RESEARCH ARTICLE

Towards Small Solar Cars for Urban Use: Implementation and Road-Testing

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Abstract:

Background:
As far as urban transportation is significantly responsible for the current environmental issues, significant effort is put on designing and implementing efficient electric vehicles. Solar power seems to be an important option in that direction, thus we have developed a zero-emissions vehicle for urban use, that makes use of photovoltaic panels to charge the battery bank. More precisely, a two-seated four-wheels buggy-type vehicle has been designed, developed and tested on the road,, which has low dimensions and is of a relatively high area available.

Methods:
Two 48 VDC /1.5 kW hub motors were positioned at the rear wheels, where four 12V/100Ah batteries connected in series were used to supply the motors. Flexible photovoltaic panels of overall 0.9 Kw peak power have also been used to charge the battery bank. The vehicle was integrated with electric brakes (front) and hydraulic disk brakes (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.

Results:
In all cases and independently of the solar radiation intense, the configurations presented good performance, being able to cover normal urban transportation for any pattern of use considered.

Conclusion:
This work is actually another evidence that solar cars for urban use are feasible, especially for locations with favorable solar potential.

Keywords: Electric vehicles, off-grid systems, solar panels, solar energy, zero-emissions.

1. INTRODUCTION

Cars and trucks fleets have been nowadays considered as major responsible for the environmental issues, faced at least at urban level. The constantly increased total amount of vehicles worldwide corresponds to increased energy consumption and enormous emissions, both during their production and use phases. To overcome this problem, car manufacturers have designed and developed several types of environmentally friendly vehicles, mainly based on electric motors (Electric Vehicles – EVs). The types of these vehicles are battery electric vehicles (BEVs), fuel cell electric vehicles (FCEVs), hybrid vehicles (HEVs) and the solar powered vehicles (SPVs) [1].

Broadly speaking, the principles for building such vehicles are as follows: one or more electric motors are used as primary or secondary mechanisms to assure vehicle's motion, while the differences between the different types of EVs encountered on the energy storage systems and the way that it is charged. In this context, there are two main classes of EVs: the vehicles that must be connected to the grid in order to charge their storage system and those that are autonomous, assuring enough energy by off-grid sources. Actually, the "grid-charged" vehicles must considered as "emissions-elsewhere-vehicles" rather

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than "zero-emission-vehicles" [2]

Typical examples of these vehicles types are the BEVs and, on the other hand, FCEVs. Precisely, BEVs include a drive system powered by batteries, thus achieving very low environmental impact (zero emissions). Beyond grid connection, a part of batteries charge is currently assured by alternatives such as braking energy recovery, suspension, etc., thus the loads needed by the grid are significantly lowered. On the other hand, FCEVs store energy differently: being fueled by hydrogen and oxygen, they are supplied by the appropriate catalytic reactor (fuel-cell) that allows the transformation of these reactants to water and electricity, supplying the motor. Nonetheless, there is no need to plug-in FCEVs, since their fuel cells are recharged by refilling with hydrogen [3].

It is important to note that the automotive industry puts some effort on liberating from grid connection all vehicles that use electric motors, either as primary or as secondary power source. In this context, the identification of reliable alternatives is a research topic of constantly increasing interest [4]. In this context, solar energy might be a serious option, especially for places of high solar potential [5]. Actually, solar vehicles become more popular through university research and low energy consumption competitions [1, 6]. In industrial/massive-production lever, solar energy vehicles 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.

Our main objective is to apply solar power as a feasible energy source for urban transportations, by actually aiming at developing a vehicle of zero emissions, being suitable for everyday use. To study the feasibility of such a vehicle, our product was tested in specific urban-use patterns, in order to quantify its performance for several meteorological conditions.

2. MATERIALS & METHODS

The main idea was to design and construct a vehicle with zero emissions, ably to make use of PV panels, with storage of electric energy in batteries while the traction is obtained by electric motors. The main problem with the PVs is the area needed to achieve the necessary electricity, therefore, the vehicle was designed as buggy-type with the motors positioned in the rear wheels (RWD). This choice allows for enough space in the front of the vehicle and on the roof, to put the panels.

Figure 1. The final configuration of the buggy-type vehicle.

Nevertheless, to take advantage of the solar radiation and, simultaneously, to satisfy aerodynamic requirements, the PVs were chosen so that to achieve the highest possible exposure to sun as well as to comply with fundamental principles of aerodynamics. To reduce car's weight, PVs were also flexible, being therefore able to be placed at the highest available position in curved planes, covering vehicles fenders, roof and front hood.

The overall dimensions of the car are quite small to assure an easy- and fun-to-drive urban car. The final configuration is presented in Fig. (**1**) while some details are depicted in Table **1**. The frame has been made by 2 inch steel tube and, actually, was only the rear back of the whole chassis, connected with a commercial typical front frame, which has been further strengthen wherever necessary. Furthermore, the batteries were put in a lower centered position to keep the gravitational center as low as possible.

To move the vehicle, two Hub Motors by Golden Motor©, 48V/1500W each, were mounted in the rear wheels and supported by four 12V/100Ah batteries (see Table **1** for details).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 due to relatively low weight, the significant saving in vehicle's available space and the high reliability of these motors, while it becomes extremely easy to achieve "reverse" option. To regulate motors' power, two 18V-60V/80A controllers by Kelly Controls LLC were used, after programming them properly. Also, both the controllers and the batteries were placed in the rear frame, to balance the front/real distribution of the full load of the car. With hub motor conversion, there is no need for external mounting brackets and transmission system to support controllable motion. Rear braking was also fully controlled by the motor. 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. This system allows for absence of rear axle, since motors are mounted directly on the ball-joints and, therefore, the rear suspension consisted of independent swing-arms, hinged on the front "stationary" part of the frame and controlled by shock-absorbers. This design allows the car to become only motor-driven, without transmission axle and gearbox. Due to relatively high weight and the high performance expected, two hydraulic front disk brakes at the internal axles have been used, while, for the front suspension, a double wishbone system equipped with gas shock absorbers was selected. All these features are completely unique, not encountered at any other commercially available buggy.

The electrical circuit is depicted in Fig. (**2**). Ten flexible solar panels were connected in the appropriate complicated form to obtain the overall voltage needed (48V), were directly connected to the two solar chargers, connected in series to achieve 48 VDCto supply the four 12V/100Ah batteries and the regulator for the supportive electric stuff (throttles, brakes, etc.). An analog 48V-to-12V/30A converter has been also used to provide the necessary 12V voltage for the secondary circuit (headlights/taillights, turn signals, horn, etc.). Needless to say, fuses, gauges and a power-lock system have been added to the vehicle.

Table 1. Operational characteristics of the vehicles

Motor Power (W)	2 X 1500
Batteries (-)	4x12 V / 100 Ah / Pb
Solar Panels	10x12 V, flexible, 900Wp overall
Length (cm)	211
Width (cm)	137
Height (cm)	110
Weight (kg)	217

3. RESULTS AND DISCUSSION

For a sufficient road-testing, it is important to simulate the common types of everyday use that such a vehicle could face. 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 limited by 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 [7], 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. Towards excluding the effect of geomorphology 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. All the measurements have been repeated twice.

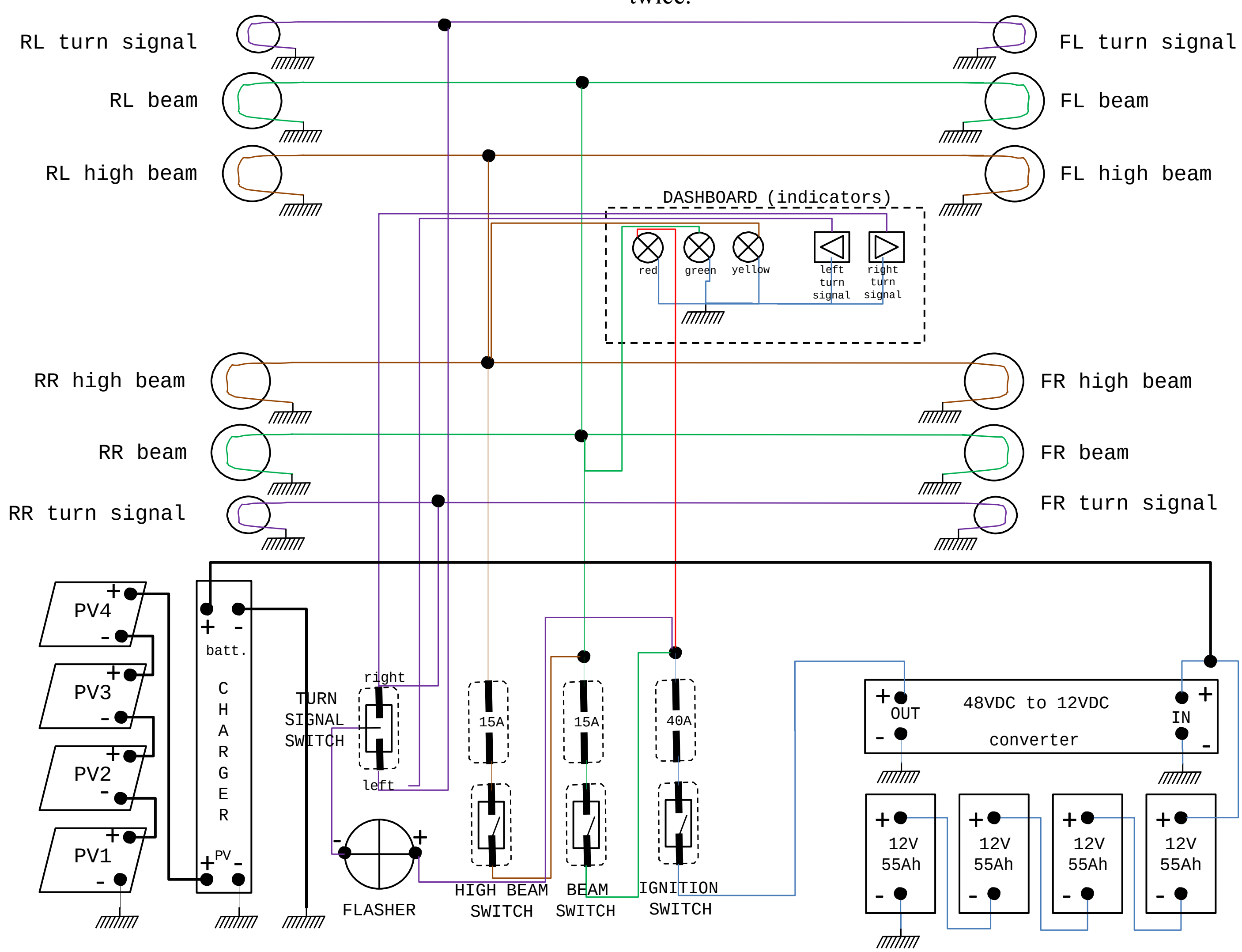

Figure 2. Electrical circuit.

Table **2** demonstrates the results regarding the first pattern. The weather in these patterns was sunny. The first measurement took place outside of the city center, where the road is both almost flat and in a very good condition, leading to a pleasant driving experience. Also, this route has minimum STOP signs, no traffic lights and only a few intersections. To investigate the effect of the traffic conditions on the measurements, the experiment was repeated in a route through the city center, where the car had to face traffic jam, several STOP signs, intersections and traffic lights, as well. It is clear that the vehicle presents the advantage of high maximum speed (approx. 51 km/h) and sufficient range (uninterruptedly, more than 21 km) with remarkable average speed. These results are more than encouraging, to proceed further with road tests concerning the other usage patterns.

Table 2. Results for continuous use.

	High traffic load (city center, 29 °C, sky clear, daily averaged solar radiation 1705 kWh/m^2)	**Low traffic load (suburban, 26 °C, sky cloudy, daily averaged solar radiation 1628 kWh/m^2)**
Distance (Km)	19.10	26.25
Average speed (km/h)	17.00	12.10
Max speed (km/h)	47.50	52.50

Table **3** depicts the results when regular urban use has been considered. The distance covered was typical for urban use, according to the standards posed elsewhere [7]. The concept was to use the vehicle for typical daily transport, therefore we have designed a route through city center with several short stops (5 min. on average) and some large ones (2 hours on average). To exclude the meteorological impact, road tests have been carried out in both sunny and cloudy day, in order to clarify the impact of solar potential on vehicle's performance. Definitely, the vehicle fully succeeded this test, achieving to return always back to the initial point, while enough energy remained stored in the batteries when the car successfully has covered the desired distance. Obviously, the remaining energy is higher for sunny days, as expected.

Finally, results for "typical employee" pattern (Table **4**) further underline the same behavior. The concept of this experiment was to simulate a typical employee's transportation to- and from- his/her work, where the distance between starting and ending points was considered 8 km [7]. The route followed was both inside and outside the city. It is worth mentioning that the consumption was low enough to assure that a significant portion of energy remains in the battery bank, thus allowing for next-day use, even for those days when the sunshine is poor.

Table 3. Regular urban use.

	Sunny day (28 °C, daily averaged solar radiation 1711 kWh/m^2)	**Cloudy day (28 °C, daily averaged solar radiation 1635 kWh/m^2)**
Distance (Km)	18.10	18.10
Average speed (km/h)	14.85	14.25
Max speed (km/h)	46.94	47.72
Energy remaining in the battery bank (%)	53.55	41.07

Table 4. Typical employee transportation.

	Sunny day (28 °C, daily averaged solar radiation 1709 kWh/m^2)	**Cloudy day (29 °C, daily averaged solar radiation 1689 kWh/m^2)**
Distance (Km)	17.05	16.89
Average speed (km/h)	26.94	26.23
Max speed (km/h)	52.85	48.00
Energy remaining in the battery bank (%)	51.15	43.11

Conclusion:

The design of an experimental solar vehicle was presented and described in this manuscript, where photovoltaic solar energy is the main electricity source. Supportive results related to transmission, weight, and flexibility were obtained using flexible solar cells. A buggy-type, 2-seater 4-wheels vehicle with two hub motors in rear, that does not make use of grid power, has been designed. The configuration implemented was based on two motors, 48 VDC /1500W each, 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 was found that, independently on the pattern selected, the results were encouraging, where the vehicle presented relatively low energy consumption. This conclusion actually solidifies the concept of off-grid solar-based EVs, proving that such a vehicle is feasible, at least for urban use when solar potential is favorable. Our design proved to be totally grid independent when used for normal urban transportation. Finally, it can be concluded that such a vehicle could be a considerable option for special cases such as use by people with disabilities, internal transportation in hotel units, as golf cars, etc.

CONFLICT OF INTEREST

Declared none.

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