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A photovoltaic light electric vehicle for project-based education in engineering

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Abstract.

This article presents a project for the design, manufacture and evaluation of a light electric vehicle prototype whose only source of energy comes from a photovoltaic generator integrated in it, that is, it does not have batteries for energy storage. In its approach and development, a project-based learning model (PBL) has been followed, for which a group of students from different degrees of the Escuela de Ingenierías of the Universidad de Málaga has been formed, who have developed all the tasks involved in the realization of the prototype.
The purpose of this prototype is to serve as a model for defining a new concept of student races on energy efficiency in mobility. To evaluate the performance of the prototype, tests have been carried out to characterize the energy consumption in different drive cycles and irradiance conditions and to obtain characteristics as limits of speed, acceleration and rising slope.
Another long-term objective and, therefore, not included in this article is the evaluation of the technical training and complementary skills acquired by the students.

Key words. light electric vehicle, photovoltaic electric vehicle, project-based education, student automotive races.

1. Introduction

Traditionally, engineering studies suffer from a high rate of student dropout during the first courses. Although there is no single cause that causes this problem, some studies [1] - [2] show that one of them may be caused by the fact that the contents of the first courses present a large number of subjects that are very often treated independently, so the student may perceive that he is studying a large amount of unrelated knowledge, without understanding the usefulness of each one of them, and this produces great demotivation in the student.

Traditional teaching methods based on lectures by the teacher do not allow students to get involved in the learning process. Certainly, these methods have been used successfully over the years, but on many occasions this rigid teaching system does not focus on the learning process as one of the fundamental activities for the development of future engineers. In addition, in recent times design engineering has been taking on increasing importance in study plans. This is one of the reasons for the changes that have been introduced in recent years and the restructuring of the degree plans and studies. Another problem, as has been mentioned before, was that the contents and practical experience in the first courses were practically non-existent and dealt mainly with theoretical aspects.

In this context, students do not begin to see the meaning and interconnect each of the disciplines on which they have been acquiring knowledge until more advanced courses. In many cases, the student who passes the second year has not yet experienced that the problems facing engineering are multidisciplinary and that it is necessary to have an overall vision of all the subjects in order to be able to solve them. This perspective is not usually reached until the last year of the degree or even until the development of the final degree project. Experience shows that a significant number of students lose motivation before reaching this level, with the consequent dropout.

As a response to this problem, some authors [2] – [3] propose the application of the methodology known as project-based teaching (PBL). This methodology consists of presenting students with a system development problem whose solution requires the application of as many engineering disciplines as possible. The main objective of this type of project is to offer a global vision that allows students to acquire a global perspective that helps them connect all subjects to solve engineering problems.

There are several experiences that are being developed in engineering schools around the world that use the PBL methodology. As exposed in [4] - [5], this type of proposal offers the possibility for students to connect their technical skills through solving real problems.

In most cases, students report that they are fully satisfied with this type of methodology and that they would recommend its application in other subjects [6]. In addition, the students consider that with this type of experience they acquire another series of transversal skills such as teamwork, decision-making, oral and written communication and application of different technologies. The results indicate that students who have been involved in this type of project showed improvements in these skills compared to those who had not participated in these experiences [7].

Consequently, it can be said that this type of projects is useful for reinforcing the motivation of students in the first years of their degree and reducing the high dropout rate as much as possible, offering them complementary training in which it is shown the usefulness and connection of the knowledge they are acquiring in their training as engineers.

The activities that can be developed with the PBL methodology are very diverse. In our case, we have verified that the development of vehicles to participate in automotive energy efficiency races is an activity is very attractive for engineering students [8]-[9]. However, from our experience in participating in several of these races, we have concluded that they present a series of drawbacks that make it impossible to organize them in academic institutions or municipalities, being only within the reach of multinationals (Shell Eco-marathon [10]) or regional governments. (Edu-Eco [11], Solar Race Region of Murcia [12]). Among these drawbacks we can highlight:

- The measurement system to determine the winner must have high precision, which greatly increases the economic cost for the organizers by having to hire teams of highly qualified judges.
- The race does not consist of a event in which all the vehicles participate simultaneously. It is more like training, in which each vehicle accesses the route at the times that most interest, within an interval of several days. This takes away a lot of interest for the audience, with the consequent damage to the sponsors. In addition, this brings about a great economic effort for the teams, who must stay several days in the locality where the race is held.

We have designed a new racing concept with the aim of overcoming these drawbacks and making both the organization and the participation of the teams more economically affordable. Therefore, they could be held in many more places and more frequently.
Its main characteristics are:

- It is a conventional race, all vehicles participate simultaneously and the one that reaches the finish line first is effectively the most efficient, so it does not require complex measurement systems.
- Its duration is less than an hour, so that its entire development can be carried out in a single day.

To achieve these goals, it is essential that all vehicles participating in the race have the same amount of energy available. This condition can be achieved in a practical way if this energy is provided by the sun, that is, if photovoltaic vehicles are used.

In this article we present the development of a vehicle prototype that adapts to these characteristics, whose only power source is the energy provided by a photovoltaic generator.

2. Work Methodology

Initially, the selection of the students who have participated in the project has been carried out according to two main criteria: that all the degrees of the Escuela de Ingenierías of the Universidad de Málaga were represented and that they were studying the second or third year of their degree. A total of 18 students were selected.

The work plan programmed for the students was divided into two stages: a first of basic training and a later one that included the tasks of design, manufacture and evaluation of the vehicle.

In the first stage, theoretical-practical sessions were scheduled so that the team members could learn the fundamental aspects of the constitution and operation of photovoltaic electric vehicles:

- Basic concepts of vehicle dynamics.
- Chassis and body.
- Mechanical components: transmission, steering, suspension and brakes.
- Electric motors and their electronic power controllers.
- Electronic systems for the measurement of the vehicle's main variables (speed, current, voltage, temperature, irradiance, etc.) and for their visualization by the driver.
- Characteristics of photovoltaic cells and their connection to make photovoltaic generators.

In the second stage, several working groups were organized in charge of carrying out the necessary tasks for the development of the prototype:

- Design and manufacture of the structure of the light aluminium chassis.
- Design and manufacture of mechanical elements: steering and braking system.
- Design and manufacture of the aerodynamic elements of the body and wheel fairings.
- Design and manufacture of the propulsion system: power circuits and electric differential.
- Design and manufacture of the interface with the pilot and data recording systems, sensors and telemetry.
- Design and manufacture of the photovoltaic generator (Fig. 2 and Fig. 3)

Fig. 1. General view of the vehicle chassis structure.

Most of these tasks have been carried out simultaneously, so several meetings between different groups have been scheduled to guarantee their coordination.

The design of the prototype was based on the following concepts:

- Selection of highly standardized mechanical and electronic components, which have the advantages of low price and easy accessibility in the market. As an example, the propulsion components, wheels, shock absorbers and brakes are those that incorporate electric bicycles.

- Selection of manufacturing processes within the reach of the students' abilities. For example, the entire chassis assembly was done with rivets. No welding was done because the aluminium welding process is highly specialized.

- Results from other works carried out by students from previous courses were used, both in the design of the electrical differential [13] and in the method of regulation of the power provided by the photovoltaic generator [14].

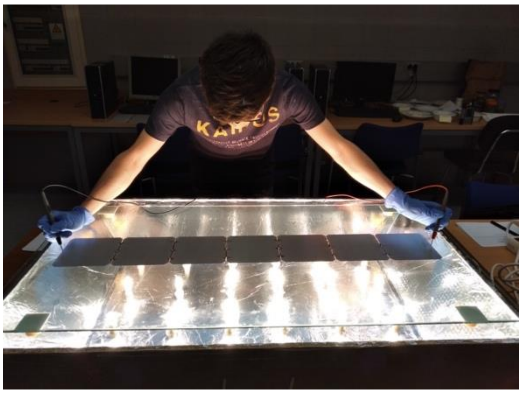

Fig. 2. Test of welded photovoltaic cells.

Fig. 3. Welding of the photovoltaic generator cells.

The technical characteristics of the vehicle are summarized in the following points:

- Quadricycle, with 135 cm track and 180 cm wheelbase.

- Total weight: 101.9 kg

- Chassis made of aluminium tubes assembled with rivets and "sandwich" panels.

- Steering system with steering wheel and gear pinion. Ackermann geometry.

- Hydraulic braking system with two independent circuits and 160 mm disc in each wheel.

- Front-wheel drive with a motor in each wheel, Crystalyte G40 model, in electric differential configuration.

- Photovoltaic generator made with 224 high-efficiency Sunpower C60 cells distributed in two parallel arrays. Its power in standard conditions is 715 Wp.

Figure 4 shows the general appearance of the vehicle, with the independent photovoltaic generator already installed, during one of the driving tests on the urban circuit of the Escuela de Ingenierías of the Universidad de Málaga.

Fig. 4. General appearance of the vehicle.

3. Testing and results

A. Tests with the photovoltaic generator

In a photovoltaic generator, the efficiency of the PV cells is a fundamental aspect. The panel is designed with cells connected in series that make up each of the individual modules, which are then connected in series and parallel to obtain the power necessary to move the vehicle. The power supplied by the generator depends to a great extent on the working point and, therefore, on the variations in the irradiance and temperature conditions of the cells. There are different alternatives that allow operating at the maximum power point, such as algorithms that use DC/DC converters to set the cell voltage that leads the generator to work in the PMP. In this section, different tests have been carried out using an electronic load. The tests carried out with the photovoltaic generator have been carried out under different irradiance and temperature conditions to obtain its real characteristics and performance. In these tests, a maximum power of 300 (W) and 280 (W) has been obtained in each of the two panel modules. Therefore, the photovoltaic generator supplies a total power sufficient to feed the two motors in the front wheels that are responsible for the traction for the movement of the vehicle.

B. Urban circuits topography

An important aspect is to know the topology of the circuit. This can be obtained in various ways, such as, for example, by means of a map of the circuit suitably divided into sections and characterizing the angles of inclination. In this case, the characterization of the circuit has been obtained with the data stored by the data acquisition system together with the GPS sensor installed in the vehicle.

Tests have been carried out in one of the urban circuits in the surroundings of the Engineering School of the University of Malaga (see Fig. 8), essentially flat with slight slopes up and down and with different conditions of irradiance and temperature. In addition, another series of tests have been carried out on sections with various uphill and downhill slopes, these sections have slopes of 7% and 14% respectively.

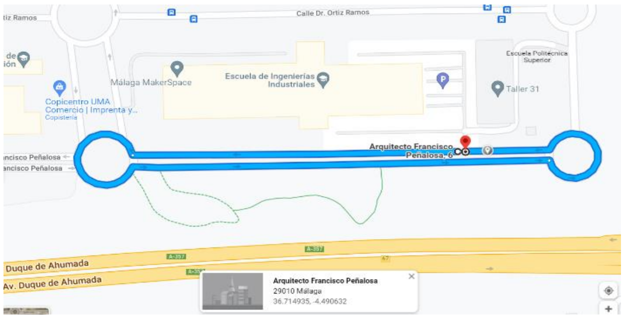

Fig. 5. ETSII urban circuit.

C. Vehicle evaluation tests

All the voltage, current, speed, irradiance and temperature data of the generator have been recorded. The objective is to establish the minimum conditions, both climatic and topology of the circuit, that must be met in order to develop a competition with this type of vehicle.

The driving tests have been carried out with a small battery, this means that the vehicle's dynamics do not depend on the generator being in the PMP. In the tests, a speed-optimized driving strategy is carried out in which it is intended to complete a lap of the circuit with the requirement that the average speed of the vehicle be constant in sections. From these tests, he obtains the driving profile when completing a lap of the circuit, which is presented together with the power in Fig. 6

The first graph shows the speed and the second graph shows the acceleration. In both they are compared with the power consumed throughout the route. It can be verified that the consumption at constant speed is quite low, producing power peaks when the vehicle accelerates.

Analyzing the data recorded in the different tests, it is concluded that in sections at a constant average speed of 10 km/h, 15 km/h and 20 km/h, the vehicle requires an average power of 65.10 W, 95.68 W and 109 W, respectively. In addition, another important conclusion that can be deduced from the data that has been analyzed in Fig 7, and that has already been commented on previously, is that the power limit and most of the consumption is due to the accelerations that appear as variations abrupt in the velocity profile.

In the driving tests, the route was completed in a total time of 253 seconds, with a total average speed of 17.23 km/h.

Finally, another series of tests have been carried out with the vehicle to check its behavior against sections with unfavorable slopes. In this sense, the vehicle has overcome without much difficulty, a section with an unfavorable slope of 7% with an average speed of 11.97 km/h and an average power of 238.88 W. In addition, another test has been carried out on a section with an unfavorable slope of 14% with an average speed of 8.96 km/h and an average power of 409.68 W. All these power values are less than the maximum value that the photovoltaic generator can supply.

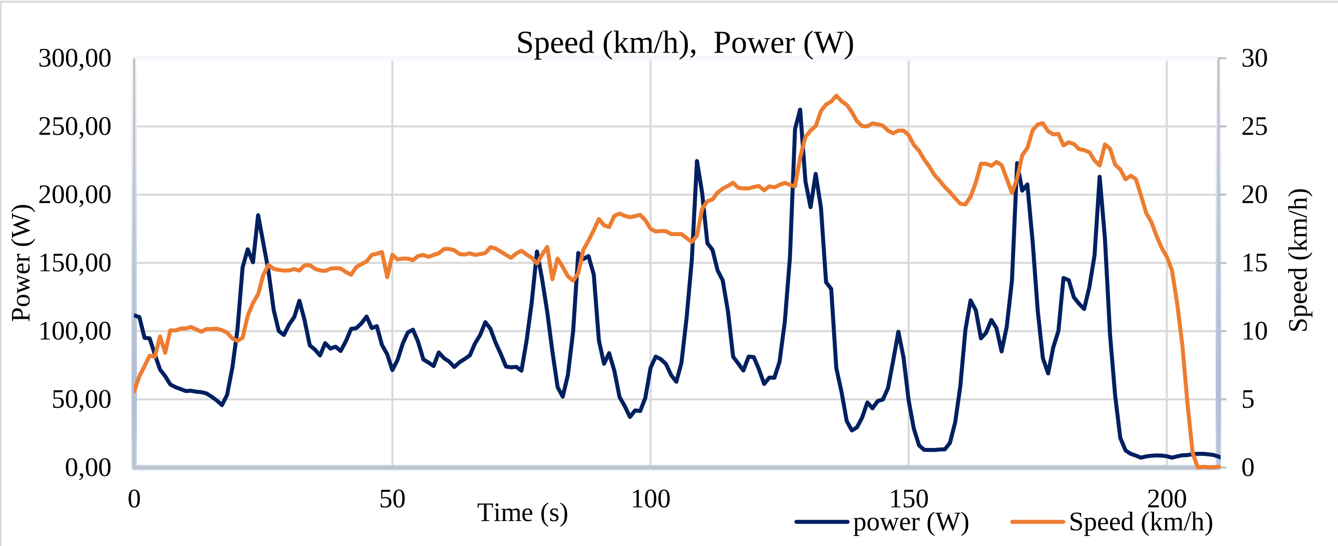

Fig. 6. Speed (km/h) and Power (W).

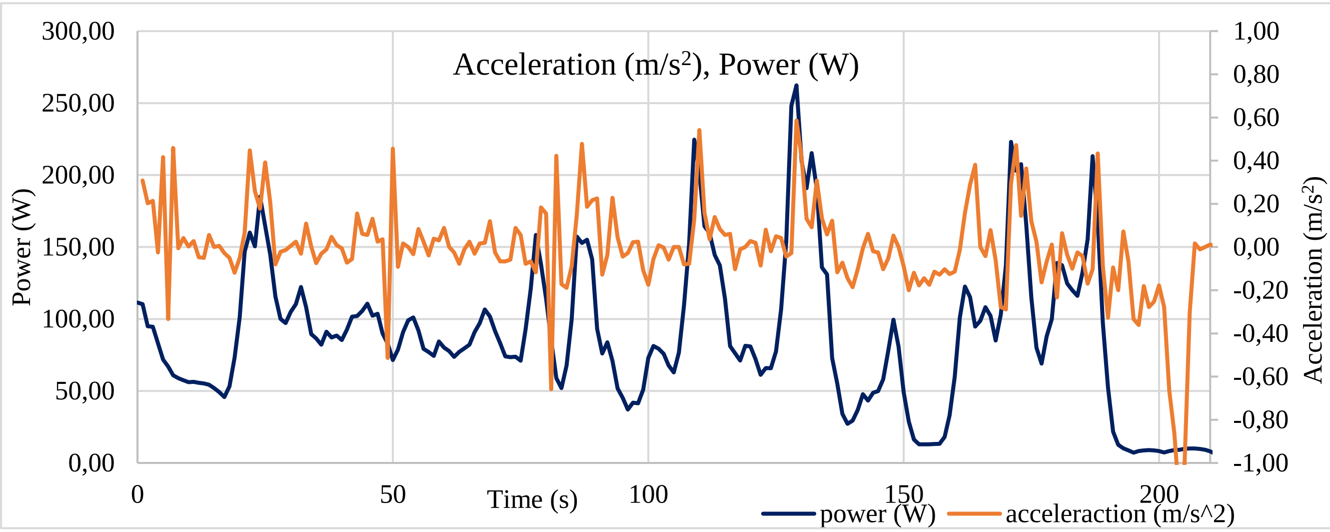

Fig. 7. Acceleration (m/s^2) and Power (W).

4. Discussion

The analysis of the data collected in the different tests of the vehicle provides us with the appropriate information to know its performance and whether or not it is suitable for the new competitions that we are studying to launch. In summary, with all the information stored and the data analysed, it is observed that the vehicle is capable of moving without difficulty along the route of the urban circuit and it can overcome sections with unfavorable slopes up to 14%

5. Conclusions

In this work, it has been shown how a project-based teaching program for students of different Engineering degrees with very little practical experience has allowed the design and manufacture of an experimental photovoltaic vehicle prototype suitable for use in a new type of energy efficiency races for students.

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