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Implementation and Road-Testing of a Solar Three-Wheeler

Frank A. Coutelieris

Abstract – *This project was developed on the basis of urban green transportation in order to obtain a zero-emissions vehicle that could use photovoltaic panels. Because of the space needed for the PVs, the core idea is to design a Three Wheeler (tricycle) with Front Wheel Drive, since the motor was located in the front wheel. On the contrary of what the most of the commercial electric bikes do, this vehicle would not use grid electric power, being charged only through renewables (PVs) in order to be completely environmental friendly. For the sake of comparison, two different configurations carried out: the first was supplied by a 36 VDC /750W hub motor along with three 12V/18Ah batteries connected in series, while a sophisticated rear axle with mechanical differential has been implemented, as well. The second one was powered by a 24 VDC /500W hub motor along with two 12V/25Ah batteries, having totally independent rear suspension with swing-arms. Both configurations were integrated with electric brakes (front) and a double - disk brake system (rear). In order to test the vehicles, tree different patterns for typical users have been selected: (a) unstoppable use, (b) regular urban use, and (c) normal employee transportation. In all cases and independently of the solar radiation intense, both configurations presented good performance, being able to cover normal urban transportation. More precisely, the 24 VDC vehicle found sufficient for all the above described patterns of usage, thus underlying that grid charging is completely unnecessary.* ***Copyright © 2014 Praise Worthy Prize S.r.l. - All rights reserved.***

***Keywords**: Electric Vehicle, Hybrid Solar Vehicle, Zero-Emission, Photovoltaic, Solar Energy*

I. Introduction

In general, transportation is significantly based on internal combustion engines using non-renewable fossil fuels, thus emitting greenhouse gases, various air pollutants and volatile organic compounds [1].

In order to resolve these problems, Electric Vehicles (EV) have the potential to offer an alternative option eliminating emissions.

Being invented more than 100 years ago and commercially available by the 1930s, EVs is one of the most promising candidates to reduce the dependence of oil in the transportation sector. In the last 10 years the world has again considered vehicle electrification, where this renewed interest represents a "third age" of electric vehicles, starting with the mass-market introduction of EVs in 2010 [2]. Generally speaking, rather than being "zero-emissions", a typical electric car is "emissions-elsewhere" vehicle, since the electricity to charge the batteries must be generated in electrical generation plants that produce emissions [3]. As far as a solar powered car crossed the Australian continent since 1983, it has been proved that solar powered vehicles could be an option for in-situ charging without making use of grid electricity [4]. After this pioneering prototype, solar vehicles become more popular through university research, economy races as well as big car manufacturers [5], [6].

Unfortunately, solar energy applications still face major difficulties in terms of storage and high initial costs, which must be consider on top of the conventional problems that electrical cars face, such as the batteries and transmission problems. To overcome these barriers, several attempts have been implemented [7], [8]. Unlike most papers that the design of a solar vehicle is for demonstrative and/or race purposes [9], [10], this paper focuses on a solar car foe everyday urban use, which is more practical.

II. Materials & Methods

II.1. General

The main idea was to design and construct a vehicle with zero emissions that could also use PV panels. The fundamental idea of a zero-emission solar vehicle is to design a vehicle powered by photovoltaic solar energy by means of solar panels, with storage of electric energy in batteries while the traction is obtained by an electric motor. In order to obtain the necessary space needed for the PVs, the vehicle was designed as a tricycle with the motor is in the front wheel (FWD).

This configuration allows for the simultaneous use of both motor and pedals, thus adding the power offered for the movement. Note such a configuration is not strange since oil-powered three-wheeled vehicles commonly used as people and goods carriers in many Asian countries, having significant impact in pollution problem due to the poor maintenance and the use of obsolete

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technology with very low pollution control [11].

In order to identify the significance of operational voltage on the overall performance, two different configurations have been designed and built: one with 36V and one with 24V. The difference is on the area required for the PVs installations, therefore on the overall dimensions, weight and performance of the 3-wheeler.

Obviously, all the fundamental aspects presented above, have been followed in both cases.

II.2. Configuration No 1: Trike with Rear Axle

The first configuration is presented in Fig. 1 while some details are depicted in the first column of Table I.

The frame has been made by 1/2" steel tube and, actually, was only the rear back of the whole chassis, connected with a commercial typical front bicycle frame.

To take advantage of the solar radiation, the PVs have been placed at the highest available position in an inclined plane at the back of the driver and above the wheels. Furthermore, the batteries were put in a lower centered position.

Fig. 1. The first configuration of the 3-wheeler

TABLE I
OPERATIONAL CHARACTERISTICS OF THE VEHICLES

	1st configuration	2nd configuration
Motor Power (W)	500	500
Batteries (-)	3x12 V / 18 Ah / Pb	2x12 V / 18 Ah / Pb
Solar Panels	3x12 V / 45 W / Polycrystalline silicon	2x12 V / 45 W / Polycrystalline silicon
Length (cm)	255	303
Width (cm)	110	84
Height (cm)	108	102
Clearance (cm)	18.5	30
Weight (kg)	82.5	60.5

One of the most critical parts of this project was the rear axle that is significantly different from the commonly used axles, encountered in stock tricycles.

Due to the requirement that the rear wheels must be able to move independently from each other and from the axle, a system of two half axles with universal joints between them has been implemented. For an easily disassembly of the axle for maintenance and repair purposes, a design where each wheel is placed on a swiveling internal axle has been implemented along with three externals permanent tubular axles, being connected in the whole construction (see Fig. 2). To support the internal swiveling axles, the two of these permanent axles were used for the assembly with the rest of the frame and the third one used for the alignment of the internal axles.

Due to the increased weight (compared with a commercially available tricycle), two rear disk brakes at the internal axles connected to one cable have been used, while the gearbox along with the chain adapters have also been put on the rear axle. All these features are completely unique, not encountered at any other commercially available tricycle.

Fig. 2. The rear axle

To move the vehicle, a Hub Motor by Golden Motor © has been mounted into the front wheel. This type of motor emerges as the standard drive method for not just e-bikes, but scooters, solar cars, and many other light electric vehicles. With hub motor conversion, there is no need for external mounting brackets and transmission system to support controllable motion. Front braking was also fully controlled by the motor.

The electrical circuit is depicted in Fig. 3. Three solar panels connected in series to obtain the overall voltage needed (36V), were directly connected to the inverter.

Then, inverter was connected with three 12V/18Ah batteries and the controller, which was connected to the other electric stuff (motor, throttles, brakes and horn).

Finally, a fuse and a power-lock system have been added to protect the vehicle. By using rubbers as well as insulation tape, some "suspension" has also been added in the sub-frame where the panels are placed, to avoid damages caused by vibrations.

II.3. Configuration No 2: Trike with Independent Rear Suspension

To implement the second configuration, the same fundamental concepts have also been followed (Fig. 4).

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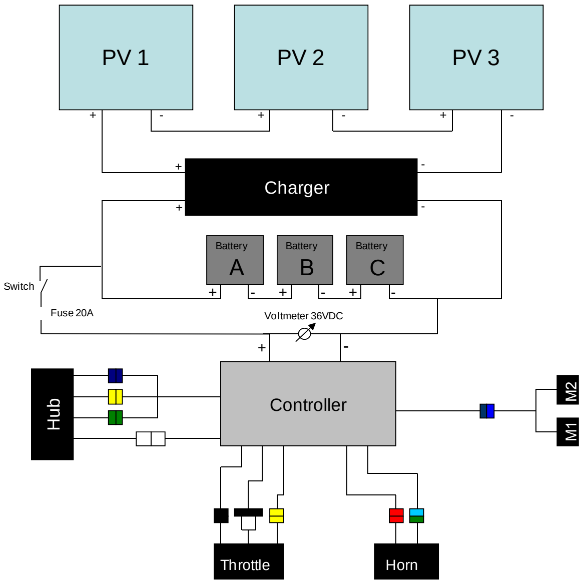

Fig. 3. The electrical circuit

Fig. 4. The second configuration of the 3-wheeler

Again, a FWD 3-wheel was built, being in general smaller and lighter than this of the first configuration (see Fig. 5 for a rough estimation and the second column of Table I for details). Towards this aim, a totally new frame has been designed and constructed, by using 1/2" aluminum tube. It is worth mentioning that no commercially available parts have been used for this frame. Rather than using a saddle, a specifically designed and made leather seat has been implemented to provide some comfort. The selected Hub Motor was a Golden Motor © 24V/500W one, mounted in the front wheel and supported by two 12V/18Ah batteries (see Table I for details). A significant innovation presented here was the rear suspension system, consisted of two stainless-steel independent swing-arms, hinged by a specifically made axle and controlled by shock-absorbers (Fig. 6). This system provides also suspension to PVs, thus preventing potential damages due to non-smooth riding. To obtain such an independent rear suspension, a rear axle has not been used, thus leading to critical modifications compared with the first configuration: vehicle become only motor driven, without pedals, chain and gearbox.

Fig. 5. Rough comparison with a typical bicycle

Fig. 6. The suspension system

The electrical circuit integrated here was the same as for the first configuration, as well as the breaking system.

III. Results and Discussion

Before road-testing, it is absolutely necessary to identify motor's energy performance when operating without load. Thus, a set of measurements were carried out in laboratory environment, where motors were mounted in the front steering/suspension system to include the friction losses due to front axle mounting but operate in ground-clearance conditions, thus excluding net forces (frictions) caused by loads.

Motors were supplied by the appropriate batteries - systems till voltage level dropped under a minimum allowable value. The throttle was locked to maximum position during the experiments. All the measurements have been made twice and the averaged values are presented in Fig. 7, where they have been normalized to become directly comparable. To achieve this normalization, the following maximum and minimum values were used:

- First configuration: Maximum Voltage = 38VDC, Minimum Voltage = 33VDC, Maximum Rounds = 350 rpm, Minimum Rounds = 250 rpm.

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- Second one: Maximum Voltage = 27VDC, Minimum Voltage = 22VDC, Maximum Rounds = 220 rpm, Minimum Rounds = 120 rpm.

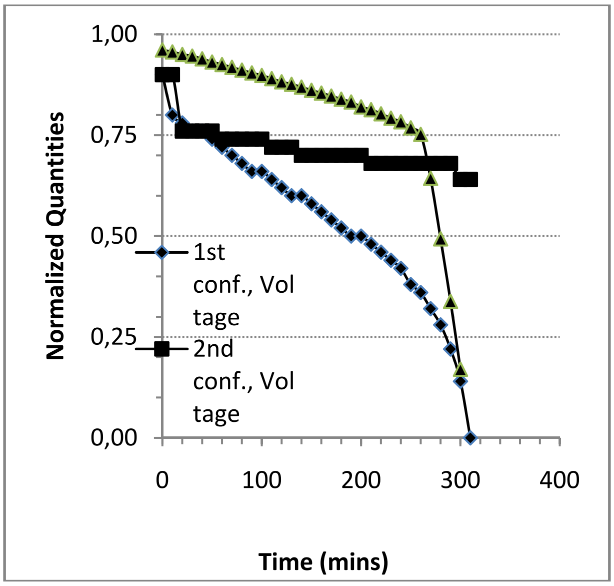

Fig. 7. Energy consumption of the motors without load. Full throttle

It is rather obvious that the 24 VDC motor is significantly more efficient than the 36 VDC one. In terms of voltage, the first motor consumes less than 50% of the available energy for less than 4 hours while the second one consumes always as less as approx. 30%.

This behavior was also recorded in RPM measurements, where the 24 VDC motor is in a range of over 90% during the whole time period where the measurements were carried out, while the 36 VDC motors drops down to 70% after 4 ½ hours. This advantage for the 24 VDC motor can be attributed to the high technology used for its implementation, since it has been designed and placed in the market more than 4 years later than the 36 VDC motor.

For a sufficient road-testing, all the possible conditions that such a vehicle could face must be covered.

Therefore, three different usage patterns have been selected: (a) unstoppable use, (b) regular urban use, and (c) normal employee transportation. The first one corresponds to continuous riding with maximum speed (as it is determined through road and traffic conditions) till power supply goes off. The second one represents the regular everyday use in urban conditions for such a vehicle: small-distance routes with many stops of various durations while several different combinations of distances and stops have been examined. The third one represents the use of the vehicle by a typical employee.

As far as the working hours are normally 8 and the average distance from the house to the work is approx. 8 km in standard urban conditions [12], this pattern is as follows: initially the vehicle must cover a distance of 8 km, then it is parked for 8 hours and, finally, the same distance must be covered again to return home.

It is rather clear that all the field-measurements for such a road testing are climate and geomorphology dependent. Climate component affects the system through the solar radiation being available for charging the batteries through the solar panels, while geomorphology has significant influence on the energy consumption.

To exclude the latter from the measurements, a rather flat area without considerable altitude differences has been selected (namely, Agrinion, Greece). On the other hand, the climate component is crucial for vehicle's efficiency, thus the measurements for every pattern have been taken four times, each one representative for a season. For statistical confidence, all the measurements have been repeated twice.

Table II demonstrates the results regarding the first pattern. It is clear that the second configuration is significantly advantageous compared to the first one, because its range seems to be 37.8 % increased (22.8 km instead of 16.55 km), while both average and maximum speed are almost identical for both cases. The same behavior is also presented in the next two measurements, where the range covered by the second configuration is constantly higher than that of the first one for both cases.

More precisely, the 24 VDC vehicle performs 38% better than the 36 VDC one under standard urban conditions (see Table III for details).

This can be attributed to the lower weight and the better energy management that the second configuration achieves.

TABLE II
RESULTS FOR CONTINUOUS USE

	1st configuration	2nd configuration
Distance (Km)	16.55	22.8
Average speed (km/h)	17.6	17.4
Max speed (km/h)	29.5	28.5

TABLE III
REGULAR URBAN USE

	1st configuration		2nd configuration	
	Sunny day	Cloudy day	Sunny day	Cloudy day
Distance (Km)	18.10		18.10	
Average speed (km/h)	17.21		17.55	
Max speed (km/h)	30.50		30.10	
Energy remaining in the battery bank (%)	36.67		59.78	

Finally, results for "typical employee" pattern (Table IV) further underline the same behavior. It is worth mentioning that the second configuration presents consumption low enough to assure that a significant portion of energy remains in the battery bank, thus allowing for next-day use, even for those day that the sunshine is poor. On the other hand, the 36 VDC vehicle failed to cover the whole distance for cloudy days, further signify the superiority of the second configuration.

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TABLE IV
TYPICAL EMPLOYEE TRANSPORTATION

	1st configuration		2nd configuration	
	Sunny day	Cloudy day	Sunny day	Cloudy day
Distance (Km)	16.34	14.63	17.10	17.60
Average speed (km/h)	14.70	15.45	18.65	15.85
Max speed (km/h)	28.70	29.30	28.50	28.70
Energy remaining in the battery bank (%)	41.20	0	60.30	39.05

IV. Conclusion

The design of an experimental solar vehicle was presented and described in this manuscript, where photovoltaic solar energy is the main electricity source.

Excellent results related to transmission, weight, and flexibility were obtained using styrene base polymer to encapsulate the solar cells. A tricycle with a hub motor in front, that does not make use of grid power, has been designed.

Two different configurations were implemented: (a) a 36 VDC /750W with rear semi-axes, and (b) a 24 VDC /500W with rear independent swing-arms. In order to test the vehicles, tree different patterns for typical users have been selected: (a) unstoppable use, (b) regular urban use, and (c) normal employee transportation. The obtained results on experimental trials of the energy systems, the tests carried out over photovoltaic solar panels, mechanics, electric and electronic systems are all satisfactory. It is found that the 24V configuration is superior, since it presents higher range than that of 36 V case, with the same average and high speed.

Furthermore, both cases proved to be grid independent when used for normal urban transportation.

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Authors’ information

Department of Environmental & Natural Resources Management, School of Engineering, University of Patras, 2 Seferi Str., GR-30100 Agrinio, Greece.
Tel.: +30 26410-74196
Fax: +30 26410-74176
E-mail: fcoutelieris@upatras.gr

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