Photovoltaic Panels LabView™ Controlled – a Platform for Educational Purposes

Nuno Faria⁽¹⁾, António Bonifácio⁽¹⁾, João Pedro Trovão^(1,2), Paulo Tavares^(1,2)

¹ Instituto Superior de Engenharia de Coimbra

Departamento de Engenharia Electrotécnica

Rua Pedro Nunes, Quinta da Nora – P-3030-199 Coimbra (Portugal)

phone: +351 239 790 320, fax: +351 239 790 321, e-mail: nmsfaria@gmail.com, abonifacio@sapo.pt,

[{jtrovao,ptavares}@mail.isec.pt](mailto:jtrovao,ptavares@mail.isec.pt)

² Instituto de Engenharia de Sistemas e Computadores de Coimbra

Rua Antero de Quental, 199 – P-3000-033 Coimbra (Portugal)

Phone: +351 239 851 040, fax: +351 239 824 692

Abstract: This paper presents a platform for educational purposes, based on photovoltaic panels LabView™ controlled. The principal objective of this work is to give a contribution to the sustainable development. For this, a batteries charging with PV panels study, in respect to voltage, current and temperature measurement and how this variables change according to Sun position and PV panels orientation, is presented. A database with these variables is created and the system is controlled with the instrumentation software LabView™. Another particularity of this project is the control of two electric motors in order to move the PV panels through the day to achieve the optimal set-up and obtain maximum power from them. That set-up includes PV panels' orientation, panels' temperature and solar radiation. Finally, a cost study of three possible configurations versus generated power, project conclusions, possible applications and future studies based on this work are presented.

Keywords: Sustainability, Renewable energy, Photovoltaic panels, LabView™, Sun's path, Education.

1. Introduction

Renewable sources of energy – wind, solar (thermal and photovoltaic), hydro, tidal, geothermal and biomass – are an essential alternative to fossil fuels [1-3]. Using these sources helps not only to reduce greenhouse gas emissions from energy generation and consumption but also to reduce the European Union's (EU) dependence on imports of fossil fuels (in particular oil and gas). In order to reach the ambitious target of a 20% share of energy from renewable sources in the overall energy mix [3-5], the EU plans to focus efforts on the electricity, heating and cooling sectors and on biofuels. In transport, which is almost exclusively dependent on oil, the European Commission hopes to increase the current target of a 5.75% share of biofuels in overall fuel consumption by 2010 to a 10% share by 2020 [6]. Energy and transport are important in climate change since they are the leading sources of greenhouse gas emissions; this is why energy policy is particularly important in the European Union's sustainable development strategy [7].

Several applications with photovoltaic panels (hereafter called PV) can be found nowadays. The most common applications are in remote areas without power lines where PV supply energy (sometimes combined with others renewable sources of energy) to rural homes, water pumps, fuel stations, exterior illumination, telecommunication antennas, road signs also used in boats

and motor homes. Recently with the improve of panel's construction technology, and the urgent need finding new energy sources, PV panels have being used to produce electricity in large scale. Portugal is an example with Amareleja project, a 64 MW photovoltaic power plant [4-5].

2. Objectives

The main objective of this work is to give a contribution to the sustainable development. With this objective in mind, it is also an objective of our educational project to study batteries charging with PV panels in respect to voltage, current and temperature measurement and how this variables change according to position of the Sun and PV panels orientation. We decided to use LabView™ to measure voltage, current, temperature in PV and air, and solar radiation and to store it in a database. Another objective is to control two electric motors in order to move the PV panels through the day. The main purpose of this project is to achieve optimal setup to obtain maximum power from PV panels. That setup includes PV panel's orientation, panel's temperature and solar radiation.

Paper is organized as described in such a way that, first we give a brief approach to Solar Tracking and inherent formulas to control motors. Next we describe how we built this system and what components we used. We also describe the system core presenting LabView™ implementation, how it controls motors and collects information. In the next item we analyse the database created by LabView™ and study how the temperature and weather conditions influences the power output, making previsions about system efficiency and avoidable costs. For last we present conclusions of this project, possible applications and future studies based in the present paper.

3. Solar Tracking – a theoretical model

The position of the Sun in the sky varies continually during the day and also changes seasonally throughout the year. Sun position is also very location-dependant, so it is critical that we know the latitude and longitude of our development site before begin any calculations. Calculating the position of the Sun at any specific date and time is not a trivial exercise. The off-axis rotation of the Earth and its elliptical orbit around the Sun add quite some complexity to the equations required. Given this

cyclical nature, there are four important dates to remember when considering solar position: Summer Solstice, Autumn Equinox, Winter Solstice and Spring Equinox. The position of the Sun is generally given as an azimuth and altitude angle (see Fig. 1).

Fig. 1. Azimuth and altitude representation [8].

Azimuth represents the horizontal angle of the Sun relative to true north. This angle is always positive in a clockwise direction from north when viewed from above, and is usually given in the range $-180^\circ < AZI < 180^\circ$.

Altitude represents the vertical angle the Sun makes with the horizontal ground plane. It is given as an angle in the range $0^\circ < ALT < 90^\circ$.

The altitude of the Sun is given by equation (1) [9]:

$$\sin \alpha = \sin \Phi \cdot \sin \delta + \cos \Phi \cdot \cos h ; \quad (1)$$

where:

α , solar altitude (angular elevation above the horizon);

Φ , geographic latitude of the observer;

δ , declination of the Sun;

h , hour angle of the Sun.

The solar azimuth angle, a (measured from north), is given by equation (2) [9]:

$$\sin a = \frac{\sinh \frac{\cos \delta}{\cos \alpha}}{\cos \alpha} ; \quad (2)$$

The equations above can be implemented in a modern microcontroller or in Personal Computer (PC) instrumentation software, like LabView™. Another method to Sun track consists in the use of a photo-sensor to achieve optimal orientation [10]. In our case we have introduced solar position equations in LabView™. The data necessary to solve the equations is obtained from the PC real settings and the solution is applied to on-line control of DC Servo Motor. In the 5th section, we describe how this is done.

4. System Architecture

The architecture of the system is illustrated in Fig. 2, through the presentation of a block diagram.

The photovoltaic system has four modules *I-22* by *ISOFOTON* (see Table I for characteristics) attached to a metal structure with longitudinal and inclination movement capability. They are parallel connected to a voltage regulator *Isolder D-10*, by *ISOFOTON*, which is connected to the batteries.

Fig. 2. System architecture

The longitudinal and inclination movement is achieved with two DC motors 18", 36V DC and 3000 N of load capacity with extensible arm (commonly used in parabolic antennas), by *SuperJack*, one for each movement. We used a desktop PC with LabView™ 7.0 and a BNC 2120 Connector Accessory for Multifunction DAQ Devices for acquire data from sensors and control motors. For voltage, temperature and radiation acquisition we used a direct connection to BNC 2120. Current measurement was done with an ampère-meter clamp that converts current values into proportional voltage ones. Temperature sensors are LM35 and radiation sensor is Pyranometer Sensor from SKYE model SKS 1110.

Table I. - Photovoltaic panels characteristics

Physical Characteristics	
Dimensions (L x W x H)	540 x 440 x 20 mm
Weight	3 kg
Electric Characteristics	
Nominal Voltage	12 V
Maximum Power (Pmax)	22 Wp ± 10%
Short circuit Current	1.64 A
Open circuit Voltage	21.6 V
Maximum Power Current	1.26 A
Maximum Power Voltage	17.4 V
Construction Characteristics	
Cells	Si Monocrystalline Textured and with Reflection Suppressing Layer
Film	EVA (ethylene vinyl acetate)
Front Face	Tempered microstructured glass of high transmissivity
Back Face	Protected with several layers of Tedlar

An overall image of the final system can be seen in Fig. 3, with a global and partial view. The presented structure was designed to achieve the following:

1. Move the system across the building for test and demonstrations purposes;
2. Support batteries, PC, interconnections box (power and command signals, transducers and actuators), etc.;
3. Have mechanical stability without the risk of crash down and a correct gravity centre.

Fig. 3. Complete implementation of the system

To properly assemble and visualise the various components and protect them to the possible extreme external climatic conditions, all the electrical components were placed in a transparent acrylic box, with the appropriate protection index, according to normative and security rules. As shown in Fig. 3, in this container were placed the voltage regulator, the motors control board and electronic circuit temperature, the battery and panels power switches, the terminal links, the interface module BNC 2120, and finally, the currents probes.

5. LabView™ System Control

The National Instruments LabView™ Real-Time Module delivers the reliability of a dedicated real-time system without requiring knowing the low-level details of real-time development. Real-time systems provide a higher level of reliability because they are dedicated to desired measurement and control tasks and, therefore, avoid general-purpose operation system fragilities. The BNC 2120 I/O platform can integrate a wide array of I/O including analogue/digital, motion control, and more.

The virtual instrument (vi) developed with LabView™ software performs some instrumentation functions such as, samples the reference continuously

at the user supplied rate, calculates solar position based in time and date and generates a signal to each DC Servo Motor. Control is done by an electronic circuit based in an integrated circuit (IC) DC Servo Motor controller/driver of Motorola MC 33030/D (see Fig. 4, for the schematic).

Fig 4. DC Motor controller/Driver of Motorola [11]

This driver receives a reference for a position set-point and operates the motor until it reaches the target position. The feedback is given by a position sensor (like a potentiometer) placed on the motors.

Set-point is possible in manual (by a 10 k Ω potentiometer) or in automatic by a 0-5V signal from LabView™ interface:

1. In manual option user can change independently entire range of vertical and horizontal position (it allows the functionality if PC is not connected or the system is in test situation);
2. In automatic option, LabView™ commands position according with the hour and the day's declination and solar tracking equations.

In Fig. 5 we present LabView™ inputs (sensors) and outputs (actuators) scheme.

Fig 5. LabView™ inputs and outputs

The program in LabView™ has the following functionalities: acquire signals from the sensors (voltage, current, temperatures, radiation and PV positions); signals view in real-time; save and create a database with the acquired signals and generate a correct set-point signal to motors control for the correct placement of the PV array, according to the presented solar tracking algorithm that was implemented in the software.

The signals acquired are all in voltage (input and output voltage and current from the regulator, ambient temperature and panels temperatures and solar radiation). Since the LabView™ data acquisition board only permits voltages in the range - 10 V to 10 V, for the voltage measurements, namely the PV voltage generation (across 24 V), it was necessary to make a voltage divider. For the current measurement, that procedure was not necessary, because the probes are based on hall-effect sensors and the output is a voltage signal in the range specified by the data acquisition module.

Temperature and radiation signals were initially calibrated, so LabView™ can measure that quantities.

The virtual instrument program makes periodic readings through adjustment of the time, based on the internal clock of the PC, and refreshes the front panel, where signals are viewed in real-time mode, as can be seen in Fig. 6.

At the same time that the signals are represented in the front panel, the programme also stores this data in a common text file that can be edited with any text editor. For reduce the data space in the PC hard disk, we used the following methodology: the system acquire all signals each minute and after 15 minutes the system integrate the previous 15 samples, and only store this result. This is done because the system response is very slow.

Fig. 6. Front Panel (in Portuguese)

6. Tests results

The tests occurred in last September, 20th with a partly cloudy day. We started at 10 a.m. until 5.30 p.m. with 2-axis regulations. In Fig. 7 we present output voltage and current of PV panels before voltage regulator (V_{in} and I_{in}), voltage and current from voltage regulator to batteries and load (V_{out} and I_{out}). Finally, Panels and ambient temperatures and the evolution of the solar radiation across this day is presented in Fig. 8.

In the following table (Table II) is presented the data collected by the data acquisition system.

Table II. - Data acquired during September, 20th

Voltage INPUT [Volt]	Voltage OUTPUT [Volt]	Current INPUT [Amp.]	Current OUTPUT [Amp.]	Panel Temp. [°C]	Amb. Temp. [°C]	Radiation [W/m ²]	Hour
28.22	27.96	1.17	0.65	54.53	29.16	939.94	10:00
28.22	27.96	1.17	0.63	54.53	29.16	944.82	10:15
28.22	27.96	1.17	0.65	54.53	29.12	947.26	10:30
28.19	27.92	1.12	0.68	57.42	29.73	952.14	11:00
27.95	27.70	1.04	0.7	62.11	32.44	971.67	11:15
27.95	27.70	1.02	0.7	62.11	32.46	974.12	11:30
27.88	27.66	1.00	0.73	63.18	32.65	988.76	12:00
27.88	27.66	1.00	0.73	62.21	32.18	991.21	12:15
27.88	27.66	1.00	0.73	62.21	32.18	983.88	12:30
27.88	27.66	1.00	0.75	62.16	32.24	986.32	13:00
27.88	27.66	1.00	0.73	62.21	32.22	991.21	13:15
27.88	27.66	1.00	0.75	62.21	32.20	981.44	13:30
27.88	27.66	1.02	0.75	62.16	32.20	991.21	14:00
24.47	24.42	1.00	0.78	59.96	35.01	815.42	14:15
24.47	24.42	0.90	0.75	59.91	34.99	805.66	14:30
24.47	24.42	1.00	0.78	59.96	34.97	817.87	15:00
24.14	24.10	1.07	0.68	65.23	34.14	871.58	15:15
25.00	24.08	1.02	0.69	65.18	34.16	798.33	15:30
25.00	24.08	1.02	0.66	65.18	34.16	805.66	16:00
25.60	25.55	0.90	0.65	62.50	33.47	686.03	16:15
25.60	25.55	0.90	0.64	62.50	35.00	690.91	16:30
25.66	25.61	0.90	0.65	62.94	35.40	881.34	17:00
25.72	25.67	0.90	0.66	63.87	35.34	749.51	17:15

In Fig. 7, we note that the output voltage values decrease with the rising temperature of the panel. This is visible when compared Table II and Fig. 7 and Fig. 8. The low values presented by the current at 17h result from the fact that batteries were almost fully charged.

Although the values of current input achieved during this test have not exceeded 1.17 A, during a preliminary test conducted in August, the magnitude of the values is

around 2.4 A. We believe that this occur because in the preliminary test, the charge of the batteries was lower than in this other tests.

Fig. 7. Voltage and current measurements during September, 20th.

In Fig. 8, the evolution of the temperatures is quite similar, both in PV and air. The initial difference results from the fact that the beginning of test is not coincident with PV exposure to the Sun.

Fig. 8. Temperature and solar radiation measurements during September, 20th

As it can be seen in the solar radiation graphic (Fig. 8.) the solar radiation reached peak at 14h local time which, in Portugal in September, corresponds to solar midday. Meanwhile in the afternoon, between 14h and 17h do the fact that day was partly cloudy we had some variations in solar radiation values. As we expected after 14h there was a voltage decrease directly related to about 10 °C increase of PV temperature and a solar radiation decrease of about 200 W/m².

This test demonstrates, as we can find in several documentation [2-3, 12-14], that solar radiation and PV temperature are the variables that most influence voltage and current. As a consequence the efficiency of the panels is also affected. The efficiency of the system, the energy production and respective costs are analysed in the next item.

7. Energy Generated by the System

In order to obtain more values about the efficiency of this system we found in internet PVWATTS v.1 simulator. It uses hourly weather data from a Typical Meteorological Year (TMY) and a PV performance model based on *Sandia National Laboratories'*, PVFORM simulator, to estimate monthly and annual AC energy production (kWh) and cost savings for PV systems. For locations in regions outside the United States of America (USA), PVWATTS uses TMYs from three sources: the Solar and Wind and Energy Resource Assessment (SWERA) project; the International Weather for Energy Calculations (IWECC) weather files; and the Canadian Weather for Energy Calculations (CWECC) weather files. [15]

Using the TMY weather data for the location selected, PVWATTS calculates the solar radiation incident in PV array and the PV cell temperature for each hour of the year. The DC energy for each hour is calculated from the PV system DC rating and the incident solar radiation, and then corrected for the PV cell temperature. The AC energy for each hour is calculated by multiplying the DC energy by the overall DC to AC derate factor and adjusting for inverter efficiency as a function of load. Hourly values of AC energy are then summed to calculate monthly and annual AC energy production. [15]

We adjust the simulator (PVWATTS v1.0) with the parameters shown in Table III.

Table III. - Parameters for Coimbra, Portugal.

City	Coimbra
Country	Portugal - PRT
Latitude:	40.20° N
Longitude:	8.42° W
Elevation	140 m
Weather Data	IWECC
Power DC	88W
Derate Factor DC-AC	0.770
Power AC	67,76W
Structure	2 axis
Energy price:	0.45 Euro/kWh

The results obtained from the simulator to our PV system: monthly and annual average solar radiation, monthly and total AC energy produced by the panels and respective costs of this energy, are presented in Table IV.

The total cost of our system is about one thousand euros. Considering the results presented in Table IV, we estimate a payback time of 7.75 years. This is the return period usually considered for attractive investments in this technology in Portugal (without considering public financing).

In Table V we can see the differences between solar radiation incident in PV for three possible mechanical structure situations: PV static or without movement, 1-axis or azimuth movement and 2-axis movement both azimuth and altitude. It is easy to understand that 2-axis is the best solution but the investment in this structure and its control does not compensate the little gains in solar radiation and energy production, as it is shown in Table VI.

Table IV. - Monthly and annual AC production and savings.

Month	Solar radiation [kWh/m ² /day]	Energy AC [kWh]	Produced energy [€ - Euro]
1	4.25	17.50	7.88
2	4.24	16.00	7.20
3	5.93	24.50	11.03
4	7.17	28.32	12.74
5	7.19	29.14	13.11
6	8.26	31.73	14.28
7	8.63	33.64	15.14
8	8.33	32.45	14.61
9	6.69	25.32	11.39
10	5.37	21.27	9.57
11	3.37	13.41	6.03
12	3.24	13.36	6.01
Year	6.06	286.64	128.99

The panels' efficiency is given by equation (3), [16]:

$$\eta_{[\%]} = \frac{P_m}{E \cdot S} \times 100; \quad (3)$$

where:

P_m , is the maximum output power under standard conditions (25 °C and 1000 W/m²); E , represents the solar radiation in W/m²; S , the panel's area.

Table V. - Radiation comparison between system structures.

Month	Solar radiation [kWh/m ² /day]	Solar radiation [kWh/m ² /day]	Solar radiation [kWh/m ² /day]
	Static	1-Axis	2-axis
1	3.58	4.07	4.25
2	3.64	4.19	4.24
3	5.04	5.90	5.93
4	5.67	6.96	7.17
5	5.49	6.73	7.19
6	6.03	7.54	8.26
7	6.36	8.00	8.63
8	6.52	8.04	8.33
9	5.57	6.63	6.69
10	4.56	5.31	5.37
11	3.02	3.30	3.37
12	2.80	3.08	3.24

For our test the maximum solar radiation was 991.21 W/m², so considering that the maximum output power of the panels is 88 W for 0.8 m² area then the maximum efficiency obtained was around 11%, a typical value for that kind of cells. The voltage regulator at the end of the tests showed a value of energy produced and supplied to the batteries of 227 Wh.

Table VI. - Economic comparison between system structures.

Structure	Average Solar radiation [kWh/m ² /day]	Energy AC [kWh]	Produced energy [€ - Euro]
Static	4.86	229.88	103.45
1 - Axis	5.81	274.81	123.66
2 - Axis	6.06	286.64	128.99

8. Conclusions

This communication presents a platform that will be used in the teaching of energy management and renewable energy. It is based on photovoltaic panels LabViewTM controlled. This work give a contribution to the sustainable development with a batteries charging study through PV panels in respect to voltage, current and temperature measurement and how this variables change according to Sun position and PV panels orientation. It is also created a database with these variables. The system is

controlled by LabViewTM software. The presented set-up includes PV panels' orientation, panels' temperature and solar radiation.

We present tests done with different loads and in different solar conditions and it is presented a comparison between gains of static, 1-axis and 2-axis movable panels and payback estimation for present configuration.

A possible future application for this project can be a microgeneration project for our department technical room with a micro turbine aided by batteries charged with PV. Other future possibility is a fast load station for electric cars charging, in development at our school.

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