Khadidja DAHLI[1], **Nawal CHEGGAGA**[2]

Electrical and Remote Control Systems Laboratory, LabSET, Faculty of Technology, Blida University 1, Blida, Algeria
ORCID: 1. 0000-0001-9649-070X

doi:10.15199/48.2023.07.21

A New Solar Tracking Strategy to Upgrade Solar Power Efficiency using ZIP codes as an Alternative to Sensors

***Abstract**. Over the last few years, solar trackers has gone from being a modern power technology to a major source of electricity production. Thus far, the solar tracking technology has dominated the market of solar power and renewable energy. Usually solar trackers use sensors to locate the sun's position with a high degree of accuracy; however; the biggest disadvantages of sensor based solar trackers is that they can be complex, inaccurate with the high response time and are slightly more expensive than their stationary counterpart. In that matter, the main objective of this work is to design a new, cost effective and simple solar tracker that increases the solar power efficiency without using sensors nor feedback loops. Instead, we have found a new and more accurate strategy to properly determine the position of the sun by using a tracking code that is based on countries ZIP codes. In this paper the design, simulation and testing of a high-precision and sensorless solar tracking system is carried out using sun position algorithm and astronomical equations. Results show that our tracking system can be 99.9% as accurate as a GPS based solar tracker; moreover, it can be flexible, efficient, low-cost and fitting for both large and small solar generation.*

***Streszczenie.** W ciągu ostatnich kilku lat trackery słoneczne z nowoczesnej technologii energetycznej stały się głównym źródłem produkcji energii elektrycznej. Do tej pory technologia śledzenia słońca zdominowała rynek energii słonecznej i energii odnawialnej. Zwykle trackery słoneczne wykorzystują czujniki do lokalizowania pozycji słońca z dużą dokładnością; jednakże; największą wadą trackerów słonecznych opartych na czujnikach jest to, że mogą być skomplikowane, niedokładne z długim czasem reakcji i są nieco droższe niż ich stacjonarny odpowiednik. W tym zakresie głównym celem niniejszej pracy jest zaprojektowanie nowego, efektywnego kosztowo i prostego trackera słonecznego, który zwiększy efektywność energii słonecznej bez użycia czujników i pętli sprzężenia zwrotnego. Zamiast tego znaleźliśmy nową i dokładniejszą strategię prawidłowego określania pozycji słońca za pomocą kodu śledzenia opartego na kodach pocztowych krajów. W tym artykule projekt, symulacja i testowanie bardzo precyzyjnego i bezczujnikowego systemu śledzenia Słońca są przeprowadzane przy użyciu algorytmu położenia słońca i równań astronomicznych. Wyniki pokazują, że nasz system śledzenia może być w 99,9% tak dokładny, jak lokalizator słoneczny oparty na GPS; ponadto może być elastyczna, wydajna, tania i odpowiednia zarówno dla dużych, jak i małych generatorów energii słonecznej. (**Nowa strategia śledzenia energii słonecznej w celu poprawy wydajności energii słonecznej za pomocą kodów pocztowych jako alternatywa dla czujników**)*

Keywords: tracking code, solar power efficiency, solar tracking system, ZIP codes.
Słowa kluczowe: kod śledzenia, efektywność energii słonecznej, system śledzenia energii słonecznej, kody pocztowe

Introduction

The Sun is an incredibly potent source of power that releases radiant energy from the occurrence of nuclear fusion process inside of it, the amount of the sun's energy surrounding the earth is roughly (1370 w)⁄m^2 , but only 644w⁄m^2 arrives at the earth surface[1]. While some of it can be used by plants or reflected by 50 % because of the ground cloudiness[2], the solar radiation striking the earth surface is more than 10,000 times the human 's energy use [3] .

Due to the fact that solar energy can profitably and expeditiously produce power, the solar PV market is swiftly developing all over of the globe with a capacity record elevated from 177 GW at the end of 2014 , to 385 GW by the year 2017[4]. The world is making remarkable advance in the development of its renewable energy sector, yet using the conventional solar power generation techniques is not enough to cover the world's total energy needs, therefore a more practical technique and high quality technology must be used such as solar tracking system.

The intelligent tracking systems optimize the electrical power output of the solar panels by keeping the solar module perpendicular as close as possible to the Sun' radiation[5].Solar trackers can be classified according to the mode of their motion as single axis or two axes trackers[6];And as passive, active or open loop trackers depending on the type of control and detection. The emitted solar radiation that falls on the panel's surface can be estimated and it consists of three components, direct, diffuse and reflected solar radiation. the output energy of a solar tracker depends on the amount of solar radiation falling on the PV panel[7].

Since solar radiation intensity depends on geographical location [8].the position of the sun (altitude and azimuth angles) must be determined accurately .The LDR sensors are highly inaccurate with the high response time, and they are so sensitive to temperature [9].In contrast, GPS sensors are more accurate and less sensitive to external conditions ;however, there biggest disadvantage is that they need power to function which drains battery in 8 to 12 hours[10].

The solar tracking system was first invented as a mechanical system by C. Finster in 1962[11]. A lot of researches has been conducted on solar trackers ever since to improve of the efficiency of the PV system and reduce cost and complexity of solar tracking systems.However, one of the biggest problems that the solar tracking technology poses is either because of the inaccuracy of the sensors in bad weathers, their energy consumption , the complexity of the system ,or because of the high cost in comparison to their stationary counterparts[12]. Thus, the objective of this work is to present a new method to determine the location of the solar tracker that can be as accurate as a GPS sensor, and cost effective as LDR sensors, with less complexity and better efficiency, by using countries ZIP codes to determine the position of the sun instead of sensors.

In this work, we have designed a new, cost-effective and more accurate solar tracker that uses countries ZIP codes instead of specific sensors to determine the tracker's angles. This new method consists of increasing solar system power efficiency without using sensors, but rather using sun position calculators and algorithms based on the astronomical equation. The sun's position from a specific set point based on a pre-calculated geographic coordinates is determined by converting a tracking code that uses ZIP codes into geographic location (altitude and longitude). A comparison between our solar tracker that uses tracking code (ZIP codes) and GPS based tracker has been conducted to test the performance and accuracy of our system .A graphical user interface was also designed to give the user the privilege of interacting with the solar panels and optimizes the user experience requiring minimum effort on the user's part to receive maximum desired outcome since it has as input parameters only the ZIP code of the location. The system was designed and simulated using Arduino microcontroller with MATLAB and Proteus environments.

By simulation results, it has been shown that the accuracy rate of solar tracking system using tracking code (ZIP codes) is approximately 99.9% in comparison to the GPS tracker, which can be a complementary factor in increasing the solar energy generation in a cost effective and less complicated way.

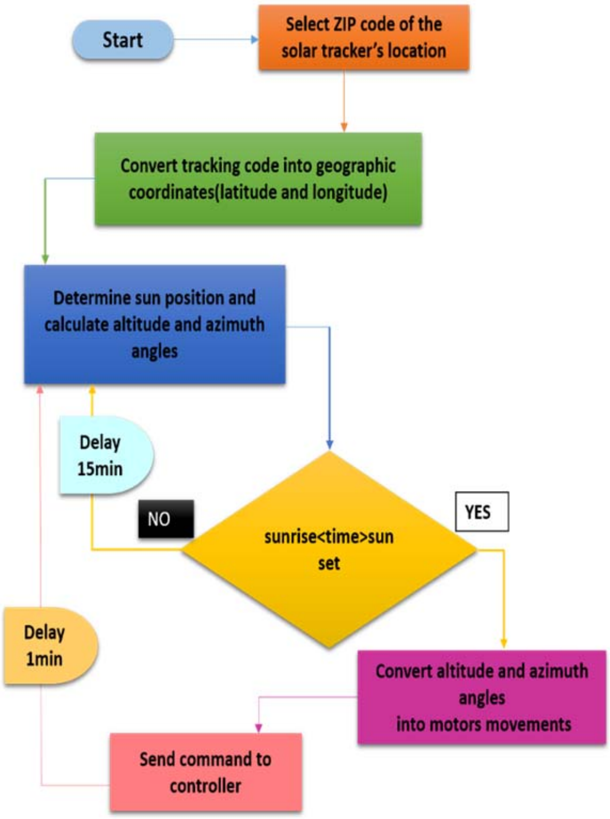


Fig. 1 Flowchart of the developed solar tracker based on tracking code (ZIP code

Methods and Materials

Proposed method

In this study, a new solar tracking technique has been designed and tested using MATLAB and Proteus software. This technique consist of using countries administrative divisions (ZIP codes) as an indicator to the position of the solar tracker in a specific geographic location.

Administrative division are generic names for geographical areas into which a particular country is divided. Each region is represented with a ZIP code. Therefore, we have used ZIP codes to provide users with positioning and timing instead of sensors. Since the position of the sun in the sky is a function of both the time and the geographic location of observation on Earth's surface. We have developed a sun tracking algorithm that can accurately determine the tracker's angle depending on the position of the sun by converting a ZIP code into geographic coordinates. The position of the sun is calculated using predefined algorithms based on mathematical calculations about sun's trajectory particularly azimuth and altitude angles. The main parts of the developed solar tracking system (shown in Fig. 1) are described as follows:

-The ZIP code of the location in which the solar tracker has been installed must be inserted.

-The developed algorithm will then give the location coordinates (latitude and longitude) of the selected ZIP code.

-Then position of the sun according to the given location (azimuth and altitude angles) will be calculated using astronomical equations in function of the location's latitude and longitude. -The solar tracker angles will then be calculated using the sun's azimuth and altitude angles.

-The calculated tracker angles will be converted into motor motion (rotation angle).

-The last step is to send the motor angles to the microcontroller so that the solar panel will face the sun directly; thus, maximize the power production.

The location of the solar tracker is determined by selecting the ZIP code of the region where the tracker is being mounted, since our study has been done in Algeria, our solar tracking system uses Algerian postal codes and convert them into geographic location. Algeria is administratively divided into 58 provinces (as shown in Fig. 2). Each province represent a county. The counties are divided into 2324 municipality. We have developed a MATLAB code that helps the user to get latitude and longitude in all of the provinces and municipalities across Algeria including 2324 different regions[13](as indicated in Table 1)

Table 1. Example of the data used in the MATLAB code (Algeria)

ZIP code	Latitude	Longitude	provinces	municipalities
9000	36.473571	2.832315	Blida	Blida
9002	36.458546	2.849169	Blida	Sidi Kebir
16000	36.779443	3.061738	Alger	Alger Gare
16081	36.694293	2.973317	Alger	Baba Hassen
14191	35.373814	1.315758	Tiaret	Ouarsenis el Beida

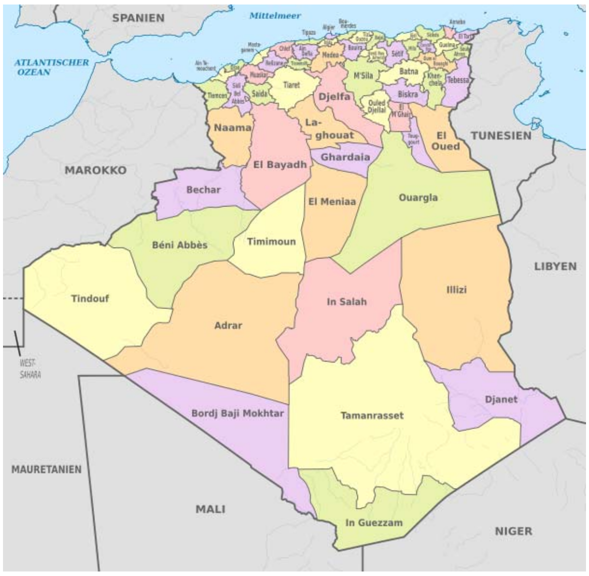


Fig. 2 Administrative divisions of Algeria[14]

Mathematical model

After getting the coordinates of the location (latitude and longitude) from the ZIP code, the control program uses astronomical equations to calculate the sun's position and track the sun firmly.

In virtue of astronomical equations, the solar tracker system pursue the movement of the sun in the sky from any location on Earth at any time and date by means of two angles altitude and azimuth. Where the azimuth angle is as an angular displacement of the Sun reference line from the observer point. And the altitude angle is the angular height

of the Sun in the sky from the same point. The Following equations, from the Astronomical data can be used to estimate the sun's position [15]:
The azimuth and altitude angles are given as:

(1) $Z_S= \cos^{-1}\big((\sin\delta\,.\,\cos\phi - \cos\delta\,.\,\sin\phi\,.\,\cos\sigma)/\cos\alpha)\big)$

(2) $\alpha=\sin^{-1}(\sin\delta\,.\,\sin\varphi+\cos\delta\,.\,\cos\varphi\,.\,\cos\sigma)$

where: Z_S – azimuth angle, δ – declination angle, ϕ – coefficients, σ– hour angle, α – altitude angle, φ – zenith angle.

The angle between the Earth–Sun vector and the equatorial plane defined as "angle of declination "is calculated by:

(3) $\delta=23.45^o\,.\,\sin B$

where B can be calculated by the number of days elapsed in a given year up to a particular date d as follows:

(4) $B = 360/365\,.\,(d-81)$

The angular displacement of the Sun from the local point known as" hour angle" is given by:

(5) $\sigma=15^o\,.\,(LST\text{-}12)$

where: LST – local Solar Time
The Time Correction factor in minutes TC defined as the true solar time is given by the daily apparent motion of the true or observed Sun as follows:

(6) $TC=4\ (L\text{-}LSTM)\ +EoT$

Where: $LSTM$– mean local Solar Time, L– longitude, EoT – Apparent solar time.
The difference between apparent and mean solar times EoT is given by:

(7) $EoT=9.87\sin(2B)\text{-}7.53\cos(B)\text{-}1.5\sin(B)$

where: LST – local Solar Time

By calculating the angles of the sun, the solar tracker can easily track the sun. However, tilt and azimuth angles are not the only facture affecting the efficiency of a PV panel [16]. The angle of incidence can as well effect occasionally the performance of a PV panel due to its technical properties [17]. keeping the solar module perpendicular to the Sun' radiation require maintaining this angle at the ideal zero degree[18] .The incidence angle of solar radiation (shown in Fig. 3) is defined as the angle between the sun's rays and the normal on a surface. the general expression for the angle of incidence is given as follows[19]:

$$\cos(\theta) = \sin(L)\sin(\delta)\cos(\beta) - \cos(L)\sin(\delta)\sin(\beta)\cos(Z_s) + \cos(L)\cos(\delta)\cos(h)\cos(\beta) + \sin(L)\cos(\delta)\cos(h)\sin(\beta)\cos(Z_s) + \cos(\delta)\sin(h)\sin(\beta)\sin(Z_s)(8)$$

where: β – tilt angle, h – hour angle, θ –coefficients, σ– hour angle, α – altitude angle, φ – zenith angle.

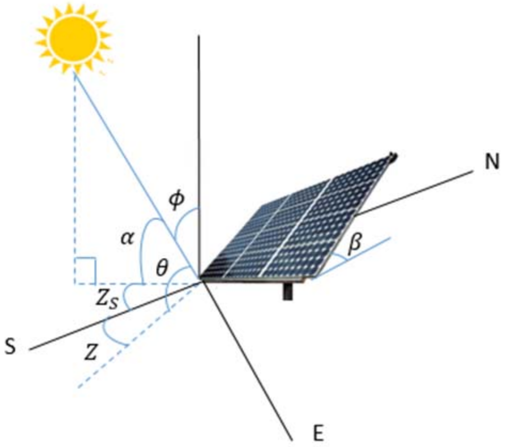


Fig. 3 the sun's position angles diagram.

Now that we have managed to keep the solar module perpendicular to the sun, we can predict the global solar radiation on a tilted surface. the amount of solar radiation on a tilted surface known as the global irradiance G_T is the sum of direct, diffuses and reflected irradiance (shown in Fig. 4)[15],it can be estimated using the following equation:

(8) $G_T=G_B+G_D+G_R$

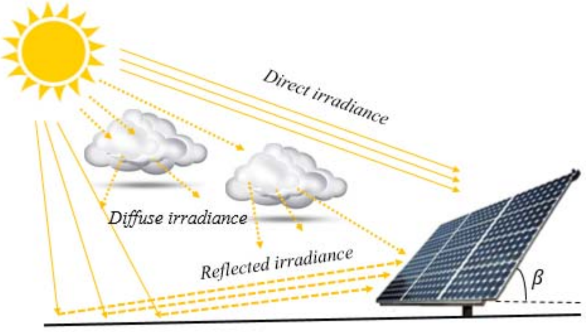


Fig. 4 Solar radiation component on a tilted surface

Design process

In this study, a solar tracker that uses ZIP code instead of sensors has been designed using MATLAB and Proteus 8 software. In this project we have chosen a dual axis solar tracker due to its high efficiency and good performance. The position of the sun was determined from a specific geographic location using ZIP code, then the calculated tilt and pitch angles of the solar panel were converted into motors motion such that the panel is faced accordingly to the sun radiation. In order to control the two motors we have used virtual serial connection between Proteus and MATLAB software, the MATLAB algorithm will generate a certain commands and send them to the tracker to follow the sun vertically and horizontally. We have also designed an attractive, accessible and efficient user interface using MATLAB app designer that allows the user to interact with the solar tracker and optimizes the user experience requiring minimum effort on the user's part to receive maximum desired outcome since it has as input parameters only the location's ZIP code.

MATLAB app designer

This interface (shown in Fig. 5) is designed to detect the position of the sun for a given location specified by a ZIP code at the present time and moves the panel accordingly. The user will have the privileged to receive information about the tracker such as: power output, voltage, current and collected irradiance, as well as the tracker's rotation angles to firmly follow the movement of the sun. The position of the sun in the sky is also presented in a global frame with the mention of the sun's azimuth and altitude angles.

The main parts of the solar tracker interface panel are described as follows:

-Specify the location of the solar tracker using ZIP code.

-Rotate the solar panel accordingly to the sun.

-Convert calculated tracker angles into motor motion-Monitor the solar tracker performance by getting information about it generated power output.

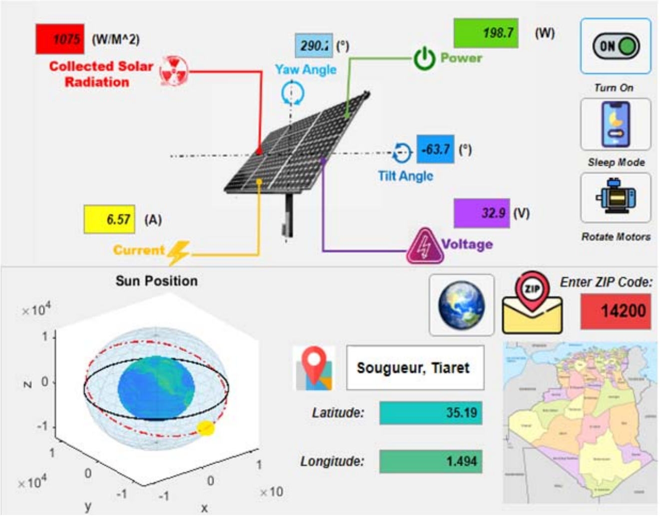
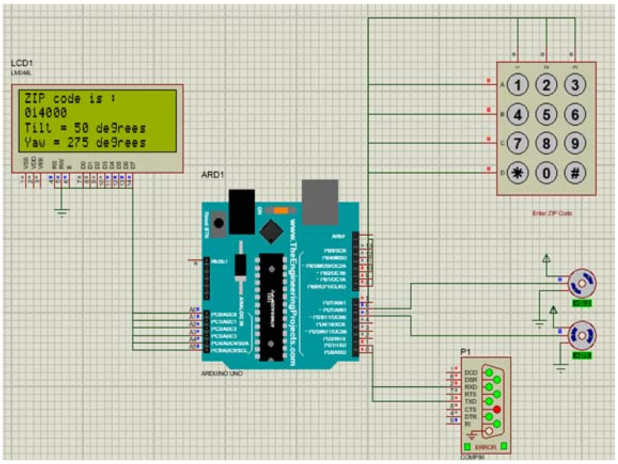


Fig. 5 Solar tracker using ZIP codes user interface.



```
ZIP code is :
014000
Tilt = 50 de9rees
Yaw = 275 de9rees
```

Fig. 6 Dual axes solar tracker simulation using Proteus software

Table 2 shows parameters used to develop our solar tracker user interface calculator program.

Table 2 Solar tracker interface calculator parameters

No	Parameter	Source	Reference
1.	Latitude and Longitude of the location	Table 1	[13]
2.	Tilt angle	Eq. (1)	[20]
3.	Yaw angle	Eq. (2)	[20]
4.	Irradiance	Eq. (7)	[15]
5.	Power, voltage and current outputs	Chapter 2	[15]

Proteus software

To test the feasibility and the proper work of our system, the designed solar tracker was simulated on Proteus software. The designed system (shown in Fig. 6) uses keypad board to get the ZIP code from the user, then the optimum tilt and yaw angles generated from the Arduino microcontroller will be sent to the solar tracker's motors. The location's ZIP code and the motors angles are displayed to the user using an LCD display.

MATLAB Simulink

The solar tracking system using a tracking code (ZIP codes) was simulated using MATLAB Simscape Multibody (as shown in Fig. 7) to simplify the design of the control system and test its level of performance. This model uses the ZIP code as an input to the MATLAB code that calculates the yaw and pitch angles and sends them as a motion input to the gear revolute joint. The outputs of the solar tracker are plotted with a scope block.

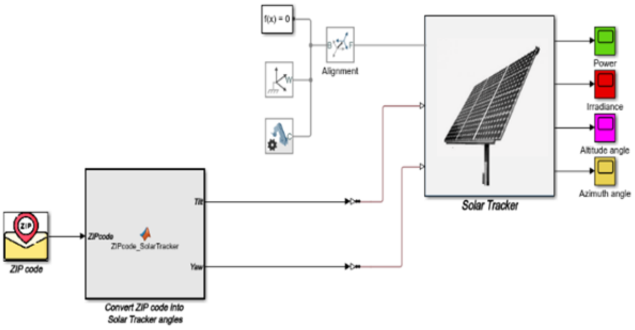


Fig. 7 Solar tracker system simulation bloc.

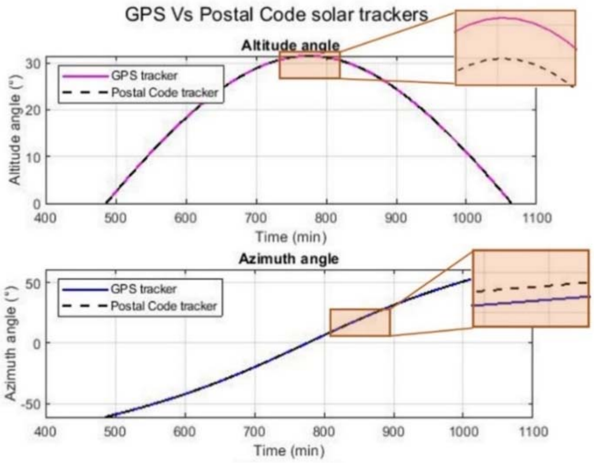


Fig. 8 A day's profile of the Sun's altitude and azimuth angles using GPS vs ZIP code tracking system

Results and discussions

In order to test its accuracy, the solar orientations based on location using ZIP codes method is compared with a GPS positioning system. Instead of getting the location coordinates (latitude and longitude) from the ZIP code, we have used MATLAB gps.sensor command. Fig. 8 shows the calculated altitude and azimuth angle profile every 1 min for a solar day (sunshine to sunset) of the 26th of December 2022 for the city of Sougueur located in Algeria, with the latitude of 35.18568 and longitude of 1.49612. by comparing the two, we have noticed a very small deference which is not even clear unless we zoomed in, from the figure we can see that both of the methods only catches the sun position in the period of time between 486min and1065min, due to the fact that in that day, the sun rises at 08:01am and sets at 05:49pm.The results shows that the ZIP code positioning method gives high precision results and it can be as presided as a GPS sensor with an accuracy percentage equal to 99.99% for the azimuth angle and 99.96% for the altitude angle .

After testing the accuracy of our solar tracking system, we have predicted the hourly extraterrestrial solar radiation profile for four different cities in Algeria, on the 26th of December 2022 as shown in Fig. 9. The results shows that the solar irradiance varies as the location of the solar tracker changes,the most collected irradinace was $10785(w/m^2)$ in El Oued city due to the fact that it is considered to be one of the hottest areas in the country.in countrast, the least collected irradinace was $10739(w/m^2)$ in Sougueur city due to the cold weather.Therefore, our tracking system using ZIP codes is flexable,simple,versatile and suitable for tracking the sun precisely in different locations with different weather conditions.

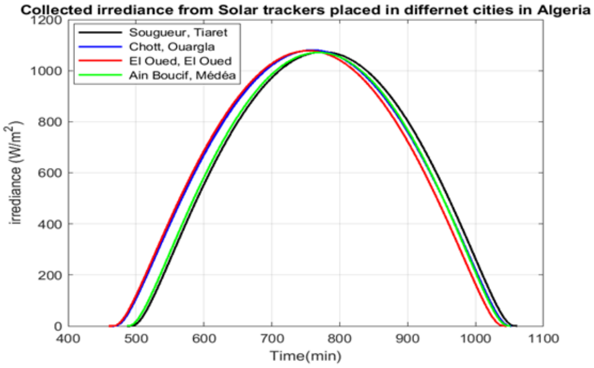


Fig. 9 Global solar radiation for four different cities in Algeria

To achieve the maximum radiation by the solar tracker, the optimum tilt angle was calculated for Sougueur city one time each week of the month of December 2022 as shown in Fig. 10. The results shows that although the results were taken in a cold and intermittent days (month of December) in Sougueur city, tilt angle of the tracker varies with the variation of days. Which proves the accuracy and high precision of our tracking system, since the sensor-based solar trackers fails to track the sun accurately in cloudy days and bad weather.

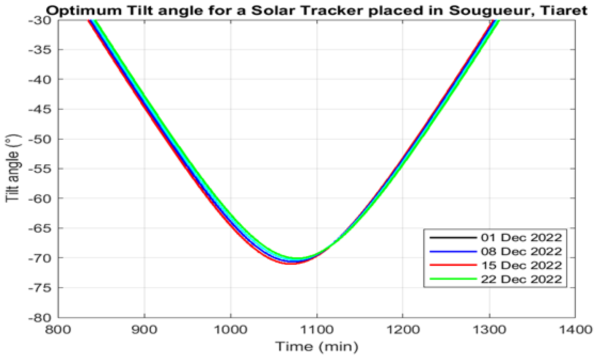


Fig. 10 Optimum tilt angle in different days of the month of December

Lastly, in order to prove the importance of using our high precision solar tracker, we have compared the output power generated from the tracker in the same location at different times of the day. Fig. 11 shows that the most generated power was at 12:52 am, reason being that the sun reaches its highest position in the sky, thus the tracker collects more irradiance and produces more power. Results proved that the power output of a solar tracking system depends on the collected irradiance. Therefore, the tracking system using ZIP codes will improve the efficiency of power generation in the country due to its high precision and low cost.

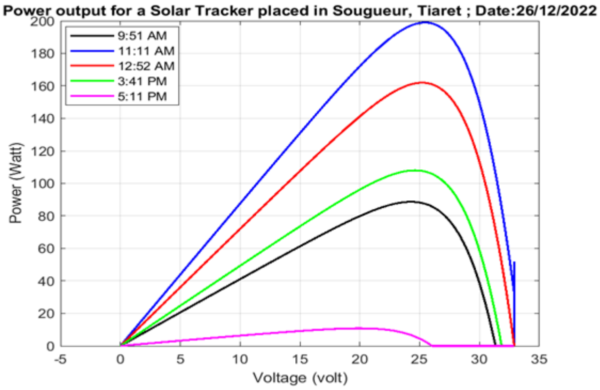


Fig. 11 Power output of the ZIP code tracker at different times in a day

Conclusion

In this paper we have designed a new, high-precision, low-cost and simple solar tracking system based on a tracking code that uses countries ZIP codes as an alternative for sensors. From the results it is concluded that:

-Solar tracking system using ZIP codes can be 99.9% as accurate as a GPS based solar tracker.

-The designed solar tracker can accurately track the sun with high response time, without getting effected if the weather is cloudy or rainy.

-This tracker can reduce energy consumption and cost of installation and maintaince, since it doesn't require any sensors to function.

-It can be suitable for both large and small solar generation.

-It is simple and flexible since it has as input parameters only the location's ZIP code.

-It could be suitable for any country in the world, so as a perspective we are willing to develop our control program to include 246 different countries with ZIP codes and administrative divisions for each one.

Acknowledgments: *The authors would like to thank the team at Electrical and Remote Control Systems Laboratory at Blida University 1 for their support in publishing this manuscript.*

Authors: *Dr.Khadidja Dahli is a PHD student in Automatic and Systems at the Electrical and Remote Control Systems Laboratory, Blida University 1, Algeria. Her research areas include increasing the energy efficiency of PV systems, E-mail: khadi.dja22977@gmail.com; Prof. Dr. Nawal Cheggaga PHD since 2012, empowered to lead university projects. Leader of the characterization of solar systems team at LabSET. Member of the scientific council of the electronics department Blida University 1., E-mail: cheggaga@yahoo.fr.*

REFERENCES

[1] Ahmet, Aktas, and Kircicek Yagmur. 2021. *Solar hybrid systems: design and application*.

[2] Fazlizan, Ahmad, Ahmed Abdulmula, Akmal Naim Amran, Chin Haw Lim, and Kamaruzzaman Sopian. 2019. Performance evaluation of maximum light detection solar tracking system in the tropics. *Journal of Mechanical Science and Technology* 33: 1391–1397. https://doi.org/10.1007/s12206-019-0240-2.

[3] Soudani, Mohammed Elbar, Kamal Eddine Aiadi, Djamel Bechki, and Smail Chihi. 2017. Experimental and theoretical study of Parabolic trough collector (PTC) with a flat glass cover in the region of algerian sahara (Ouargla). *Journal of Mechanical Science and Technology* 31: 4003–4009. https://doi.org/10.1007/s12206-017-0747-3.

[4] Why is renewable energy important? 2019. *REN21*.

[5] Selvam, P. Surendhar. 2018. Efficient Solar Tracking System using GPS. *International Journal for Research in Applied Science and Engineering Technology* 6: 3842–3849. https://doi.org/10.22214/ijraset.2018.4635.

[6] Samira, Boujenane. 2017. Tracker solaire à deux axes.

[7] Huld, Thomas. Estimating Solar Radiation and Photovoltaic System Performance, the PVGIS Approach.

[8] Rafique, Muhammad M., S. Rehman, and Luai M. Alhems. 2020. Assessment of solar energy potential and its deployment for cleaner production in Pakistan. *Journal of Mechanical Science and Technology* 34: 3437–3443. https://doi.org/10.1007/s12206-020-0736-9.

[9] ECSTUFF4U for Electronics Engineer. 2022. https://www.ecstuff4u.com/. Accessed October 9.

[10] Advantages and disadvantages of GPS - GeeksforGeeks. 2022. https://www.geeksforgeeks.org/advantages-and-disadvantages-of-gps/. Accessed December 24.

[11] Mpodi, Emmanuel Karabo, Zeundjua Tjiparuro, and Oduetse Matsebe. 2019. Review of dual axis solar tracking and development of its functional model. *Procedia Manufacturing* 35: 580–588. https://doi.org/10.1016/j.promfg.2019.05.082.

[12] AL-Rousan, Nadia, Nor Ashidi Mat Isa, and Mohd Khairunaz Mat Desa. 2018. Advances in solar photovoltaic tracking systems: A review. *Renewable and Sustainable Energy Reviews* 82: 2548–2569. https://doi.org/10.1016/j.rser.2017.09.077.

[13] Liste des codes postaux d'Algérie. 2022. *Wikipédia*.

[14] NordNordWest. 2020. *Deutsch: Karte der politischen Gliederung von Algerien (2019)*. Own work using:Algeria, administrative divisions - de - colored.svg by TUBS.

[15] Khatib, Tamer, and Wilfried Elmenreich. 2016. *Modeling of Photovoltaic Systems Using Matlab: Simplified Green Codes*. Hoboken, New Jersey: Wiley-Blackwell.

[16] Jafarkazemi, Farzad, and S. Ali Saadabadi. 2013. Optimum tilt angle and orientation of solar surfaces in Abu Dhabi, UAE. *Renewable Energy* 56. Elsevier: 44–49.

[17] Gualla, Filippo. 2015. Sun position and PV panels : a model to determine the best orientation. *undefined*.

[18] Sidek, M.H.M, W.Z.W Hasan, M.Z.A.Ab. Kadir, S. Shafie, M.A.M. Radzi, S.A. Ahmad, and M.H. Marhaban. 2014. GPS based portable dual-axis solar tracking system using astronomical equation. In *2014 IEEE International Conference on Power and Energy (PECon)*, 245–249. https://doi.org/10.1109/PECON.2014.7062450.

[19] Kalogirou, Soteris A. 2014. *Solar energy engineering: processes and systems*. 2. ed. Amsterdam: AP, Academic Press/Elsevier.

[20] Kuttybay, Nurzhigit, Ahmet Saymbetov, Saad Mekhilef, Madiyar Nurgaliyev, Didar Tukymbekov, Gulbakhar Dosymbetova, Aibolat Meiirkhanov, and Yeldos Svanbayev. 2020. Optimized Single-Axis Schedule Solar Tracker in Different Weather Conditions. *Energies* 13. Multidisciplinary Digital Publishing Institute: 5226. https://doi.org/10.3390/en13195226.