Efficient Solution of PV System with Solar Tracker – Laboratory Prototype

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Abstract - **Despite its inexhaustible nature, the use of solar energy is temporally limited. In addition, the efficiency of fixed photovoltaic panels is influenced by climatic conditions over a day, resulting in lower efficiency of energy production (about 15%). To operate close to the maximum production point, the photovoltaic panels must be kept perpendicularly to the solar radiation. Therefore, there is a need for solutions to improve the energy efficiency of the PV solar panel and a solar tracker system could be a solution. The paper presents the features of a bi-axial solar tracking system developed by the authors in the laboratory and based on an Arduino Uno microcontroller platform. A small solar panel is oriented in the direction corresponding to the maximum energy point by means of two servomotors controlled by the microcontroller platform, which receives the information from a system of 4 photodetectors.**

Cuvinte cheie: *microcontroller, panou solar, fotorezistor, sistem de monitorizare.*

Keywords: *microcontroller, PV panel, photoresistor, tracking system.*

I. Introduction

The solar energy is an alternative energy source, clean, easily accessible and inexhaustible.

In order to develop a solar energy conversion system, it is necessary to know the available potential of the solar energy in the country, data provided by literature or specialized sites. Information on solar radiation is available for two cases of atmospheric transparency: clear sky conditions (nebulosity 0-3 degrees), which characterizes the maximum possible sun radiation, as well as medium nebulous conditions [1-3].

Sunshine duration is the time interval of a day when the sun shines and is expressed in hours and tenths of an hour. In Romania, according to data provided by the National Meteorological Administration NMA, the highest values, over 2300 hours per year, are recorded in the south-east of the country, on the Black Sea coast, due to the clear weather in the most part of the year and the downstream airflow at the seaside. Plain regions are distinguished by a characteristic duration of sunshine generated by the air mass circulation conditions. Thus, in the Romanian Plain, the average annual sunshine sums over 2100 hours in the

eastern and south-east and over 2200 hours in the central and western parts, predominantly the continental air. In the Western Plain, it varies between 2047 hours and 2178 hours, under the influence of the oceanic circulation from the West. In the case of the high mountain ridge regions, the annual duration exceeds 2000 hours. In hilly and mountainous regions, mist and heavier skies have a higher incidence, the average annual sunshine hours are between 1900 hours in hill and plateau areas and 1,600 hours at altitudes higher than 2500 m. In the intermountain depressions, the duration of the insolation is greatly reduced due to the obstacles that limit the horizon, as well as the persistence of the fog and stratiform nebulosity due to the predominant thermal inversions [4-6].

In order to design a solar energy conversion installation, it is necessary to know the possible solar radiation on the collector surface of either the solar collector or the photovoltaic module. In addition, the solar radiation is a variable function depending on: site position, season, day, day's hour, degree of nebulosity, dust, water vapor and aerosol content in the atmosphere. The prediction of these parameters is based on systematic historical measurements available in NMA publications. In order to maximize the solar energy extraction process and to increase the efficiency of the photovoltaic system, the solar collector plane should be normal to the incident radiation. The diurnal and seasonal motion of the Earth affects the intensity of the radiation received by the solar collector. A sun tracking device allows the solar collector to move in order to track the solar trajectories and maintain its orientation at an optimal angle of inclination, thus leading to increased energy output [7,8].

This paper presents the features of an automatic prototype system with bi-axial tracking (azimuth angle and altitude angle) of solar radiation captured by a small-size photovoltaic panel. The system was designed, programmed and developed by the authors in the laboratory, being driven with a servomotor controlled by a platform with Arduino microcontroller, which accesses the control data from photodetectors - photoresistors (LDRs).

II. The Solar Tracking System's Technology

A solar tracker allows the sunlight orientation of photovoltaic panels, reflectors, lenses, or other optical devices.

For the photovoltaic panels (PV) applications, the trackers are used to minimize the angle of incidence of solar radiation with the panel. This allows for increasing the amount of energy by comparison with that produced by a fixed power generation unit.

The solar beam has two components: the "direct beam" carrying about 90% of the solar energy and the "diffuse skylight" carrying the rest - the diffuse fraction increases proportionally on cloudy days. Since most of the energy is contained in the direct beam, maximum reception requires the sun to be as much as possible in the panel's exposure area. Using a bi-axial solar tracker is extremely beneficial, following the azimuth and altitude. The bi-axial tracking device is following the nearly permanent perpendicular orientation of the sunlight on the controlled panel, resulting in a net superior performance over the fixed or with limited freedom degrees solar panels [9].

There are four main types of solar energy tracking technologies:

- solar tracker based on photodetectors, achieved with light dependent resistors (LDRs) [3];

- the astronomical method, using a historical pattern of annual sunshine radiation [4];

- a digital camera tracker that uses the processed digital images of the sun [5];

- tracker with hill-climbing algorithm, which uses an iterative algorithm to obtain the maximum power point [6].

The prototype system developed by the authors includes a solar tracker that operates on the basis of information gathered by light-dependent resistors LDRs.

A photoresistor is a passive device whose resistance changes under the influence of a luminous flux. It is based on the phenomenon of photoconductivity by which, the electrons released under the action of light radiation increase the electrical conductivity of the semiconductor and implicitly decrease the resistance of the resistor. This property is used to locate the sun's position. In LDR-based solar tracking systems, three or more sensors are arranged in different ways to locate the sun's position. The method used by the prototype tracker uses shadow formation by changing the position of the sun to locate its current position with 4 LDR sensors. They are located one in the immediate vicinity of the other, being separated from dark areas (partitions) with an LDR sensor in each area. The data achieved from different LDR's are compared to determine relative radiation and therefore to find the sun's position relative to the panel. This data are provided to an Arduino microcontroller platform, which calculates the difference and controls two actuators to align the panel. This method of tracking the sun is cheap and relatively simple. Photoresistors tracking tools have a position control system that periodically checks the current position of the panel.

Nevertheless, this method has the disadvantage of lower precision for the weather with cloudy sky or fog. The system tends to enter in a stand-by mode, which leads to substantial energy consumption [7].

III. THE CONFIGURATION AND COMPONENTS OF THE SOLAR TRACKER SYSTEM

A. Characteristics of Component Parts

The tracking system includes in principle two subsystems: the mechanical subsystem and the electrical one, with the block diagram shown in Fig.1.
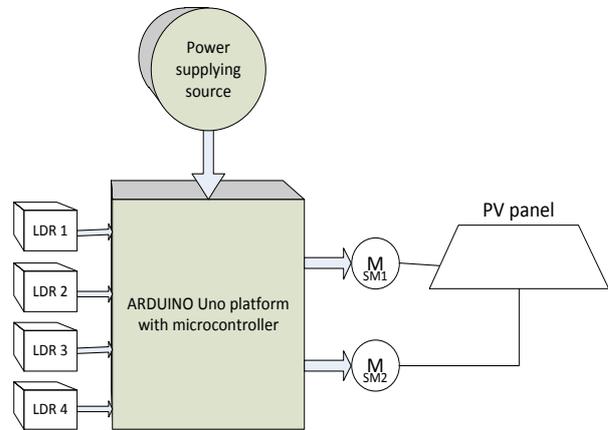

Fig. 1. Block diagram of the solar tracker system

The mechanical subsystem is represented by the metal structure supporting the PV panel and allowing it to rotate with 180^0 around the vertical axis and 90^0 around the horizontal axis.

The electrical subsystem consists of:

i) Arduino Uno platform control module with ATmega328P microcontroller [8];

ii) powering module with battery type 9V or HUAWEI 100-input 240 V AC, 50 Hz, 0.5 A, 12 VDC output, 1.5 A;

iii) data acquisition module with 4 Token photoresistors, 150 V cc, 100 mW, 30 ... 90 kΩ resistance to 10 lx;

iv) 2 controlled actuators for solar panel positioning, type FS5109M, with following characteristics: supply voltage 4.8 ... 6 V; speed 0.16 sec / 60 degrees at 6V, 0.18 sec / 60 degrees to 4.8V; torque 10.2 kgf x cm at 6V, 9 kgf x cm at 4.8 V; rotation angle 1800 counterclockwise; weight 56 g.

The system controls a PV mini panel of 30 x 25 cm^2, 4 x modules (6x12 cells), with a surface of 0.075 m^2 and an efficiency of 12% yield. It works only in the presence of the sunlight.

LDRs detect the intensity of light incident to the solar panel and send sequentially information to the Arduino microcontroller that controls the powering of the two servomotors. The actuators' control is performed according to the algorithm implemented on the Arduino platform. This one will move the solar panel toward the LDR whose resistance will be lower, that is the one on which the light beam falls so that the panel will continue to follow the light.

If two neighboring LDR units are subject to equal light radiation, then the connected servomotor will not be actuated. This one will attempt to move the solar panel to the

position where both LDRs will have the same resistance (when exposed to the same light radiation) and will rotate only if the resistance of one of LDRs will decrease (according to higher sun radiation) [10-13].

B. System Architecture

Execution of the control algorithms for actuating the positioning servomotors of the PV mini-panel's support structure is performed in accordance with the wiring diagram included in the solar tracker are detailed in Fig.2 and architecture shown in Fig.3.
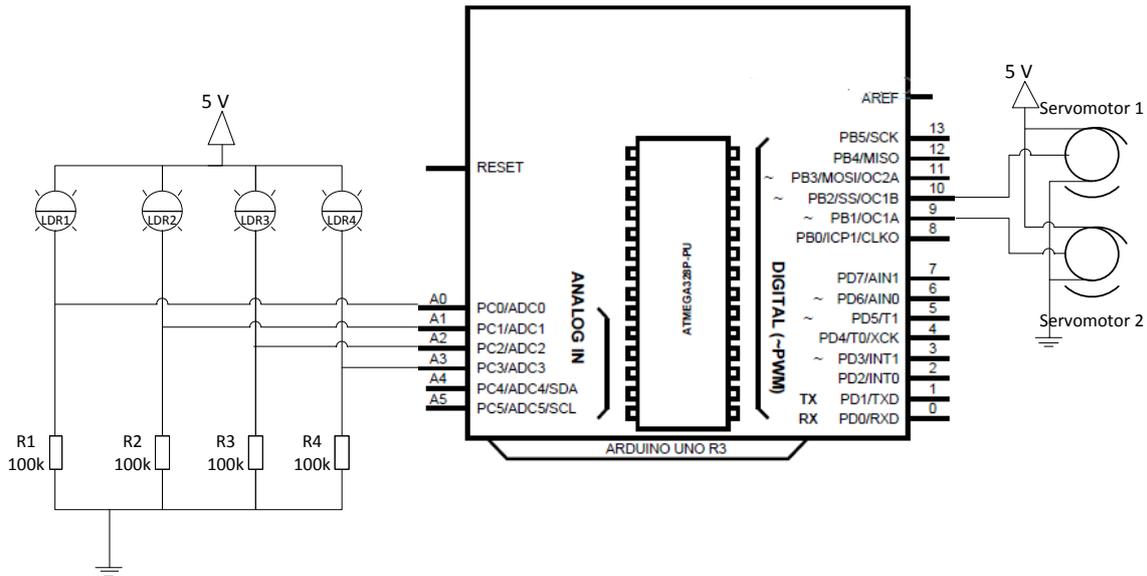

Fig. 2.   Connection of the control subsystem components to the microcontroller platform
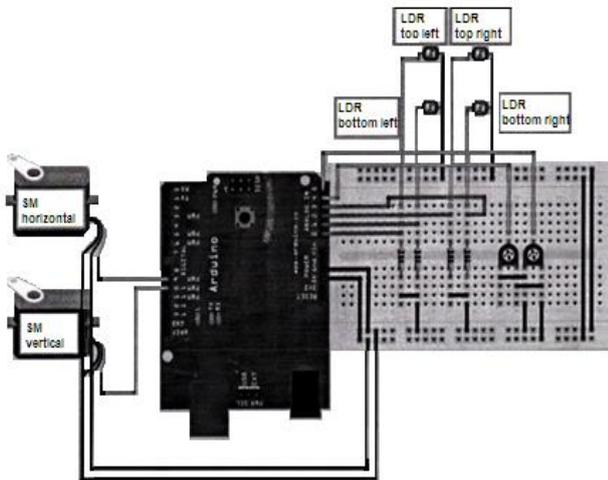

Fig. 3.   Picture of base plate subsystem control with Arduino Uno platform

The connections of the servomotors to Arduino are accordingly to Fig. 3, the following:

- positive servomotor pin to microcontroller's + 5V pin;
- servomotor's negative terminal to GND pin of microcontroller;
- the signal cable of the actuators connected to the microcontroller's digital pin 9 (horizontal actuating), respectively 10 (vertical actuating).

The connection of photoresistors to Arduino is achieved as:

- terminal 1 of photoresistor 1, 2, 3, respectively 4 to pin A0, respectively A1, A2, A3 of microcontroller;
- terminal 2 of photoresistor 1, 2, 3, respectively 4 to pin + 5V of microcontroller.

IV. ANALYSIS OF THE SOLAR TRACKER SYSTEM PERFORMANCES

A. Test Conditions

The solar tracker prototype system shown in Fig.4 has been tested under real conditions for different daytime and atmospheric conditions.
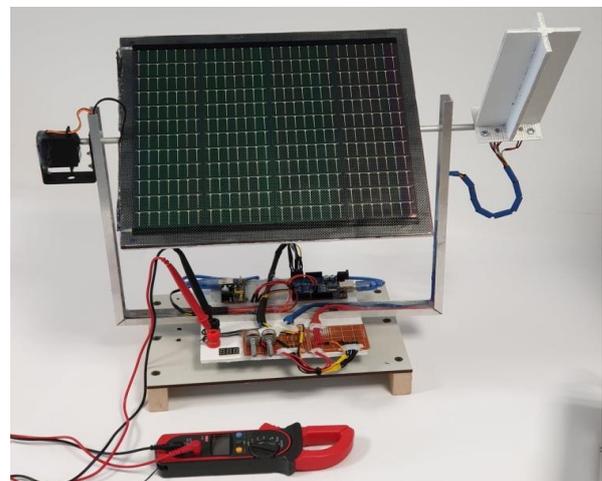

Fig. 4.   Bi-axial solar tracker system controlled with Arduino platform and LDR photoresistors - laboratory prototype

The test site is located on the INCESA Applied Science Research Infrastructure building of the University of Craiova, at a height of 20 m. The geographic coordinates of the location are 44.3302 ° N x 23.7949 ° E.

According to NASA application Power Data Access Viewer [6], the annual solar radiation at the terrestrial surface, available at the location with indicated coordinates, has registered a value of approximately 1347 kWh / m^2 year during the past year (01.01.2024-01.01.2025), as in Fig.5.

The application also allows computing the maximum power value produced by the controlled PV panel of 8W power and 12% efficiency under climatic and environmental conditions specific to the considered location [7].

As it can be seen in Fig. 6, for annual solar radiation of 1347 kWh / m^2, a maximum power of about 9 kWp can be estimated to be delivered by the actuated PV panel.

B. Testing the Performances of the PV System with Solar Tracker

Determining the performance of the PV power system oriented with a solar tracker requires the determination of the characteristic electrical values for different PV panel orientations, given by the panel's tilt angle and the rotation of its support frame.

The PV's panel position controlled by the solar tracker's electrical subsystem is depending on the available sun radiation at that time for the chosen location.

The results of successive readings of the operation electrical values associated with different light conditions and correspondent positions of the mechanical structure are given in Table I.

Experimental testing of the solar panel tracking system has led to the extraction of important observations that allow comparison of the performance of the tracked solar panels with those of the similar fixed panels.

Fig. 5.   Annual solar radiation at ground level of approx. 1347 kWh / m^2.year - 44.3302 ° N (lat) x 23.7949 ° E (long), 01.01.2024-01.01.2025) (NASA Forecast of Worldwide Energy Resource POWER Higher Resolution Daily Time Series 1/2 x 1 / 2 degree, Climatology Resource for SSE-Renewable Energy)

Yellow cell = enter your own data
Green cell = result (do not change the value)
White cell = calculated value (do not change the value)

Global formula : $E = A * r * H * PR$

E = Energy (kWh)	9	kWh/an
A = Total solar panel Area (m²)	0.075	m²
r = solar panel yield (%)	12%	
H = Annual average irradiation on tilted panels (shadings not included)*	1347	kWh/m².a
PR = Performance ratio, coefficient for losses (range between 0.9 and 0.5, default value = 0.75)	0.75	

Total power of the system	0.009	kWp

Losses details (depend of site, technology, and sizing of the system)

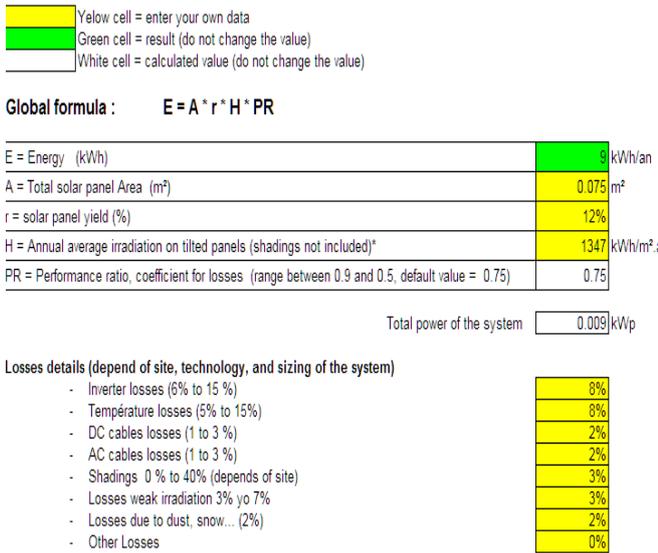|	
- Inverter losses (6% to 15 %)	8%
- Température losses (5% to 15%)	8%
- DC cables losses (1 to 3 %)	2%
- AC cables losses (1 to 3 %)	2%
- Shadings 0 % to 40% (depends of site)	3%
- Losses weak irradiation 3% yo 7%	3%
- Losses due to dust, snow... (2%)	2%
- Other Losses	0%

Fig. 6. Computing of the power of PV panel injected in the specified location

TABLE I.
OUTPUT ELECTRICAL VALUES OF THE PV MINI-PANEL ACCORDING TO
RADIANCE (MAY 2024, 14:00)

PV panel's values		Weather conditions					
		Cloudy		Partly cloudy		Sunny	
		Tracker off	Tracker on	Tracker off	Tracker on	Tracker off	Tracker on
Tilt angle(deg)	Horiz. axis	45^0	50^0	45^0	35^0	45^0	40^0
	Vert. axis	0^0	15^0	0^0	15^0	0^0	15^0
Open circuit voltage Voc, (V)		14.200	14.500	18.900	19.020	18.900	19.020
Short circuit current Isc, (A)		0.048	0.050	0.180	0.200	0.318	0.340
Maximum power, (W)		0.681	0.725	3.402	3.804	6.010	6.466
Power gain with tracker, (%)			5.986		10.567		7.061

It can be seen that the maximum output power of the panel increases by up to 11% for panel displacements up to (35^0, 15^0) by comparison with the value corresponding to the fixed reference position (45^0, 0^0). Further testing measurements confirm the opportunity of extending the prototype application in order to increase the efficiency of a larger-scale PV installation [14, 15].

V. CONCLUSIONS

The paper presents the characteristics and performance of a prototype bi-axial tracking system of small solar panels, designed, programmed and developed by the authors in the laboratory.

The purpose of the solar tracker is to track the position of the sun for a better efficiency of the solar installations with PV panels, as demonstrated by the experimental results.

System performance can be improved by using smarter and more efficient sensors, as well as individual components with lower power consumption (e.g. servomotors).

These measures would make possible to increase efficiency and reduce the time till the break even.

Contribution of authors:
First author – 20%
First coauthor – 20%
Second coauthor – 20%
Third coauthor – 20%
Fourth coauthor- 20%

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