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Photovoltaic System with Solar Tracker

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ABSTRACT

The report describes a project for the development of a real photovoltaic system with a solar tracker aimed at increasing the energy yield of standard photovoltaic panels by means of a panel positioning system. An overview of the existing technical solutions to this issue is provided, along with a forecast of the increased performance of panels equipped with positioning.

Keywords: tracker, solar tracker, solar panels, battery, microcontroller.

INTRODUCTION

The effort to reduce carbon emissions in the atmosphere brings to the forefront the production of electricity from renewable energy sources. This necessitates the search for technical solutions to improve the efficiency of these sources. One such solution is the improved positioning of solar panels with respect to the solar trajectory.

The efficiency of photovoltaic panels directly depends on the intensity of sunlight and the angle at which the rays strike the panel surface. The maximum efficiency is achieved when the rays are perpendicular to the panel surface. This necessitates the development and implementation of systems for aligning the panels with the solar trajectory.

Systems with an integrated mechanism for tracking the trajectory of the Sun, also known as trackers or positioners, aim to maximize the generation of electricity by rotating the photovoltaic panels into an optimal position [1].

Solar tracking systems are mainly designed to maintain the surface of the photovoltaic (PV) panel perpendicular to the direction of solar radiation. Solar irradiance, azimuth angle, altitude angle, tilt angle, declination angle, and zenith angle are important parameters that determine the optimal position of the solar tracking system. The most significant angles in determining the position of the sun are the altitude angle (elevation) and the azimuth angle.

Moving solar tracking systems can be manually or automatically operated. In most cases, the solar tracking system includes different factors, such as one or two motors, various types of optical sensors, and independent or auxiliary

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power supply. The classification of these aspects depends on different parameters, including the force driving the movable elements and the mode of operation [2].

On this basis, the following solar tracking systems have been developed:

Passive solar tracker

Passive solar trackers can orient their sensing elements towards the direction of solar radiation without using mechanical actuators. Most of these trackers consist of a pair of actuators filled with expandable gas or shape-memory material. This system uses the concept of thermal expansion or pressure imbalance between the two ends of the tracker.

When the PV panel is perpendicular to the Sun, the two ends are in equilibrium. Once the Sun moves, one side heats up, causing expansion, while the other side contracts, leading to panel rotation.

Passive solar trackers feature simplified operation and do not require electronic components or motors. However, this method of solar tracking has low accuracy and strongly depends on the meteorological conditions of the site. If the location does not receive sufficient continuous sunlight, the efficiency of this type of tracker is significantly reduced. The problem of passive trackers can be solved by using active solar tracking systems [2].

Active solar tracker

The active solar tracking system determines the position of the Sun throughout the day by means of continuously operating sensors. The sensor activates the motor or actuator to move the structure in accordance with solar radiation. If the sunlight is not perpendicular to the tracker, then there will be a difference in the illumination between one light sensor and the other. This difference can be used to determine the direction in which the tracker should rotate to become perpendicular to the Sun [2].

Active solar tracker with a single-axis system

The single axis tracking system provides only one degree of freedom, which acts as a rotation axis. The single-axis solar tracking system is the simplest type of tracker - it generally consumes less energy and is less complex compared to multi-axis systems [2].

Active solar tracker with a dual-axis system

The Earth moves along a complex trajectory that involves two types of motion - daily and annual. The daily motion makes the Sun appear to move from east to west over the Earth’s surface. The annual motion causes the Sun to tilt at a certain angle while moving in the same direction [2].

Recent studies confirm the significance of tracking systems. According to several reviews, single-axis trackers can improve the annual energy yield by approximately 20 - 35 %, while dual-axis trackers may achieve even higher improvements depending on geographical location and control strategies [3, 4]. This demonstrates that the expected gain of about 20 % for the region of Sliven is within the range reported in international research.

Chronological solar tracker

The chronological solar tracking system is a time-based system in which the structure moves at a fixed speed and angle throughout the day as well as across the different months. Accordingly, the motor or actuator is controlled to rotate at an average speed of one revolution per day (15° per h) [2].

EXPERIMENTAL

A good way to increase the performance of photovoltaic panels is to use a Chronological Solar Tracker. This solar tracking method is more energy-efficient, since no energy losses occur during tracking adjustment, owing to the minimal tracking error.

The following distribution of the angular movement of the solar panels during the daylight hours is assumed:

At the Vocational High School of Electrical Engineering and Electronics "Maria Curie" in Sliven, a photovoltaic system with static panels has been constructed. The system consists of four monocrystalline panels of 400 W each, with a total installed peak power of 1.6 kWp. Its performance can be forecast using the Photovoltaic Geographical Information System [5]. The main view of the system, at the assigned geographical location, is presented in Fig. 1.

The forecasted performance results are shown in Fig.2.

RESULTS AND DISCISSION

A project is planned for the construction of a photovoltaic system with a single-axis, chronological solar tracker to increase the energy output from the existing photovoltaic panels. The main components specified in the project are:

- Monocrystalline solar panels with a nominal power of 400 W - 4 units. They will be mounted on a metal frame with dimensions of 2 × 5 m.
- Arduino UNO (or Mega) microcontroller, which will provide enough data pins for system monitoring and control.
- RTC module: DS3231 to track the precise

Table 1. Distribution of the angular movement of the solar panels during the daylight.

Time of day	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00
Step (°)	0	15	30	45	60	75	90	105	120	135	150	165	180

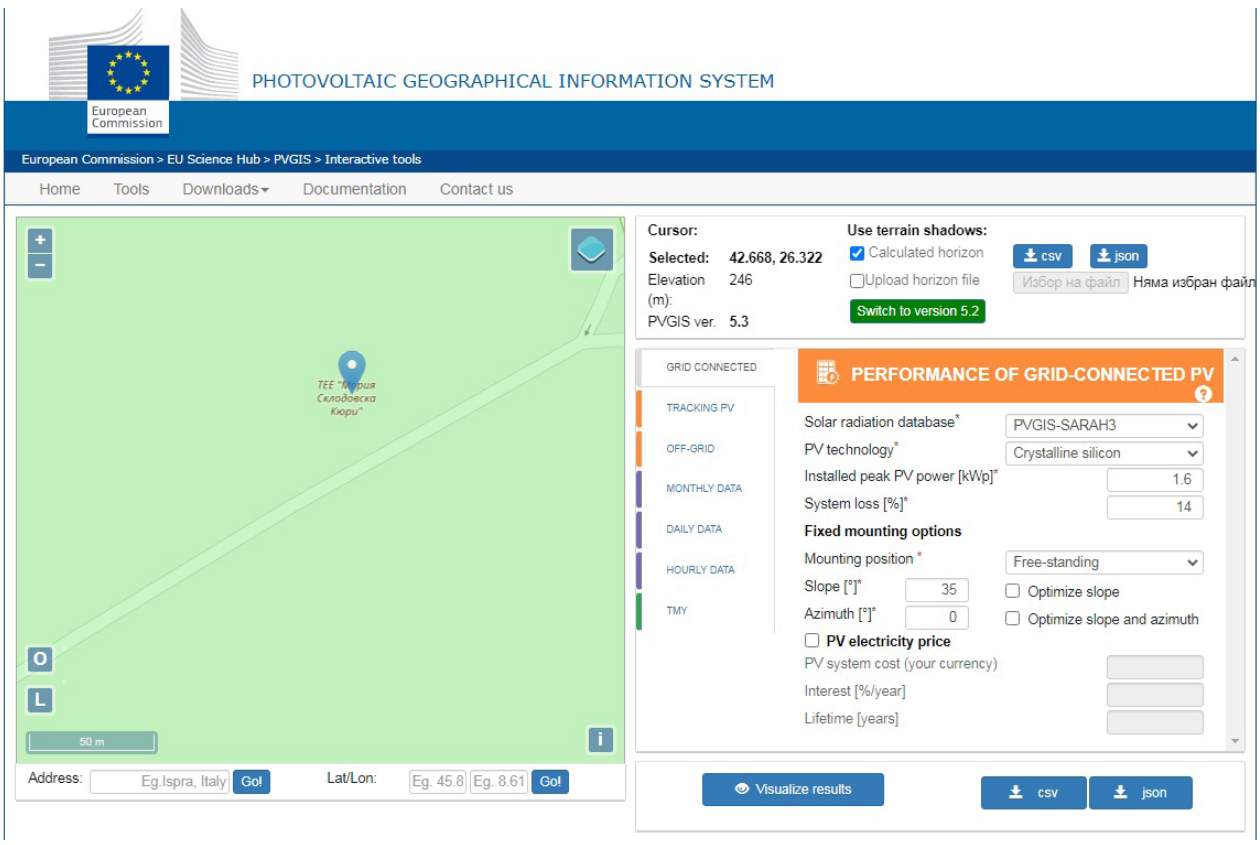

Fig. 1. Main view of the Photovoltaic Geographic Information System.

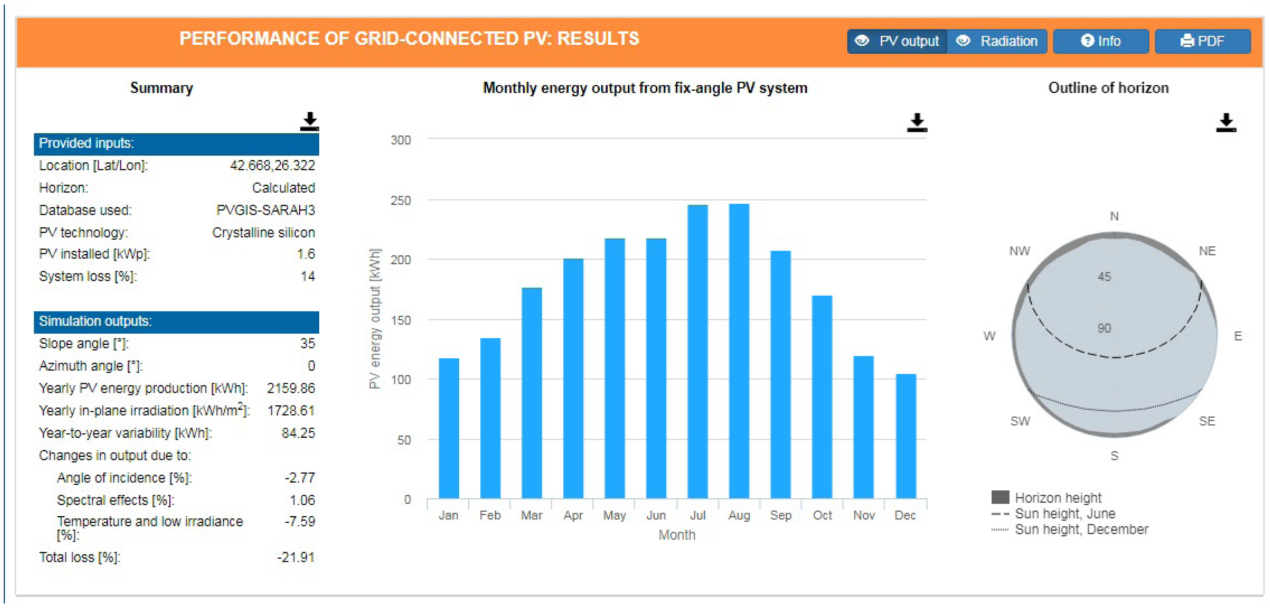

Fig. 2. Projected performance of the photovoltaic system.

time, independent of system resets. The module has its own power supply from a rechargeable 3 V CR2032 battery. An I2C interface will be used for communication with the microcontroller.

- System sensors: 2 limit switches. Option to add an angular potentiometer to monitor the panels' position. A sensor to monitor wind direction.
- Frame drive: The frame with the panels will be driven by two NEMA24 motors with a gear reduction and a self-locking feature. The minimum power of the drive mechanism is 6000 N [6].
- Power supply: A solar inverter with a power output of 2 kW/230 V AC, 24 VDC. A step-down adapter from 220 V to 5 V will be used to power the microcontroller.
- Lead-acid battery for storing excess energy with a capacity of 100 Ah.

The simulation results for the Sliven region, showing an increase of around 18 - 22 % compared to fixed panels, are consistent with global findings. For example, Yang and Xiao emphasize the sustainable development of solar tracking technologies but also note challenges such as cost, complexity, and durability [7]. Furthermore, experimental implementations of dual-axis trackers in Asia demonstrate substantial improvements in energy output [8]. These comparisons strengthen the reliability of our forecasted values and underline the practical benefits of the project.

Technical specifications for Arduino UNO R3 [9]

- Microcontroller: ATmega328P, 8-bit.
- Operating voltage: 5 V.
- I/O Pins: 14 digital (6 PWM), 6 analog inputs.
- Clock speed: 16 MHz.
- Flash memory: 32 KB (0.5 KB used by the bootloader).
- SRAM: 2 KB, EEPROM: 1 KB.
- Serial communication: UART, I2C (SDA/SCL), SPI.
- Power supply: via USB (5 V) or Vin/barrel jack (7-12 V regulator).
- Dimensions: Standard UNO board; suitable for prototyping and logic/sensor control.

Table 2. Pin connection.

Module / Signal	Arduino UNO Pin	Module Pin
RTC DS3231 - SDA	A4 (SDA)	DS3231 SDA
RTC DS3231 - SCL	A5 (SCL)	DS3231 SCL
Stepper - STEP	D2	DM542 PUL-
Stepper - DIR	D3	DM542 DIR-
Stepper - ENA	D8	DM542 ENA-
Home Limit Switch	D9	NC contact to GND
Limit (West/End)	D10	NC contact to GND
Anemometer (reed/Hall)	D11	Sensor output → to GND
LED Indicator	D13	LED + 330 Ω to +5 V
Buzzer/Alarm	D12	Piezo/transistor drive to buzzer
Angle Sensor	A0	Potentiometer 0 - 5 V

Control - chronological approach

The system uses an RTC module (real-time clock) and pre-defined tables or calendars with angles for each hour and day. The chronological method moves the system with a fixed angular step based on the time.

Algorithm components:

RTC (DS3231) for accurate timekeeping.

A table or function to determine the desired tilt angle.

The panel will move 1 degree every 4 min, tracking the sun's movement from a theoretical sunrise at 8:00 AM to sunset at 8:00 PM. The start and end positions will be adjusted each month to account for longer or shorter days. A sensor will also be added to monitor wind speed and direction, protecting the panels from damage.

Example chronological algorithm:

```
// 1) Define start and end positions for the day (in degrees), based on the day of the year.
// 2) Interpolate over time from sunrise to sunset.
// For simplicity, we use fictitious values:
float sunriseHour = 6.0; // can use a table by month
float sunsetHour = 18.0;
float currentTime = hour + minute / 60.0;
float fraction = constrain((currentTime - sunriseHour) / (sunsetHour - sunriseHour), 0.0, 1.0);
// Daily angles (example): In winter, tilt is greater and vice versa
float tiltMorning = 10.0; // degrees (at sunrise)
float tiltNoon    = 30.0; // degrees (at noon)
float azStart = -60.0; // degrees from south (west=-, east=+ or vice versa)
float azEnd  = 60.0;
// Simple interpolation: tilt linearly from sunrise to noon and back - simplified model
float desiredAz = azStart + fraction * (azEnd - azStart);
float desiredEl = tiltMorning + fraction * (tiltNoon - tiltMorning);
```

CONCLUSIONS

The development of this project at the Vocational High School of Electrical Engineering and Electronics "Maria Curie" has shown that photovoltaic systems with solar trackers can achieve better efficiency compared to static systems. Based on PVGIS simulations for the region of Sliven, the expected annual increase in electricity production is in the range of 18 - 22 %, which we summarize as approximately 20 %.

Although such systems are more complex and require higher initial investment, they demonstrate to students the real advantages of renewable energy technologies. The project provides valuable hands-on experience in combining electronics, mechanics, and programming, which are directly applicable in modern energy engineering.

In addition to its educational role, the implementation of solar tracking systems contributes to more efficient use of renewable resources and supports efforts to reduce carbon emissions.

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