, is estimated based on assumptions of how the rickshaws are operated and how the batteries are transported. This load is also a function of the battery technology used, but it should be distributed in a way which matches the output of the solar array. Over a 24 hour period, the amount of energy produced by the recharging station should equal the energy used by the rickshaws in addition to the energy used for transporting the batteries, and compensate for all losses.

After deciding to use wind and solar energy systems and to avoid connecting to the grid, the chosen energy buffer is a propane generator. Next, there are four stages to optimizing the size of the recharging station components, implemented and tested in HOMER: (a) determine the optimal ratio of wind to solar capacity to minimize the month-to-month fluctuation in energy availability based on historical resource data; (b) set the load profile to match the renewable energy availability but still meet daily energy demand; (c) size the renewable resources to meet all of the demand during the months when renewable resources are at their maximum, resulting in no losses due to overcapacity during those months; and (d) vary the size of renewable systems to minimize excess electricity produced, but maximize the ratio of energy produced by renewables [1].

We used HOMER software to find optimized ways of charging (and in some cases discharging) the batteries given the other goals listed above. Once the station layout is found, the average amount of power produced by renewable energy sources is calculated and three optimized layouts are presented below in Table VII. The procedure used involves a delicate balancing act, so there may be other optimal designs not shown here.

TABLE VII
OPTIMIZING RECHARGING STATION COMPONENTS [1]

	Case 1			Case 2			Case 3		
	PV	Wind	Gen	PV	Wind	Gen	PV	Wind	Gen
Size (kW)	**600**	**438**	**350**	**540**	**394**	**350**	**480**	**358**	**350**
Output (MWh/yr)	**1288**	**1128**	**896**	**1159**	**1031**	**1053**	**1030**	**914**	**1246**
Excess (%, MWh)	**4.82, 159**			**2.74, 89**			**1.11, 35**		
% Renewable	**73**			**67.5**			**61**		

VII. AUTO RICKSHAW 2.0

The classic auto rickshaw can be characterized by its tin/iron body supported by three small wheels (one in front, two in back), with a seat for the driver in the front and a bench seating three in the rear. It has an open design: no doors for the driver or passengers, allowing quick pick-ups and drop-offs. In our redesign of the rickshaw, we do not want to change any part of the above characteristics, which we consider to be aspects of the "signature," or identity, of the rickshaw. We want the new rickshaw to be compatible with the old, that is, to be used by drivers and passengers like the old rickshaw is used.

Table VIII shows the technical specifications of a model design for the next generation auto rickshaw. These are technical aims, not actual results; they have been chosen based on business and engineering aspects of the rickshaw.

There are a few options for incorporating solar technology on the rickshaw, as discussed and analyzed below: (1) solar power for auxiliary (low voltage) loads, (2) solar power for propulsion (high voltage) loads, and (3) solar power for all loads (integrating high voltage and low voltage systems).

The solar radiation per square meter per day, on average received in most parts of India is about 4-7 kWh [8]. The rickshaw has about 3.4 meters square of space available on the roof alone to put solar panels. Considering only being able to capture about 5-10% of that energy due to inefficiencies of the panel, converters, dust, and less than ideal tracking conditions, the actual energy recoverable per day may be less than 1-2.5 kWh when using the entire surface.

TABLE VIII
SPECIFICATIONS OF A MODEL DESIGN FOR THE AUTO RICKSHAW 2.0

Components	Value
Electric Motor	15 hp (max), 48 V
Batteries	Lithium, 5 kWh, 48 V, 100 Ah
Solar Cells	250 W (max)
Energy Efficiency	Up to 16 km/kWh (10 mi/kWh)
Range	Up to 120 km or 75 mi per charge with solar, 80 km or 50 mi per charge without solar
Top Speed	70 km/h (43 mph)

Using information from [9], the auxiliary load is estimated at 500 Wh per day, depending on the use of the rickshaw and the weather conditions. Therefore, solar panels covering the roof would supply more than enough to meet this requirement, even if they were downsized by 25%. Using these assumptions, a cost-benefit analysis of the three systems described above is performed, shown in Table IX.

TABLE IX
COST-BENEFIT ANALYSIS OF VARIOUS SOLAR ASSIST TYPES

Solar Assist Type	Extra Cost ($)	Extra Weight (kg)	Estimated Extra Range (km)
Auxiliary Loads (LV)	835	16	11
Propulsion Loads (HV)	955	19	13
All Loads (LV and HV)	1195	23	16

VIII. DRIVE TRAIN OPTIONS

The following are the options of new drive trains for electric and hybrid rickshaws (Figures 6-9). Relative advantages and disadvantages are presented below.

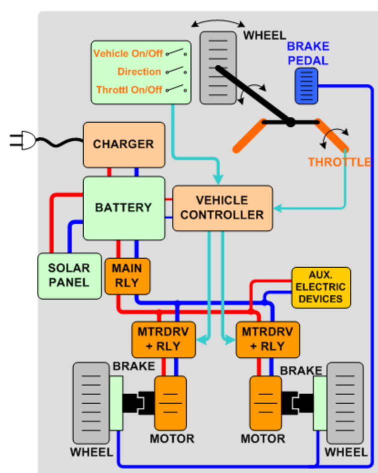

Fig. 6. Type I drive train with direct drives.

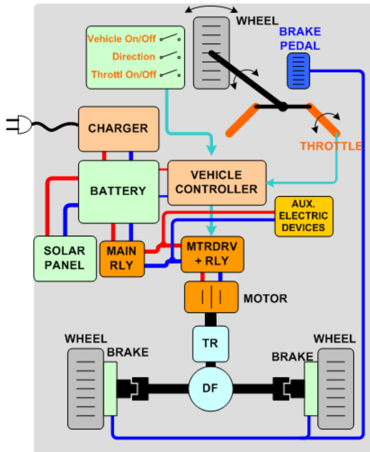

Fig. 7. Type II drive train with one electric motor.

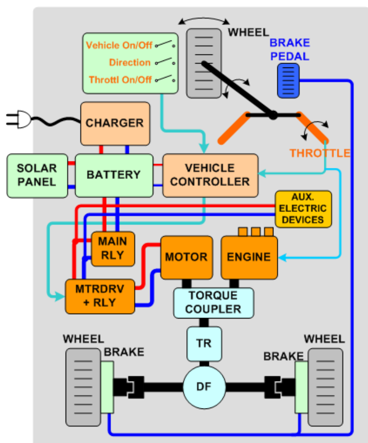

Fig. 8. Type III drive train with a parallel hybrid configuration.

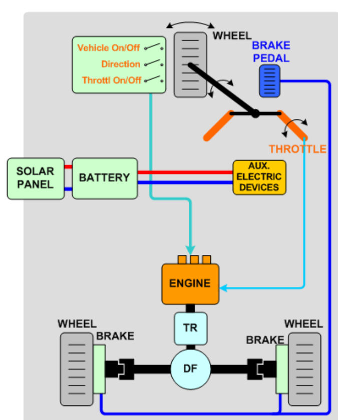

Fig. 9. Type IV drive train—conventional rickshaw with a solar assist auxiliary unit.

The options are rated in terms of potential efficiency, performance, reliability, and cost. Type I has advantages in performance because of its direct drive propulsion system. However, type I is more expensive compared to type II, which is simpler to implement. Type III is a hybrid drive train, which is not as attractive as the all-electric systems, because of the small size of the vehicle. All-electric drive trains of types I and II are fully capable to achieve the performance and range requirements of the rickshaw. Type IV is a conventional rickshaw with a solar assist auxiliary power unit.

IX. Solar/Battery Auto Rickshaw: Selected Configuration and Simulations

Of drive train types I through IV, we chose to implement type II based on the factors listed above. Figure 10 shows the block diagram of the Auto Rickshaw 2.0, to compare to Figure 1.

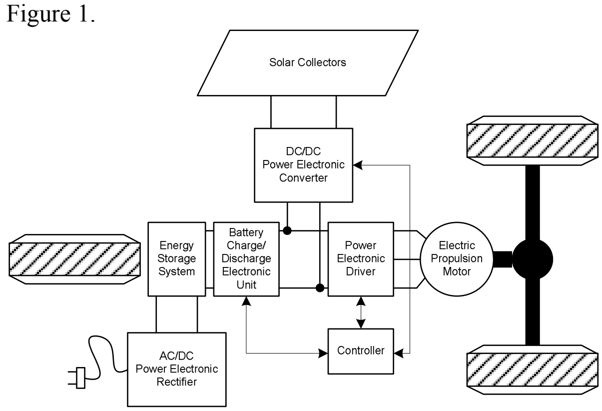

Fig. 10. Drive train of the Auto Rickshaw 2.0.

We have simulated four vehicles in ADVISOR software: an all-electric vehicle and three electric vehicles with extra energy supplies for added input from the various arrangements of the solar panels. The objectives of these simulations were to (a) examine whether it is possible to achieve the design objectives outlined in Section VII with the new drive train and its components, and (b) to test the relative advantages of the three types of incorporations of solar panels (Section VII). Table X and Table XI lists various results gathered from ADVISOR simulations.

TABLE X
Specifications of Auto Rickshaw 2.0 Simulations

Components	Value
Electric Motor	Unique Mobility 15 hp (max), 5000 rpm
Batteries	Lithium, 5 kWh usable
Solar Cell Output Power	200-250 W
Gear Type, Ratio	Single Speed, 7:1

TABLE XI
Simulation Results for Various Rickshaw Types

Vehicle Simulated	Efficiency of Gear, Axle and Wheel (%)	Efficiency of Motor/ Controller (%)	Vehicle Economy (Miles per kWh)	Range (km)
All Electric Rickshaw	73	77	9.94	78.4
Solar Auxiliary Assist	73	77	9.57	84.7
Solar Propulsion Assist	73	77	9.53	88.3
Solar Assist (All Loads)	73	77	9.51	92.1

All simulations of the rickshaw meet the drive cycle. The rickshaw achieves around 49 miles or 78 km per charge without solar and 57 miles or 92 km per charge with the solar assist. These results assume (a) that the usable range of a lithium ion battery pack is 65-70% of the full capacity [10]; (b) that the rickshaw is driven for half light traffic and half heavy traffic miles; (c) that most of the day, the rickshaw carries the driver and half of the time it carries one passenger and his luggage; (d) that a maximum power point tracking (MPPT) system is used; (e) that there is not a large amount of dust on the solar panels. Regarding (d), there is research in papers [11]-[16] to suggest that MPPT systems can be designed in such a way to achieve great output even under changing atmospheric conditions, shading or irradiance conditions, such as those that would inevitably occur on the roof of a vehicle.

The results show that we do not achieve the maximum increase in vehicle range from solar panels that we had estimated in Table VIII. This is because our simulated vehicle has not been optimized yet. System efficiency as well as drive train efficiency will improve by such optimization, improving the range. In addition, a more efficient solar panel will be used.

Overall, these data indicate that the design choices so far give us a viable solution for this vehicle in terms of performance and range. Performance is indicated in both the vehicle efficiency, which is substantially improved over a petrol-based system, and meeting the drive cycle. The range of the simulated vehicle, though it does not match the estimates given in Section VII, is within limits suggesting that small vehicle or control improvements can help push it further.

X. Conclusions and Future Work

The rickshaw plays a fundamental role in the Indian auto industry. We have explored that role and the role of alternative technologies in this industry, including renewable energy technologies. Research shows that there is adequate support and a great premise for technologies incorporating renewable energies. Thus, simulations have been performed on the supporting infrastructure for an electric rickshaw and on the rickshaw itself.

The simulations show that an all-electric rickshaw with solar assist can achieve a feasible range of operation during a single charge. One rickshaw design considered as a case study here can go about 90 km. With appropriate control and solar energy input, it is possible to achieve the average daily range of the vehicle, which makes the case for the technology of a plug-in electric rickshaw with solar assist. From this point, efforts should be focused partly on increasing the efficiency of the electrical system and all mechanical components. Future work will also entail a detailed analysis of solar technologies, including dimensions and schemes. For example, an analysis of the advantages of adding a partial sun-tracking system and MPPT system and the trade-offs associated with such additions will be explored. In addition, further investigation of the motor and controller efficiency is necessary to optimize overall vehicle efficiency.

Acknowledgement

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