Solar Cybertech: A Competition of Digitally Controlled Vehicles Poweredby Solar Panels

O. García, J. A. Oliver, D. Díaz, D. Meneses, P. Alou, M. Vasić, J. A. Cobos

***Abstract*—Solar Cybertech is a conquest/subject at Universidad Politecnica de Madrid where student teams deal with electronics and renewable energies. The conquest is based in the design and construction of a vehicle powered by solar panels to complete a circuit that has different zones as a flat region, rising and falling slopes and a shaded region as well where different operating conditions are required. To optimize the energy consumed by the motors of the vehicles from the solar panels, a dc-dc converter is used. The control stage of the converter is digital and a maximum power point tracking algorithm has been used. Besides these objectives, this subject is intended to enhance the team work and cooperation as well as the application of the theoretical knowledge in a practical application.**

***Index Terms*—Solar panel, dc-dc converter, student competition.**

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I. Introduction

CYBERTECH started in the year 2001 in the Escuela Técnica Superior de Ingenieros Industriales (ETSII) of Madrid with a single event, with the objective of designing and implementing a robot that able to complete a circuit following a black line in the floor over a white floor. During the next years, more events were added, as well as the development of a robot to escape from a labyrinth in as less time as possible. Other new event added is the implementation of a bullfighter robot that has to interact with a robotic bull created by the organization.

Few years later, it was introduced in a new event, based on the growing interest in the renewable energies. This new event is based in the implementation of a vehicle capable of completing a circuit with several difficult zones in as less time as possible, using as the only power supply a solar panel.

The difficult zones of the circuit are:

- Rising slope (climbing the bridge).
- Shaded region (under the bridge).

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These different regions allow the implementation ofan 8-shaped circuit with two mechanical parallel guides to facilitate the races between two cars and having the circuits of both vehicles exactly the same length. Figure 1shows a photograph with the final circuit during the celebration of the competition where the different regions can be appreciated, that appear naturally when the bridge to close the 8 shaped circuit is placed.

Considering these difficulties in the vehicles operation, it is critic to optimize the energy flow obtained from a limited power source, a solar panel. To optimize the energy obtained from the panel a dc-dc converter has been added between the source and the load, a low voltage dc motor or motors used to power the vehicle.

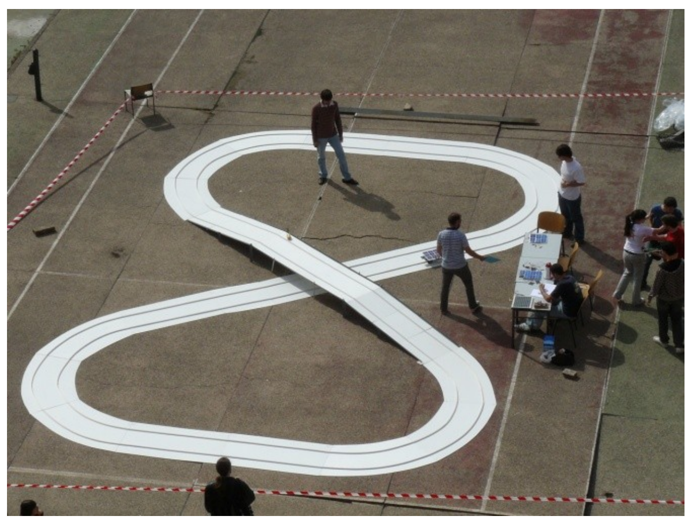

Fig. 1. Photograph of the Solar Cybertech circuit on a tennis courtyard during the competition.

To comply with the conquest objectives, to complete the circuit in as less time as possible, is necessary to maximize the power delivered by the solar panel.

For this reason the students have to implement a control algorithm that makes the dc-dc converter operate in the maximum power point tracking (MPPT).

Figure 2 shows the block diagram of the system used for the Solar Cybertech conquest.

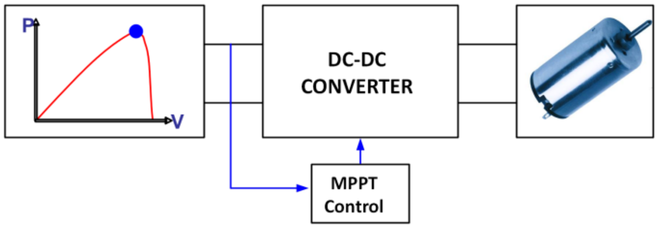

Fig. 2. Block diagram of the system.

II. TEACHING

With the new plan of studies, the Solar Cybertech conquest became part of the optional subjects of the industrial engineering grade, being two professors the responsible of the subject. As part of the subject the participant teams attend to theoretical lessons where they acquire the basic knowledge to carry out the conquest tasks as well as a set of conferences that deal about different aspects of the technology in other areas as the art or the environment conservation.

Each participant team in the subject and conquest has a supervisor, normally a student with a certain degree of experience that has been a participant in the previous years. This supervisor helps and controls the work of his assigned teams, two or three maximum to guarantee an adequate attention. Additional tasks are the technical supervision and advice in different aspects as the converter design, the control algorithm or in the design of the vehicle (Figure 3).

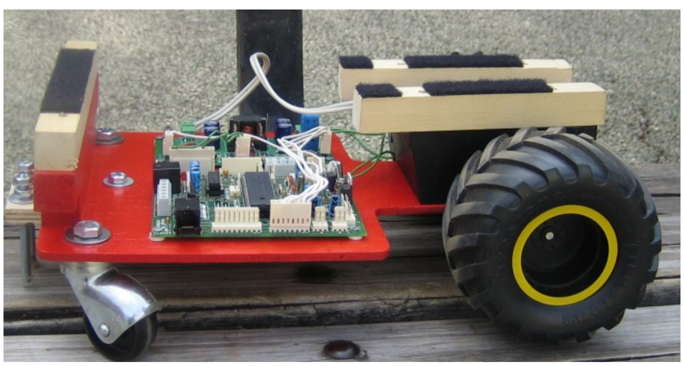

Fig. 3. Participant vehicle: structure, converter and control PCB.

The teams are formed by three to five students maximum, with the intention of a proper share of the amount of work between all of them and also to facilitate an adequate control of the work done by each student. Each team has to provide documentation before the competition with the proposed solutions to complete the conquest and to inform to their supervisors in the previous knowledge that has each group. As the final task, there is a final exam, which is also a condition to participate in the competition, as one of the parts of this exam is to complete one of the zones of the final circuit.

With this subject format it is intended, besides the team working and competitive improvement of the students, to provide the first contact with the electronic, developing a practical application, developing a prototype and doing experimental tests on it.

III. Implementation of the Solar Car

As it has been commented, each participant team has to implement a vehicle, which from now will be called the solar car, which is based on a structure where the components of the blocks of Figure 2 are added. The different components are analyzed in the following subsections.

A. *Solar Panel*

The power supply of the solar car will be photovoltaic solar panels. The panels obtain the energy from the solar radiation, with the limitation that not always it is available, and not always the same level of power can be obtained.

The solar panels are implemented by the combination of solar cells. Each cell has the equivalent circuit shown in Figure 4.

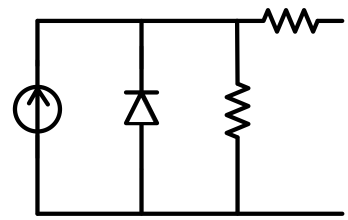

Fig. 4. Schematic circuit of a solar cell.

The selected solar panels for the contest can deliver a maximum power of 10W. The weight is 2Kg and the dimensions are 340x330 (cm). The open circuit voltage is 21.5V while the short-circuit current is 0.62A.

The solar panels have been characterized and the voltage-current and voltage-power are shown in Figure 5.

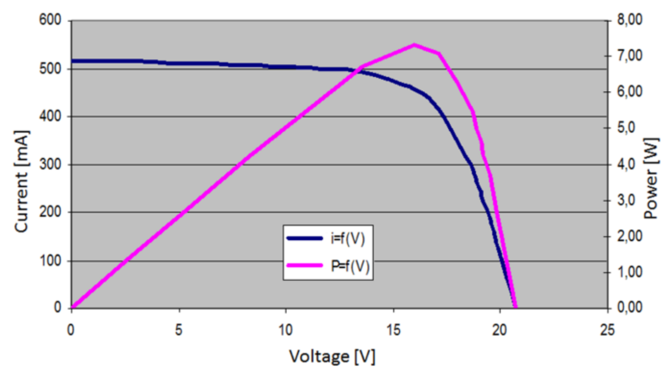

Fig. 5. Measured I-V and P-V curves for the 10W panel.

It can be seen in Figure 5 that, even in the best conditions, the maximum power is 80% of the nominal power in the maximum power point. Therefore, the design must optimize the efficiency and reduce the weight so the available power is enough for the solar car to complete the circuit, and to do it as fast as possible.

B. *DC-DC Converter*

To process the energy correctly and to obtain as much power as possible, a dc-dc converter controlled by PWM modulation will be used.

Due to the input voltage range obtained from the solar panels, with lower and higher values than the nominal operation voltage, the Flyback topology was chosen for the dc-

dc converter operation, as it is capable of producing higher and lower output voltages than the input voltage.

Forthe firstedition, the organization made the design of the converter as well as the PCB, shown in Figure 6, for the physical implementation as well as a tutorial for the soldering and assembly of the components in the PCB.

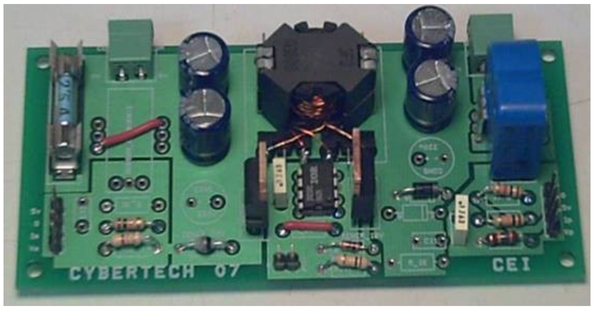

Fig. 6. PCB of the Flyback converter used in the first edition ofSolar Cybertech.

C. Converter control

The control of the dc-dc converter is of essential importance for the complete system due the following reasons:

- It has to find the peak power point of the solar panel.
- It adjusts the energy from the solar panel towards the dc motor of the car.

For the practical implementation it has been chosen a digital control implemented using a PIC18F442. The board with the microcontroller had been previously developed and given to the students by the Cybertech organizers.

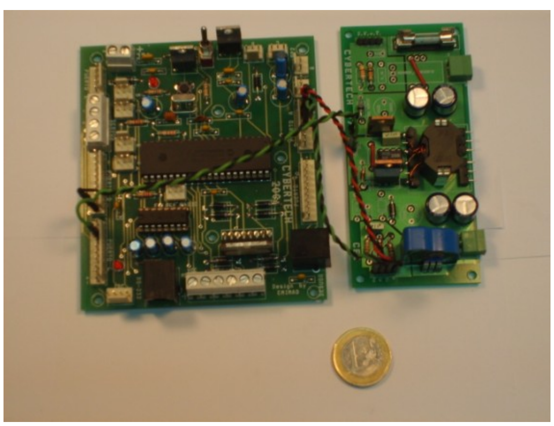

Fig. 7. Control PCB (left) and Flyback converter (right)used in the first edition of Solar Cybertech.

In order to implement the Maximum Power Point Tracking (MPPT) algorithm, it is necessary to measure two parameters, the input current and voltage. For the voltage measurement, a simple voltage divider is used, while the current is measured using a commercial current sensor.

The algorithm consists of constantly search the MMP by doing small incremental changes on the duty cycle. With these changes the algorithm is able to move the operation point along the power curve of the solar panel, having in mind two different zones. The first zone is for voltages higher than the V_{MPPT} (on the right side from the maximum power point), while the second one is for voltages lower than V_{MMPT} (on the left of the maximum power point). In each new working point it is necessary to measure the power and compare it with the previous measurement and decide if the panel voltage should be increased or decreased taking into account if the power has decreased or increased. Figure 8 illustrates the basic idea of the algorithm.

The procedure is the following: after each measurement the voltage and current measurement arestored, the duty cycle of the flyback converter is incrementally changed and the new output power is compared with the previous measurement. If the output power has increased and the working point is in the second zone (voltages higher than the V_{MMPT}, from x_n to x_{n-1} in Figure 8) it is necessary to increase the duty cycle. Similarly, if the working point is in the first zone, (from X1 to X2 in Figure 8), the duty cycle has to be decreased. In order to know in which part of the power curve we are, so we can define the sign of the duty cycle increment, the voltage measurement has to be saved together with its corresponding output power. If this information is not saved, the duty cycle will saturate in its minimum or maximum value and the output power will fall to zero.

The PWM signal that comes from the control board is sent to a driver which generates the proper control signals for the MOSFET of the flyback converter.

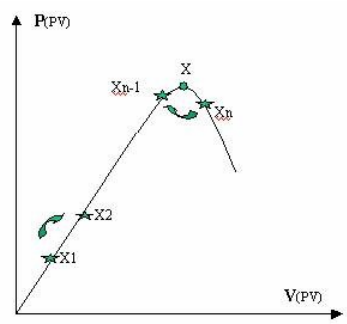

Fig. 8. V-P curve of a solar panel. MPPT algorithm representation.

D. DC motor

The dc motor receives the controlled power from the dc-dc converter and transmits it to the vehicle wheels through a set of gears. These gears decrease the nominal speed of the dc motor (3000 rpm) increasing the torque which is necessary for the vehicle to drive up the slope in one part of the test circuit.

The student teams were not limited with the number of dc motors. Each team decides for itself which dc motor will use and how will it connect to the vehicle.

In the first edition of the competition, there were 14 registered teams (approximately 70 students) and each constructed vehicle was able to complete the test circuit. Two teams were able to complete the test circuit including the shadowed part of the circuit as well. One team implemented a system and an algorithm for the solar panel orientation so that it always receives the maximal solar panel in each part of the test circuit. This team won the award for the best innovation given by the organization committee of the competition.

IV. 2ND EDITION OF SOLAR CYBERTECH

For the second Solar Cybertech competition, that was held in the last week of April, few modifications were introduced in order to enhance the learning and motivation of the students.

Instead to use a single solar panel, like in the previous year, it was possible to use different alternatives, which provide different output powers and have different sizes (mm x mm) and weight (g):

1. 10W/ 340x330/ 2000
2. 5W/ 270x270/ 800
3. 1.38W/ 75x116/ <10
4. 1.38W/ 75x64/ <10
5. 770mW/ 75x46/ <10
6. 550mW/ 75x116/ <10
7. 220mW/ 35x30/ 100
8. 100mW/ 67x35/ 50

The panels 1 and 2, 10W and 5W respectively, are complete commercial solutions, with several interconnected voltage cells and with a protecting glass. Their advantage is that these panels are quite robust, however, the main disadvantage is the increased weight due to the safety glass. Solutions from 3 to 6 are individual cells, which each team can combine in order to obtain a configuration that will provide desired voltage and power. Solutions 7 and 8 are complete solar panels with low weight, but with decreased output power.

Having in mind these characteristics, it is necessary to introduce some restrictions for solar panel selection:

- The maximal size is 330mm x 340mm
- The solar cells that can be combined are 3 to 6
- The maximal output power of one combination is 10W

For the cells between 3 and 6 it is necessary to put several panels in series due to the cell open circuit voltage of 0.55V, which is significantly lower for the proper functionality of the system

Having in mind that each solar panel has different electrical characteristics, the voltage of the peak output power varies among them. In the most of the cases, this voltage is different from the nominal output voltage of the dc-dc converter.

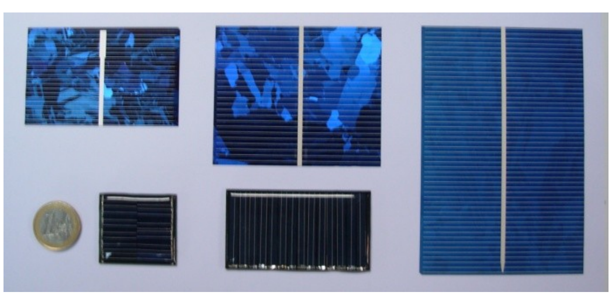

Fig. 9. Different types of solar panels used in the second edition of Solar Cybertech.

The new panel configurations have different voltages and, therefore, it is necessary to consider different topologies for the dc-dc converter:

- boost topology
- buck topology
- flyback topology.

The flyback topology is the most versatile, because it will operate correctly for any panel configuration and any dc motor selection. The buck topology is used when the minimum panel voltage is higher than the nominal voltage of the dc motor. Similarly, the boost topology is used in the opposite case.

Additional task was to design the dc-dc converter. For this task a new workshop was included and a design guide was created [1] to simplify this task.

The digital platform for the implementation of the control was another point where an improvement has been made. The board forthe first edition had high energy consumption (higher than 1W) because it was designed to include other functionalities of the microcontroller. Another drawback of this board was the high number of components which makes difficult the hardware debugging when something is not working.

To solve this, a new selected control board was Arduino, an open hardware platform, which has lower consumption and lower complexity than the previously used control board. The power consumption with Arduino was around 200mW (comparing to 1W with a PIC platform). The processor in this case is an ATMega 168. The employed board has an USB connection which is used as the power supply and programming cable at the same time.

Although Arduino is an open platform and the implemented programme is shared among users, it was impossible to find a library that generates a PWM signal of desired frequency (100 kHz) and also with a variable duty cycle. Therefore, it was necessary to develop this library.The code can be seen in Figure 11.

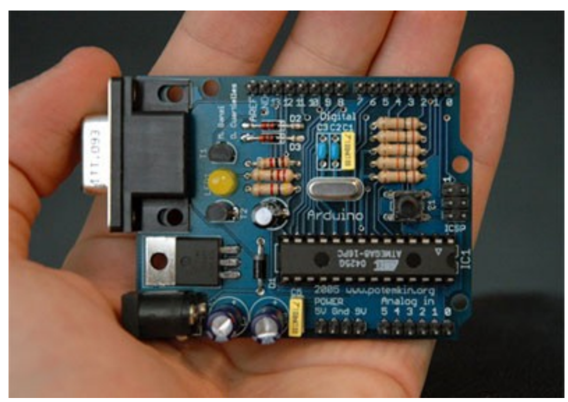

Fig. 10. Control board (Arduino) that was used in the second edition of Cybertech competition.

In the competition there were 10 teams (approximately 50 students) and all the teams were able to complete the test circuit. Four teams were able to finish the circuit passing the shadowed part of the circuit as well. The award for the best innovation was given to the team that implemented an additional system of gears activated by a servo-motor and a signal generated by simple light sensor (LDR). A photograph of the competition is shown in Figure 11, where two cars are at the beginning of the rising slope, one of the most challenging zones of the circuit.

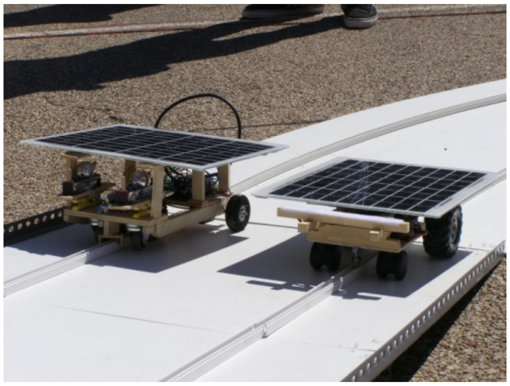

Fig. 11. Photograph of the Solar Cybertech competition.

All the information regarding the Cybertech competition can be found at the following link:
http://www.disam.upm.es/cybertech/

V. TEACHING EXPERIENCE

The experience obtained during the Solar Cybertech competition was very positive, due to the high motivation level of the participating students and their dedication. The students showed great interest in the buyinga solar panel in order to enhance their solar vehicle in their spare time.

This competition was made as a subject, serving to the students as an introduction to electronics, developing a practical application. Additionally, they obtained some basic knowledge regarding solar energy, switching power supplies, programming and usage of microprocessors. Finally, they had to deal with all the problems that can occur during the implementation of a complete system (from the control algorithm to the mechanical adjustment of the implemented vehicle).

Generally, the student teams were composed from the students who are specialized in electronics and automatics. It was common to find teams composed from the students from different areas of specialization, which in a natural way share the tasks. At the same time, this subject was very attractive for the students from the first years of studies in order to choose their area of specialization.

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- Pilar Montero Morales
- Beatriz Tato Eirín
- Pablo López Cenamor

```
#include "WProgram.h"
#include "pwmfast.h"


#ifndef cbi
#define cbi(sfr, bit) (_SFR_BYTE(sfr) &= ~_BV(bit))
#endif
#ifndef sbi
#define sbi(sfr, bit) (_SFR_BYTE(sfr) |= _BV(bit))
#endif


pwmfast::pwmfast(int pin)
{
  pinMode(pin, OUTPUT);
  _pin = pin;
}


void pwmfast::configurar()
{
  sbi(TCCR1A,COM1A1);
  sbi(TCCR1A,WGM11);
  cbi(TCCR1A,COM1A0);
  cbi(TCCR1A,WGM10);

  sbi(TCCR1B,WGM13);
  sbi(TCCR1B,WGM12);
  cbi(TCCR1B,CS12);
  cbi(TCCR1B,CS11);
  sbi(TCCR1B,CS10);
  cbi(TCCR1B,ICNC1);
}


void pwmfast::writePeriod(int T)
{
  sreg = SREG;
// Disable interrupts
  cli();
  ICR1 = T;
  SREG = sreg;
// Enable interrupts
  sei();
}


void pwmfast::writeDuty(int d)
{
  sreg = SREG;
// Disable interrupts
  cli();
  OCR1A = d;
  SREG = sreg;
// Enable interrupts
  sei();
}
```

Fig. 12. Library developed for Arduino platform in order to obtain a high frequency PWM signal.

REFERENCES

[1] Tutorials written for the students: http://www.upmdie.upm.es/Cybertech_08/solar.html
[2] Arduino website: http://www.arduino.cc/
[3] Datasheet of ATmega168.