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Design and implementation of a performent low cost microcontroller based dual-axis sun-tracker system

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***Abstract*— Photovoltaic panel (PV) efficiency depends strongly on its sun's position. In the literature, different sun-tracker systems have been suggested in order to improve the output power of the PV. Two major methods could be cited: the first is based on a solar position algorithm, while the second is using a photo-resistor sensor.**

In this work, we combine both methods to implement a low cost microcontroller based dual-axis (azimuth-elevation angles) sun-tracker system. It is driven by a microcontroller to generate the maximum output power of the PV in all weather conditions. Our system tracks the sun on azimuth axis using a special solar position algorithm who calculates firstly the sunset and the sunrise angles and then rotates the PV on the west direction; by one degree each four minutes. The solar elevation angle is determined by two photoelectric sensors where the sun light intensities are compared with each other to identify the zenith angle. We use some recycled components to implement our PV sun-tracker system.

We compare the output power of the PV in the cases of the mobile system and the standard fixed PV. With our method, we significantly improve the yield of the PV by 32%. We compare the simulated and experiment curve of sun elevation angle.

***Keywords*— Sun tracker, photovoltaic panel, sun position**

I. INTRODUCTION

Because of a damage caused by fossil fuel to earth environment and limited sources of this kind of energy, it's very necessary to develop renewable energies technologies to preserve the earth ecologic environment and procure a clean energy for the next generations [1]. The photovoltaic energy occupies an important place because of sun abundance (The quantity of energy attainment the surface of the Earth every hour is greater than the quantity of energy used by the Earth's population over an entire year) and PV devices are unique in that they directly convert the incident solar radiation into electricity. The major challenge is to increase the cost / performance ratio in order to rival with polluting sources of energy (fossil) or dangerous (nuclear) [2], [3].

For good conversion efficiency of PV, the solar radiation must be perpendicular to surface of PV during daylight hour; it's why the sun tracker is used to keep them pointed to sun and collect maximum sunlight to generate more energy [4].

There are different sun-tracker models with one or two axes tracking system. The one degree sun tracker system moves PV on one angle to be normal to sun [5, 6]. The two degrees sun-tracker system tracks sun on two directions: azimuth and elevation angles [7], [8].

The program of control used to move PV can be with algorithm calculating the geo-solar coordinate (astronomical equation) to know the position of sun in the sky at every moment of day of year [9], or with sensor used to compare sunlight intensity and determine which side the sun-tracker must oriented PV [10], [11].

In this paper, we present a two axis prototype model of sun-tracker combining both systems: azimuth orientation with calculating the geo-solar coordinates and sun elevation angle will be determined by two Light Depend Resistance (LDR) in the aim to catch direct and diffuse sunlight. The arduino uno board collects information and controls the sun tracker motions. We expose the software, hardware elements and different organs constituent the expose prototype. We compare the PVs output power results of fixed and mobile panels every one hour; the sun elevation angle simulated with MATLAB and measured at the sun-tracker model will be traced and superposed.

II. CALCULATION OF SUN POSITION

The sun's position in the sky is determined by two angles: azimuth and zenith (elevation) angles, who depend on solar declination angle [12].

Solar declination δ is the angle between the sunlight and the equator plan of earth, its regularly changing over the year. It's given by equation (1):

$$\delta = 23.45 \times \sin(360 \times \left(\frac{284+N}{365}\right)) \quad (1)$$

N: is the range day of the year with 1 January = 1.

The variation of solar declination angle during an yearly cycle is included between -23.45° and 23.45°. On vernal and autumnal equinox δ = 0°, then that for winter solstice δ = -23.45° and δ = 23.45° on summer solstice. The fig.1 shows the solar declination angle curve and the different points of equinoxes and solstices.

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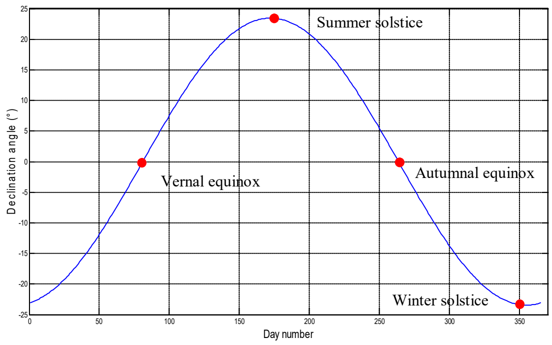

Fig. 1 The curve of solar declination.

Azimuth angle is the angle between the north meridian and the perpendicular projection of the sun on the horizontal plane of observer, the sun turn by one degree (1°) every four (04) minutes on azimuth angle either 15° of longitude every one hour. It's given by equation (2):

$$A = \cos^{-1}\left(\frac{\sin(\delta)\cos(\varphi) - \sin(\varphi)\cos(\delta)\cos(\omega)}{\cos(\alpha)}\right) \quad (2)$$

The sunset angle is the angle between the sun meridian and the north meridian at sunset time; it's given by (3):

$$\omega_s = -\arccos(-\tan(\delta) \times \tan(\varphi)) \quad (3)$$

Where:
Φ: latitude of locality.
ω: hour angle (the angle between the observer meridian and the solar meridian), its equal to 0° at local noon.
α: elevation angle.

The elevation angle α is the angle between the sunlight trajectory and the projection of the sun on the horizontal plan of observer. It's given by relation (4):

$$\alpha = \sin(\delta)\sin(\varphi) + \cos(\delta)\cos(\varphi)\cos(\omega) \quad (4)$$

The solar elevation angle of Constantine city relative to the day time for equinoxes and solstices is shown on fig. 2.

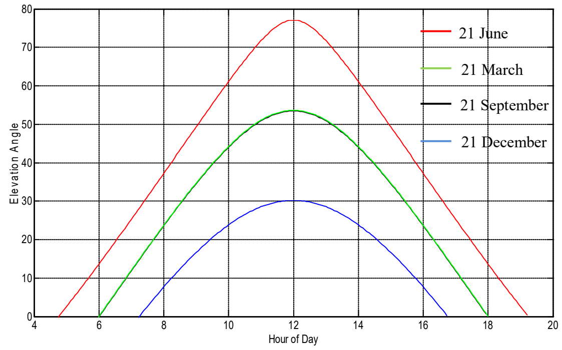

Fig. 2 The solar elevation angles.

After giving equations to calculate the sun position in the sky, we present schematically on fig. 3 the elevation angle and azimuth angle relative to the observer plan.

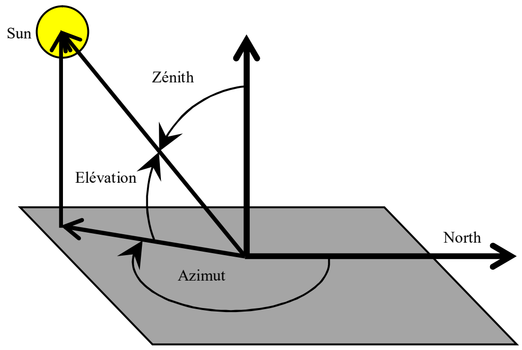

Fig. 3 The azimuth and elevation angles.

III. SUN TRACKER: DESIGN AND IMPLEMENTATION

In the aim to simplify the principal sun tracker system functioning, we divide our study on several parts: The first part is software where we present the role of program charged on Arduino Uno board microcontroller; the second hardware part who boards the command and control of system; finally the third part in which we describe the realization of the sun tracker.

A. Description of Software

To write the code of program who control the sun tracker motion and charged it on Arduino Uno board microcontroller we use the open-source Arduino software IDE (Integrated Development Environment) using like code editor and compiler with a C++ simplified language.

The code charged on Arduino Uno microcontroller calculates the sunrise and sunset angle given by equation (3) for the location of experiment (ZERZARA Campus, Constantine, Algeria) with φ=36.36°.

Then the azimuth angle DC motor rotate PV from south direction to the east side by an angle rise already calculated and waits the moment of sunrise to be commanded every 4 minutes to turn by 1°.

For aligning the photovoltaic panel to the sun's elevation angle, we connect two (2) LDR (light depend resistance) to Arduino Uno analog pins to compare the sunlight intensity received on every one then order the actuator to move up or down the PV until the difference of irradiance light becomes lower than respective set values in both LDR. We separate LDR with an opaque divider to create shadow on one side of it if the sunlight is not perpendicular to PV. The flow chart of sun tracker principle is given by the following figure:

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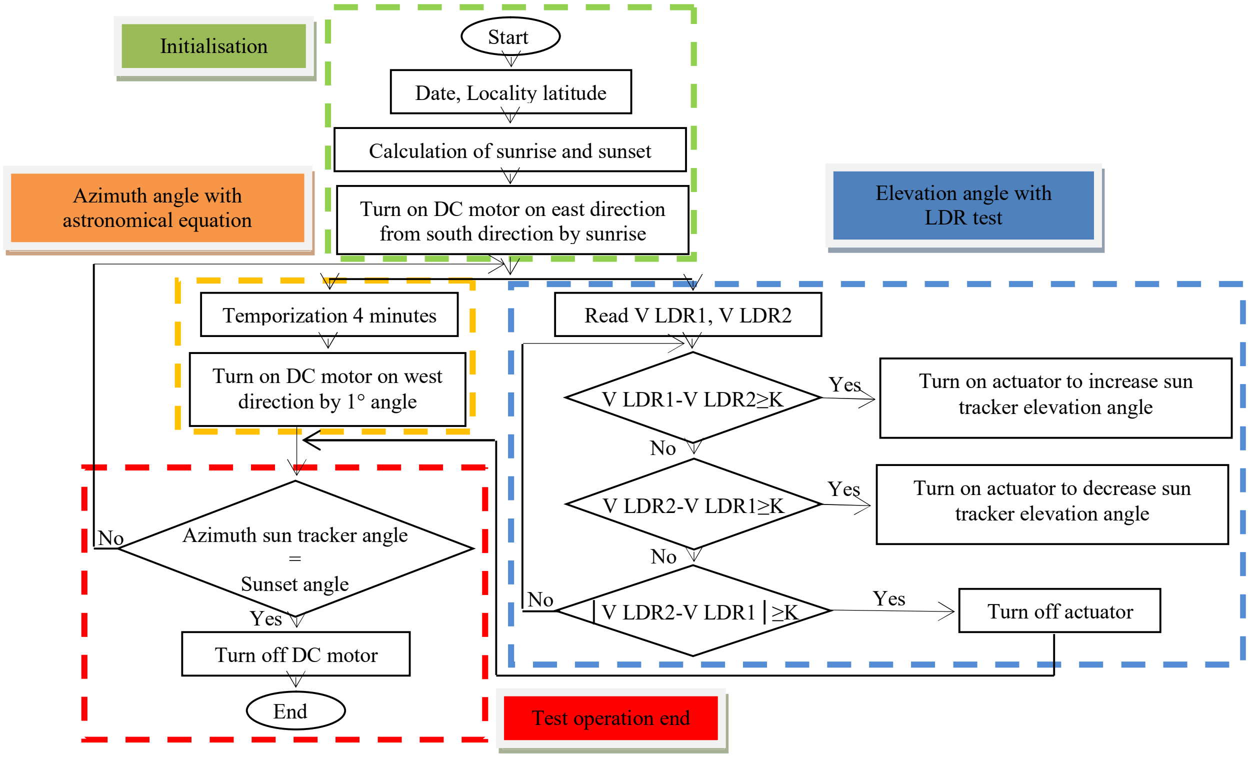

Fig.4 The flowchart of the sun tracker system

B. Description of Hardware

In this part, we expose the connection diagram of LDR and the control board of DC motor and actuator.

1) *Captors LDR*

The light depend résistance (LDR) is an electronic semiconductor component wish the resistance varies with sunlight intensity; it's a resistor whose resistance increases with decreasing light intensity. We use it like an input to arduino uno microcontroller to orientate PV toward the sun. The mounting of LDR is shown on fig. 5.

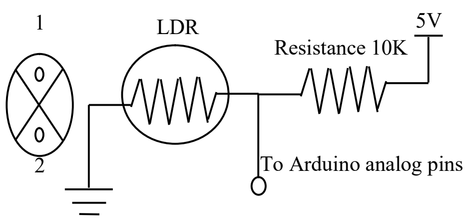

Fig. 5 Mounting LDR.

2) *Command of DC motor and actuator*

The command DC motor (azimuth angle) and actuator (elevation angle) is realized by two (2) L6203. It is an H bridge driver MOSFET integrated circuit who can operates at high switching speeds. For choosing the direction of rotation, the microcontroller controls two input pin IN1 and IN2 for every DC motor. We enable and disable the driver by a logic input enable pin: if this pin is HIGH the Mosfet driver is enable, if LOW its disable.

The DC power supply circuit to feed the control circuit of sun tracker system is used by LM7812 regulator. In order to have the current intensity needed to rotate DC motors we use the high current mounting indicated on LM7812 datasheet. We have two possibilities to feed the power supply circuit: with an alimentation block fed by 220V~ who delivers DC 24V or with 12V photovoltaic battery. The Arduino Uno microcontroller is feeding 5V power supply with LM7805 regulator mounting or with connecting to PC by USB port.

On this work we use the block alimentation (220V~24V-) to feed the sun tracker system. Fig. 6 shows the block diagram of sun-tracker system control.

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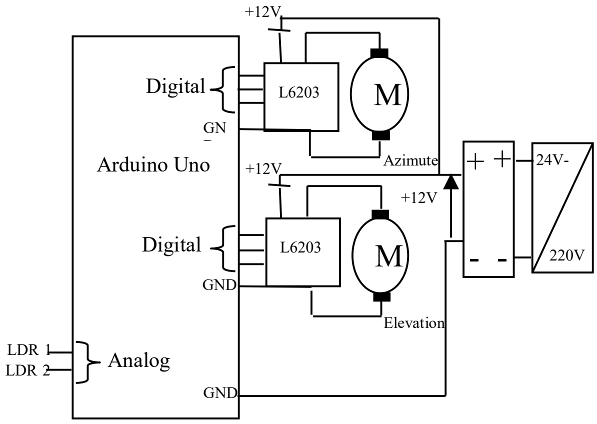

Fig. 6 Block diagram of sun tracker system control.

C. The implementation of solar tracker

The sun tracker implemented on this work pivots around two axes of rotation to form two angles: azimuth and elevation angles. We use a dc actuator to command the PV elevation and a DC motor dismantling from a failure actuator and modified to orientate PV on azimuth rotation axes, using pinions flywheel that bring from failure car (FIAT RITMO 1981) and starter motor dog of Volkswagen POLO 1997.

For a large utilization of our system by students on their studies, we opted for the manufacture of a system who can set different panel dimensions: panels with width less than 70 cm, length between 50 cm and 140 cm. For less or larger dimensions we can replace the upper part of sun tracker with another larger or smaller like we need. The movable fixation is shown on fig. 7.

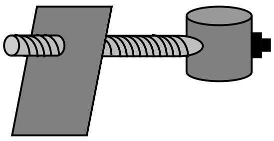

Fig. 7 Fixation organe.

IV. RESULTS AND DISCUSSION

We made our experience on June 2, 2016 during a sunny day at Mentouri Constantine Campus (Latitude: 36.36° East, Longitude: 6.61° North). We use two PV Canadian solar Inc (Model type: CS4-55), one PV fixed on support in south direction with an elevation angle of about 45°; the second one is placed and fixed on sun tracker prototype like shown on fig. 8.

We compare the PV output power recuperated from two PV every one hour and the elevation angle of the movable PV with the curve of sun elevation angle simulated by MATLAB.

We compare the PV output power recuperated from two PV every one hour and the elevation angle of the movable PV with the curve draws by MATLAB.

Fig. 8 Double axes sun tracker system.

As shown on fig. 9, the energy generated by a movable PV is clearly higher than the fixed one by about 32%, the difference between the output power of every panel decrease until the sun is highest in the sky and begins widen until the sunrise time. It's due to the sunlight perpendicularity to surface of PVs.

Fig. 10 shows the elevation angle of movable PV measured everyone hour and compared to curve of theatrical elevation angle traced with MATLAB. We observe that curves are relatively close because the experience was made during a sunny day.

The results obtained are given by the following two figures:

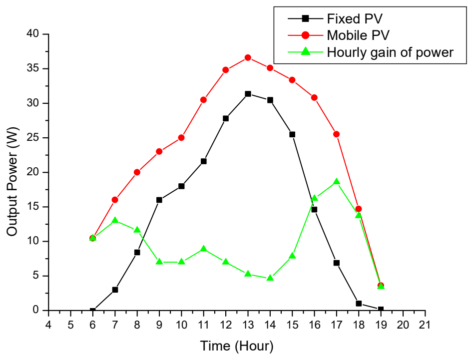

Fig. 9 Output power of fixed and mobile PV.

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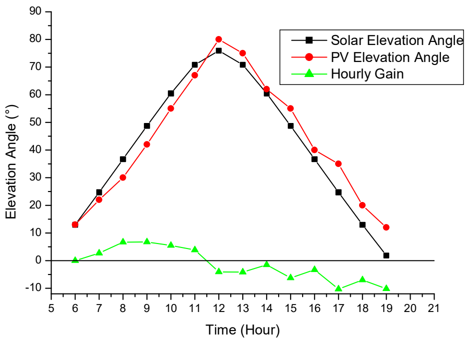

Fig. 10. Comparison between simulated and experimental angle of elevation.

V. CONCLUSION

On this work, we used a sun tracker with an algorithm to calculate the sun azimuth angle and LDR sensor to found the sun elevation angle in order to increase the PV efficiency by positioning it perpendicular to solar radiation to collect the maximum of solar energy during one day on all kind of weather (direct and diffuse radiation).

We used recycled material by modifying it on our way to not spend much money and to preserve earth ecologic environment.

Fig. 9 shows that using a sun tracker system improve the power output of PV relative to the fixed one. Fig. 10 shows the PV elevation angle relative to the simulated sun elevation angle by MATLAB, for a sunny day the curves are close but it tends to change for a cloudy day.

The prototype realized has increased the output power of PV by about 32% compared to the average power generated by the fixed PV.

Our future study will be focus on correcting of the position of a sun tracker relative to the sun position in the sky by using a flowchart with calculating and comparing to improve the PV yield.

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