Educational equipment : a sun tracking photovoltaic system for a transversal teaching approach

Vincent Grennerat
Teacher
E-mail: vincent.grennerat@ujf-grenoble.fr

Eric Chamberod
Assistant professor
E-mail: eric.chamberod@ujf-grenoble.fr

Jean-Marc Boggetto
Teacher
E-mail: jean-marc.boggetto@ujf-grenoble.fr

Pascal Xavier
Professor
E-mail: pascal.xavier@ujf-grenoble.fr

Electrical engineering and computer science department (GEII2), IUT1 de Grenoble
University Joseph Fourier, BP69, 38402 St Martin d'Hères

Abstract: *The paper is devoted to an educational program being developed at the Technological University Institute, Department of Electrical Engineering 2. This program is aimed to design a custom made platform of eight sun tracking photovoltaic systems and the associated transversal teaching approach. The educational goal is to integrate the main benefits of project based educational techniques into traditional lecture and lab classes. Instead of relying on a ready made commercial product, the systems were designed by the teaching and technical staff. This maximizes educational exploitation, and can be used as a fully transversal tool. Some students were also involved in the design process, through project classes. Educational activities can start from basic circuit classes in the bachelor's first year, and spread to advanced courses in the fields of power electronics, radio-frequency electronics, computer science, field bus and ethernet network, control and automation, physics, mathematics.*

Keywords: Educational photovoltaic system, transversal teaching, project and lab classes, renewable energy, thermal and photovoltaic association, MPPT, embedded control.

1. Introduction

In recent years, environmental issues combined with economic and social aspects have led the international community to reconsider the energy's distribution and to further develop renewable energies. From an educational point of view, technical teaching staff should take into account this new industrial and technological context, and answer the following difficult questions.

- Should this influence the content of courses ?
- What equipment has to be used for the introduction of these new concepts ?
- Is ready made professional hardware the only solution for teachers at a bachelor level, or could they also develop their own equipment?
- Could additional information be provided through software simulation ?

This paper does not try to completely answer these questions. Answers belong to educational staffs, and they depend on student curriculum, educational structures and course organisation. As an example of such an initiative, this paper presents the development of a two axis sun tracking photovoltaic system and its transversal teaching approach, carried out at the Technological University Institute 1, Department of Electrical Engineering 2, Grenoble, France.

2. Educational context

A A local and custom made platform

Although they may seem straight forward, we insist on the fact that technical choices for the system were based on educational goals. This explains several questions that might pop up while exploring its structure and technology.

The main idea that led our choices was to provide teachers with a system which will escort students throughout the entire bachelor course. It had to have the following qualities.

- Visibility : touching and seeing are important actions for young technical students learning practical skills.
- Dynamic : moving systems involve more technologies and are more attractive.
- New technologies and renewable energies: during the five last years, we observed that students are more enthusiastic when they work on a project involving renewable energies.
- Transversality : in order to maximize the platform educational efficiency, it had to be exploited by almost all disciplines.

Among the renewable energies field, due to the question of visibility, only photovoltaic array and wind generators were serious candidates. Wind generators were excluded because of the lack of wind at our location, excessive cost, and security reasons. And the photovoltaic array is not dynamic at all ! This led us to the sun tracker system. Although photovoltaic trackers are not of great interest at our locational latitude, it satisfied to all the above requirements.

The large rooftop on our low level central building was well suited for a photovoltaic installation allowing physical access from our central patio. It has great direct visibility from several lecture rooms and three of our labs, located in the building across the patio.

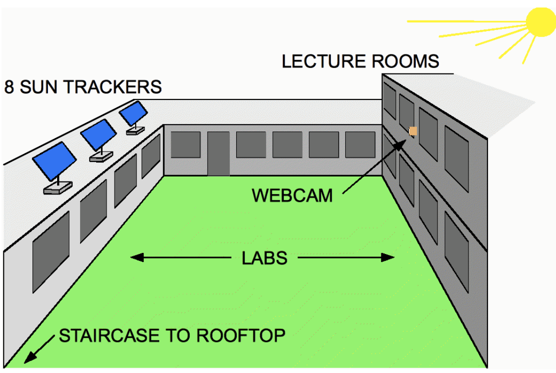


Figure 1 : Sun trackers platform situation.

In order to get external visibility on the internet, and view from our four other labs, a webcam was installed on the wall of the opposite building.

Companies specializing in educational equipment build ready made photovoltaic trackers. The ones we examined did not fully meet the transversality specification, and none of them were designed for outdoor usage with remote access to analog signals and various numeric informations of the control box. The concept of a local design, by the teachers and the technical staff, appeared as a well matched solution. In our case, it offers benefits listed below.

- Such a substantial project is an opportunity for better collaboration between teachers, giving them a better global vision of the whole bachelor course.
- Owning the intellectual property of the whole system eases future evolution and exploitation in project classes.
- The design phase is rich training for project actors, also involved in the teaching of lab and project based courses.
- The proximity between students and designers or makers illustrates that the involved technologies are in their scope.
- Students are used to the black box teaching approach which has shown its efficiency, but which is also a source of discouragement ; here, since the teachers own the design, there is no black box which can't be opened.

The cost effective side of the local design has a drawback : it is not time effective for the teachers whom have other prime concerns. Hopefully, long term investment will pay back !

Concerning the financial aspect, the current political context, privileging project based requests for financing, was quite a plus. However, the whole teaching staff had to be convinced by the project, in order to facilitate budget choices.

B The transversal teaching approach

The didactic idea here is to import from the project classes what works best. In these classes, the educational gain comes mainly from great interest, motivation and implication on the part of the students. But the drawbacks are that teachers are not able to oversee the learning process as easily as in classic lab class. Indeed, teachers have to look after each individual student, working on separate projects.

With the sun photovoltaic trackers, we hope to integrate some of the project based educational technique benefits into traditional classes, avoiding the drawbacks.

One could think this kind of system is dedicated to renewable energy teaching. Indeed, it claims to be much more ! As mentioned above, this equipment is going to be used as an underlying tool, throughout the duration of our students bachelor course. This doesn't mean it could replace current lab resources. It's one more equipment, with a plus others don't have : it can be exploited in almost all courses. The typical usage will only be a couple of lab sessions per course, but it will be enough to convince students that disciplines are strongly related to each other.

We hope that the progressive demystification of the system will stimulate their motivation and enthusiasm.

This project raises a question : does renewable energy, and in extenso this equipment, require new educational techniques ? The answer is no. Indeed, one of our important educational goals will always be to train them to face permanent change in technologies. Thus, this system won't be intrusive in teachers educational methods. In order to obtain maximal transversality, we provide support to our colleagues, to show them where they could illustrate their lecture with the sun trackers, or where they could use it during a lab session.

3. Technical overview

A Constraints from educational usage

Our department's labs are suited for a maximum of 14 pairs of students (14 workstations). In most of the lab sessions, students work on the same object, in the aim of keeping a good synchronization between lab and lecture classes. This requires 14 identical equipments, if a group of 24 to 28 students is not split in half. Due to platform size and overall cost, a tradeoff was made : 7 identical systems were installed plus a spare one with a special thermal module (see 3.b.). If students are in full group configuration in the lab (14 pairs), each pair will have to share one system with another pair of students.

The outdoor installation choice is a strong constraint : physical access is random, relying on weather conditions. Thus, no practical class can really take place on the platform. From there, lab sessions are of two categories :

- practical work on a didactic model (for instance the motor chopper on a board, for power electronics class),
- remote work on the system.

Teachers are familiar with the former technique which is widely used and unproblematic, but which does not have the above listed qualities. The latter is the subject of the next paragraph.

B Remote control and connectivity solutions

The two constraints that led the connectivity design are :

- maximizing the possibilities of remotely actuating each system (and getting measures) through the required way of the different courses,
- keeping the overall wiring reasonable.

All labs get a general purpose serial access for each system (eight links, one per two workbenches). Network topology looks like a Controler Area Network (CAN) bus.

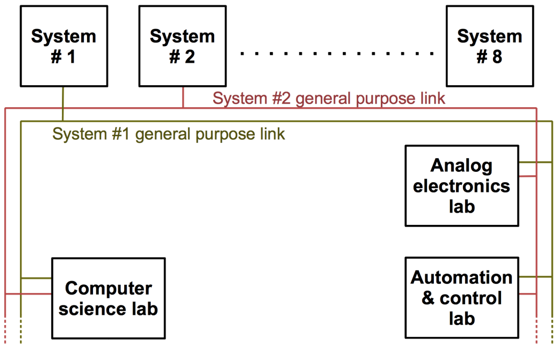


Figure 2 : systems – labs interconnections topology

Of course, only one class at a time will use the platform, but one must be able to control a system from one lab or the other without electrical conflicts. The RS485 standard seems to meet the requirements but it's a one master, multi-slaves configuration, and one need multi-masters (labs), one slave (system). Thus, we developed an original bus, based on CAN transceivers, but only using standard UART/RS232 protocol. The end connection to workstations is USB, with a virtual COM driver.

Other links rely on each lab's activities. To summarize, five labs will be connected to the platform.

Because of power wiring reasons, direct control of choppers signals and motors was excluded. Thus, the electrotechnic lab won't be connected to the platform.

- Embedded computer science lab : most of the educational activities rely on a Freescale Coldfire development kit. In the aim of controlling it, each system embeds a Coldfire kit, redesigned on purpose. Remote access involves a second serial link, connected on system's side to the kit's debug link, and sharing on the other side the workstation USB link.
- In the general programming lab, the general purpose link is adequate : the main activity is C language programming. Given C libraries to control the system through the universal serial link, students will be able to program various control and measurement algorithms.
- Control and automation lab : the general purpose link, thanks to our development of drivers, enables control from PLCs and Labview. For control lab sessions, access through Matlab is possible and a dedicated software is currently being designed in order to ease remote numeric identification. A set of analog signals will be available, as described below in the analog lab paragraph.
- Network lab : each system has a double ethernet 100baseT link and a CAN bus.
- Analog and power electronics lab : a set of four 4-20mA loop signals can be selected among eight system's analog signals such as module output current and voltage, sun direction photocells signal, analog speed... In order to work on the eight 50Wc modules output power, power cables link each system to a wiring cupboard in the power electronics lab (see didactic activities in §4A).

Project based classes taking place in the embedded computer science lab will be able to use the system. With this activity, students are more free to move to another lab, or to the secured rooftop, if required by a special experiment. The remote access is then less critical.

C System design answers course needs

In project classes, some students could work on embedded communication & control boards (new board or software design). This is feasible, with few deterioration risks, thanks to the electronics architecture that was chosen.

Insisting upon the fact that the whole platform is based on eight identical systems, a single system can be divided into five primary functions :

- mechanical structure and actuation (the mechanical part is not intended to be studied by students),
- power production, distribution and exploitation,
- power electronics interface and its command,
- sensors and their associated electronics,
- control and communications.

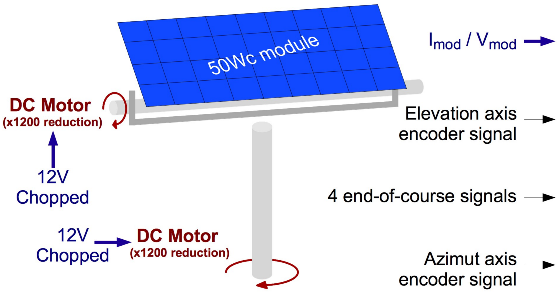


Figure 3 : Sun Tracker with its input-output signals.

Electronics is fitted in a IP66 box attached to the tracker's base. It was split in five basic boards. This is inefficient in terms of room occupation and requires a large box for each system, but it has advantages :

- boards designs can be quite separate, which is a very important point regarding self design, which takes place over a long period,
- future revision and maintenance will be easier,
- electronic structures are easily identifiable to their associated function. Students will appreciate it when working on the functional analysis.

Below, we will discuss the technical choices and their relationships with the different disciplines.

<u>Motorization</u> : two 12V brushed DC motors from the automotive industry (one per axis). The advantages are :

- great torque, to confront windy conditions,

- more didactic exploitations than with step motors, especially for the control class,
- the whole mechanical part (motor + gears + mechanics) has relatively large main time constant, which eases remote numerical identification activities (communication delays are consequently negligible),
- speed measurement is done with an integrated incremental encoder which allows speed control and microcontroller speed measurement with a timer (see §4B).

<u>Chopper board for motor speed variation</u> : power source can either be the french electrical network or photovoltaic power from the module. In this case, source isn't reversible and the four quadrant chopper has to be unusually driven. Switches are four NMOSs, which require two bootstrapped drivers. A microcontroller, with dedicated Enhanced PWM module, controls the drivers.

This whole configuration offers several rich didactic activities, starting from basic chopper architecture and leading to advanced driving techniques.

The safety extra-low voltage AC 24V distribution powers the eight systems, when not self powered. This part of the system, will be studied in the power distribution course.

<u>ADC and analog board</u> : analog signals like module current and voltage, sun irradiation, are dealt with on this board. Eight signals can be digitized with a ten bits ADC sharing the SPI bus as a slave. In order to ease future educational applications, an analog boards add-on space was designed. It provides -12V, -5V/ +5V,+12V power supplies and receives up to six analog signals. All analog signals can be sampled and four of them can be selected to be transmitted in the labs via 4-20mA loops. Sensors and analog electronics courses will exploit this board. In project classes, they develop their own analog add-on board with little risks of deterioration.

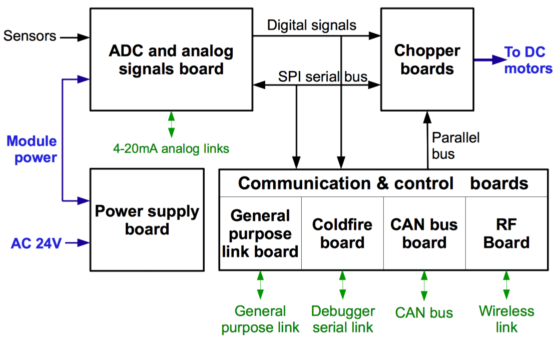


Figure 4 : Electronics diagram

<u>Multi-master communication&control boards</u> : one of the most interesting activities is to actuate the system and get measurements from it. Figure 4 shows that several communication & control boards can be fitted to the system, in order to involve all kinds of communication technologies and educational activities. All these boards communicate with chopper boards and with the ADC board via a serial SPI bus. In order to ease student programming activities, they are all concurrent masters, and ADC / chopper boards are slaves. Accidental electrical conflicts between master boards are avoided due to open collector signals.

- General purpose link board. The main communication&control board, which has a priority access to the buses, is connected to the general purpose link. Students won't work on it's firmware, and will only use it as a remote control, through a dedicated software or with a set of ascii commands, enabling various sources of control (see §3B). If an absence of control activity for more than half an hour is detected, this board resumes the sun tracking demo mode.
- Embedded computer science board (Coldfire board). It is dedicated to embedded computer science class. In order to enable very basic activities like GPIO (general purpose input output) programming, a parallel bus connects it to chopper boards and can carry basic commands such as motor speed, start/stop etc... This board receives digital signals like end of course signals and encoders outputs. More advanced algorithms like position control programming can then be implemented, which is a pleasant transversal activity that will be carried out at the end of the control course. For the third year of the bachelor course, real time kernel is implemented on the board, enabling advanced embedded programming.
- Controller Area Network (CAN) board. It is dedicated to network and field bus courses. Various activities are possible : thanks to network analyser modules, the physical layer and protocol can be studied. More advanced activities will analyse and set up a CAN supervision.
- Ethernet board. Although the Coldfire board has 100baseT ethernet connexion, a dedicated linux based ethernet board will embed a web server, which will be used as a web based control demonstrator. Third

year bachelors will study and program the CGI-bin embedded web server.

- RF board. In the radio-frequencies lab, students will work on a transmitter / receiver in order to communicate with each system. Various activities are possible : study of modulations, antenna tuning, configuration of the transmitter etc...
- Project boards. In project classes, students will design their own communication/control board and implement it in the system. In fact, the Coldfire board was the object of a student project, and ethernet and RF boards are currently designed by two groups of students.

For the purpose of the Physics course, a unique thermal-photovoltaic module has been designed.

It aims at showing that the recovery of heat energy is possible in front of the PV panel (a concept which is not new because it has existed in some commercial products), in order to heat a small volume of water (22 liters). This has also the advantage of allowing a temperature control of the panel, thus improving its performance. In that way, a demonstration of the greenhouse effect is done and the illustration of the concepts of heat resistance, heat capacity, conduction, convection and radiation are carried out (some analytical calculations and finite element simulations can be compared).

A controlled water circuit has been chosen, as opposed to the thermosyphon. Indeed, the higher the temperature gradient on the panel, the better the thermosyphon works. This means that this kind of technical solution is more useful for high power systems.

The front of the panel is mounted with three windows of high transmittance in the visible spectrum, separated on one side by air space, on the other by a layer of water.

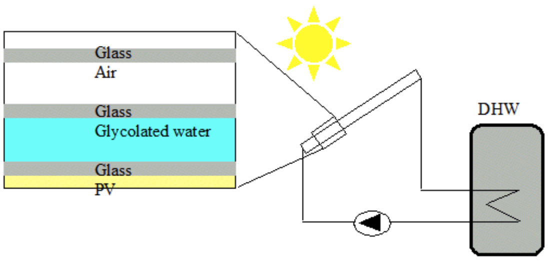


Figure 5 : Combined module.

This module is also linked to the sensors course, because it deals with temperature measurements (done with a Pt100 resistor), signal conditioning and a 4-20 mA loop.

4. Examples of educational activities

A Photovoltaic energy conversion, MPPT

From the photovoltaic modules output energy, many educational activities are possible. The choice between those is not that obvious. Indeed, technical teaching, especially in the field of renewable energies, must find the right balance between focusing on one interesting object, and a general academic course which will not go into depth into the real technical content of the studied topic. This balance will guide the choice between the several possible educational activities.

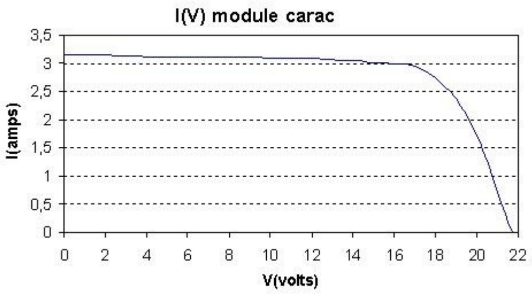
One could think that this kind of system should be mainly used for studying specialized disciplines in the photovoltaic field. But as a transversal educational object, basic courses of the first year of the bachelor program are completely part of the educational goals of the system.

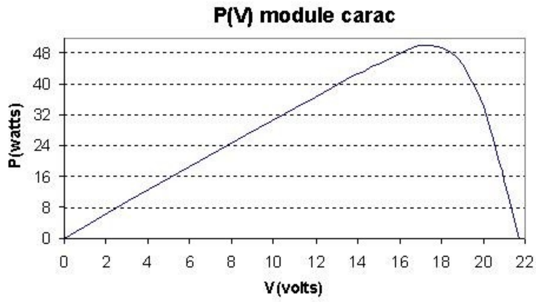
In this frame, active dipole associations will be studied, exploiting the two connexion configurations of the eight modules (serial or parallel). Through this basic course, more advanced topics will be mentioned, e.g. battery cell association, highlighting the global performance degradation of all modules, resulting from the weakest one.

At first, I(V) dipoles characteristics are manually plotted. The plot will show the limits of a real source. From there, students build a simple model based on voltage / current source behavior of the module. The model will be simulated with a spice based software and then be compared and discussed. This exercise will be an introduction to model limitations and sources limits.

Modules are then rotated in order to get a higher or lower solar irradiation. A new I(V) plot is done, in order to study the characteristic changes, according to the incoming solar energy. This will provide new elements for the model validity discussion. From there, a first MPPT approach is set by plotting the module output power, in one of the two later configurations. The maximum power point will be determined and related to the optimal resistive load concept.

This lab session will be prepared with calculations from the PWX500 modules data-sheet.





Figures 6 & 7 : with this module, maximum power is about 50W. Students locate it on the plots, and optimal resistive load R_{opt} is deduced.

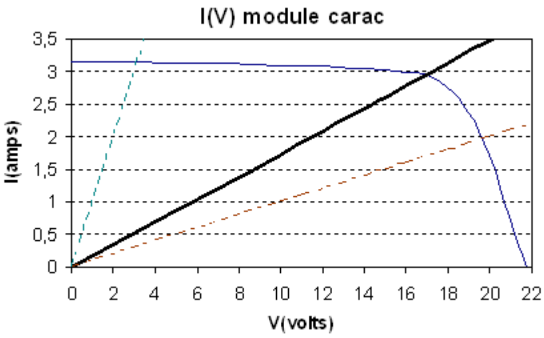


Figure 8 : optimal load resistance is about 6Ω for this module.

This simple work unites several concepts such as load lines drawing, working point determination, optimal load for a given source.

Also, students will be shown that the MPP (Maximum Power Point) changes greatly, according to module working conditions, thus making the automatic MPP search mandatory.

During the second year of the degree course, the computer and power electronics approach of the MPPT will be developed. This will be done thanks to an automatic I(V) plotter, custom made by the teaching staff. It will be studied and operated by students : this device is transversal because computer science, electronics and power electronics are equally present in it. It's a converter which behaves like a variable load in order to scan the whole I(V) characteristic.

This device is meant for direct lab usage, but will not be rebuilt by students. It will be also used in other classes, for studying interfaces between signal electronics, control, and power electronics.

The MPPT lab class will firstly study and exploit the I(V) automatic plotter. In the second part of the lab class, the eight 50W modules will load a battery, through a commercial MPPT converter. This will provide students with a commercial documentation and allow work on dimensioning parameters.

Thus, this set of lab classes regarding photovoltaic energy conversion will enable students to study the whole chain, from the module to the battery, including commercial converters and dedicated measuring and testing tools.

B A microcontroller timer for axis speed measurement.

The aim of this practical class is to build, download and test on the Coldfire board, a program that measures the angular speed of one axis. The incremental encoder outputs a square signal and the measurement principle is to use a timer in capture mode, in order to deduce the signal's period.

Given the number of periods per revolution, minimum and maximum motor speed, one must calculate minimum and maximum measured signal frequencies.

Coldfire timer counter is 16 bits wide and students must determine the optimal timer counter clock frequency in order to optimize accuracy and to avoid counter overlap. From there, the clock prescaler can be set.

Next step is to determine the timer configuration for capture mode and the associated value to assign to the timer configuration register.

The init function is then written (C language).

Students must then code an algorithm that :

- waits for a timer counter capture,
- stores the 16 bits captured value,
- waits for a new timer capture, and stores the new value,
- detects if an overlap occurred and computes from the two captures the number of counter clock periods during one encoder period,

- prints on the debug serial link the 16 bits result.

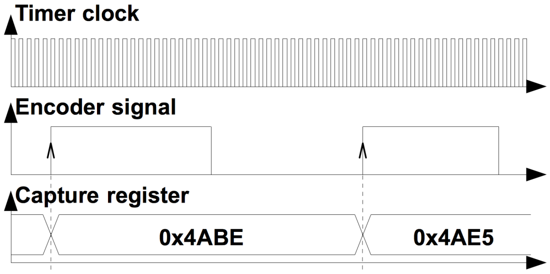


Figure 9 : timer capture chronograms

One then has to build the project and download the executable code through the debugger serial link. The system is put in rotation remotely, thanks to the general purpose link, and its associated PC application. Students can check qualitatively their program.

The next step is the motor axis speed calculation in revolutions per minute and system axis speed. The computation is made exclusively with integer variables in order to initiate a reflexion on rounding errors generated by divisions. Students will realize that the system axis speed is too slow to give an accurate integer result in rpm.

The final step is to implement a full program including previously coded functions that start, stop and change reference speed. A periodic cycle is programmed and measures can be quantitively checked with the measure given by the general purpose communication & control board. From the computer science lab, there is no direct view of the platform ; In case of abnormal program behavior, the webcam can be used, to check that the cycle executes properly.

5. Conclusion

An outdoor custom made platform of eight sun tracking photovoltaic systems has been developed to offer, through a transversal teaching approach, the integration of project based educational techniques into traditional lecture and lab classes. These systems were designed by the teaching and technical staff, bringing better collaboration between teachers, easy future evolution, and exploitation in project classes. The technical choices were described and justified. Two examples of educational activities were given to demonstrate that, for the students, this platform will bring higher interest, motivation and implication and will avoid black box approach drawbacks. Above all, it convinces students that disciplines are strongly related to each other.