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INTELLIGENT SOLAR PANEL ORIENTATION SYSTEM WITH ARDUINO AND SENSOR

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Abstract. ***The article describes a sun-tracking system based on Arduino Nano, designed to optimize the output of a solar panel. It incorporates an INA219 sensor for current monitoring, two servo motors for dual-axis orientation, and four photoresistors for light detection. The system automatically adjusts the panel's position, maximizing solar energy capture and enhancing energy efficiency.***

Keywords: Arduino Nano, solar panel, sun-tracking, sensor, Proteus.

1. INTRODUCTION

In the current era of solar technology, developing innovative solutions that harness natural resources to provide sustainable energy is increasingly essential. This study focuses on constructing a solar-powered lamp, which serves not only as an efficient lighting source but also as a demonstration of sustainable engineering and energy efficiency. Equipped with an intelligent solar panel that automatically tracks the sun's movement and a system for monitoring generated and stored solar energy, the study aims to contribute significantly to the sustainable use of solar resources.

The proposed system uses a solar panel combined with an Arduino Nano, programmed to interpret light sensor data, and continuously determine the panel's optimal position. This allows the panel to automatically align with the sun, maximizing energy capture. Solar energy offers numerous benefits: reducing dependence on non-renewable sources, lowering pollution and long-term energy costs. An efficient photovoltaic system includes performance monitoring via sensors, automatic orientation control, battery management, and data transmission through Wi-Fi or GSM. These functions, integrated with Arduino, optimize solar energy use, highlighting sustainability and technological efficiency.

2. GENERAL CONCEPTS

The analysis utilizes Arduino Nano technology combined with a current sensor to create an automatic sun-tracking system, maximizing the efficiency of the solar panel. By optimally orienting towards the light source, the panel captures more renewable energy. Solar energy, an inexhaustible and eco-friendly source, has the potential to revolutionize electricity production, and this system highlights the technological potential to enhance energy sustainability.

The proposed solution has a significant social and ecological impact. By increasing the efficiency of solar panels, it can provide a more consistent and predictable energy source, improving electricity access in rural or remote communities. Additionally, by using solar energy, the study contributes to reducing greenhouse gas emissions, positively impacting the environment.

The use of Arduino Nano technology, a compact and powerful microcontroller, adds an innovative dimension to the work. This device allows for precise programming and control of the solar panel, quickly adapting to changes in light conditions. The integration of the current sensor and photoresistors completes the system, providing essential data for optimal decision-making.

Based on the information obtained, Arduino Nano sends commands to the solar panel motor, adjusting its position. This continuous process ensures efficient sun tracking, optimizing the solar panel's energy production. The work not only optimizes the solar panel's efficiency but also demonstrates the potential of innovative technologies in promoting renewable energy sources. Implementing this system in practical applications can lead to increased battery lifespan powered by solar panels and maximize energy output.

Work is not only a theoretical solution but also opens a path for future developments. With the evolution of technologies, there is the potential to expand the system to manage multiple solar panels and even incorporate energy storage technologies, thus contributing to the development of sustainable and scalable energy systems.

The importance of measuring energy at low costs and with precision for IoT devices is justified by two key aspects: firstly, the percentage of energy consumed by connected devices is increasing due to the significant rise in the number of IoT devices; the number of connected IoT devices is 24.4 billion in 2024 and is expected to grow to 30.2 billion in 2025. Secondly, most IoT devices are powered by batteries or rely on energy harvesting. Therefore, it is essential to measure, profile, analyze, and improve the energy efficiency of these devices to meet the QoS requirements of applications [1-2].

The proposed system can also be implemented in agriculture, which is one of the driving forces of societies and economies worldwide. There are several challenges to address in this sector, such as food security, sustainable use of natural resources, climate change, increasing food demand, controlling the large ecological footprint, and biodiversity loss. Agriculture 4.0 and the technological paradigms of the Internet of Things (IoT) aim to tackle these challenges by enabling better and more precise use of available resources and applying new agricultural practices for optimal results [3-7].

3. DESCRIPTION OF COMPONENTS

The main components used in the system are divided into three categories:

- Components for the Solar Panel:
  - Arduino Nano.
  - SG90 Servo Motor.
  - 4 Photoresistors.
  - 4 Resistors of 1kΩ.
  - Motion Sensor.
- Components for Energy Recording:
  - Lithium Battery.
  - Lithium Battery Charger TP4056.
  - INA219 Current Sensor.
  - OLED Display.
  - SD Card Module.
- Components for the Lamp:
  - 1W LED.
  - Motion Sensor.
  - Voltage Booster Module SX1308.

The key features of the Arduino Nano (Figure 1) include an ATMega microcontroller, an integrated USB interface for programming and communication with a computer, 14 digital pins, and 8 analog pins, making it compatible with the Arduino development environment (IDE) [8].

Figure 1. Arduino Nano board

The SG90 servo motor (Figure 2) is compact and features a position control mechanism, making it suitable for a variety of applications such as robotics, model airplanes and helicopters, toys, and more [5, 9]. Its key features include:

- Operating voltage: 4.8 - 6V (typically 5V).
- Operating current: 100 mA (no load).
- Rotation torque: 1.5 kg/cm at 4.8V.
- Rotation speed: 0.12 sec/60° at 4.8V.
- Rotation angle: 180°.
- Control signal type: PWM (Pulse Width Modulation).

Figure 2. The SG90 Servo Motor

The solar module used is a 1-watt solar module with 1N4004 diodes, which will convert solar light heat into voltage (Figure 3) [10].

Figure 3. The solar module

The voltage will be sent through the IC TP4056 input, and the output from the IC TP4056 will charge the 18650 battery, which is intended to power the 12W lamp amplification circuit. Alternatively, the 3.7VDC input from the 18650 battery can power the 12W LED light [11-12].

The TP4056 (Figure 4) is an integrated circuit (IC) for charging Li-Ion and Li-Po (Lithium Polymer) batteries. It is designed to provide a safe and efficient charging solution for lithium batteries. Its technical specifications include:

- Operating voltage from 4V to 8V.
- Adjustable charging current, up to 1A.
- Automatic charging cutoff when the battery reaches the specified voltage.
- Protection against overvoltage and overcurrent to ensure safe charging.
- Operates within a specified temperature range, with certain versions providing thermal protection to prevent overheating.
- Modules are widely available and cost-effective [11-12].

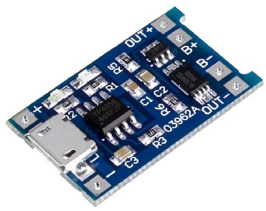

Figure 4. The TP4056 module

The INA219 current measurement module (Figure 5) is a digital device used for monitoring and controlling electricity consumption in various applications. It uses a Hall current sensor and an analog-to-digital converter (ADC) to measure current and voltage in an electrical circuit. The module communicates via the I2C interface and allows for configuration of various settings, such as measurement range and shunt resistance [13].

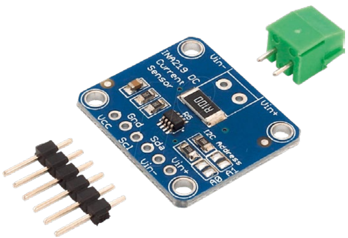

Figure 5. The INA219 module.

The INA219 provides accurate measurements and includes over-voltage, and over-current protection features to ensure the safety of connected devices. It is used in various applications, such as IoT devices, switch-mode power supplies, batteries, chargers, and robots. The module can be powered within a range of 3V to 5.5V and provides measured data through the I2C interface, allowing efficient monitoring of current and voltage [13].

The OLED display with SSD1306 driver (Figure 6) is a type of display using organic light-emitting diodes, offering low power consumption and extreme contrast. The SSD1306 is a commonly used driver for controlling these screens. The I2C and SPI interfaces allow easy connection to microcontrollers or other devices [14].

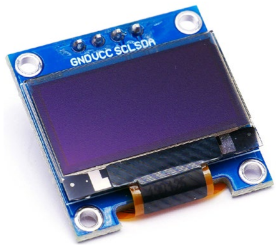

Figure 6. The OLED SSD1306 display.

The SD card module (Figure 7) for Arduino is a device that extends the storage capacity of Arduino projects by interacting with SD or microSD memory cards. It uses the SPI interface to communicate with the Arduino board and is compatible with distinct types of cards, including standard SD and microSD. The power supply voltage ranges from 3.3V to 5V, making it compatible with different Arduino board models. The modules may include LEDs to indicate the operational status or read/write activity [15].

Figure 7. The SD card module.

The HC-SR602 motion sensor (Figure 8) is a compact and easy-to-use device for detecting motion in various environments. Based on passive infrared (PIR) technology, this sensor reacts to temperature changes generated by moving objects [16].

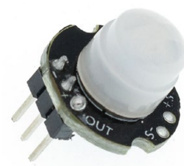

Figure 8. The HC-SR602 motion sensor.

The SX1308 (Figure 9) is a boost-type integrated circuit designed to provide an output voltage higher than the input voltage. The researcher positioned a probe on the output of the solar panel and connected another to the battery. It can operate with a wide range of input voltages, making it suitable for applications with varied power sources. The system has been specifically engineered for energy efficiency, minimizing power loss during the voltage conversion process [17].

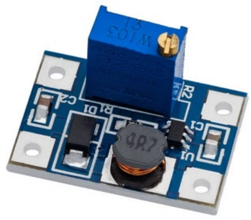

Figure 9. The SX1308 module.

4. SIMULATION AND IMPLEMENTATION OF THE CIRCUIT

I carried out the circuit simulation in Proteus 8 because it is a very user-friendly program, and I have utilized its features in the university laboratories [18].

The circuit diagram appears in Figure 10.

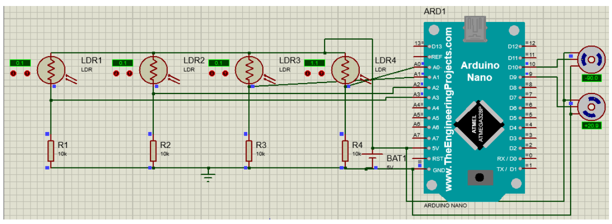

Figure 10. Simulation in Proteus – case 1.

From Figure 10, one can observe that the lower motor changed its position to the right, moving from -90° to +90°. The motor reached +90° because there was no equality between the sensors to stop the motor. To stop the motor, sensor 3 needed to be equal to sensor 4. Now that it has reached +90°, the value of sensor 3 has increased to 2.1, as shown in Figure 11.

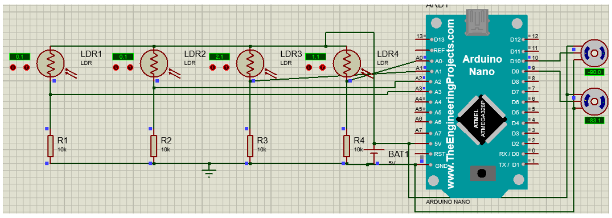

Figure 11. Simulation in Proteus – case 2.

From Figure 11, one can observe that the servomotor moved back to its starting position at -90°.

The schematic for the current sensor appears in Figure 12.

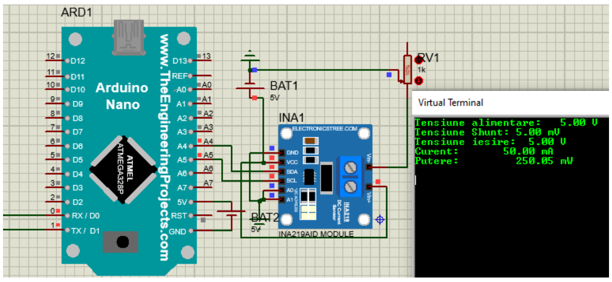

Figure 12. The current circuit simulation – RV1 position 10%.

We can observe in Figure 12 that the supply voltage, shunt voltage, and output voltage are all 5V, with the current being 50mA. The power calculation formula is:

Power = supply voltage × current =
= 5V × 50mA = 250mW

From the simulation results, we observe that the current value decreased, along with the shunt voltage (Table 1).

Table 1. Results obtained using Proteus.

Potentiometer (%)	10	30	50	80
Supply voltage (V)	5	5	5	5
Shunt voltage (mV)	5	1.67	0.1	0.63
Output voltage (V)	5	5	5	5
Current (mA)	50	16.7	10	6.3
Power (mW)	250	83.5	50	31.5

The system support was made using a 3D printer in the shape of a pyramid, with the solar panel and servo motors mounted at the top, as shown in Figure 13.

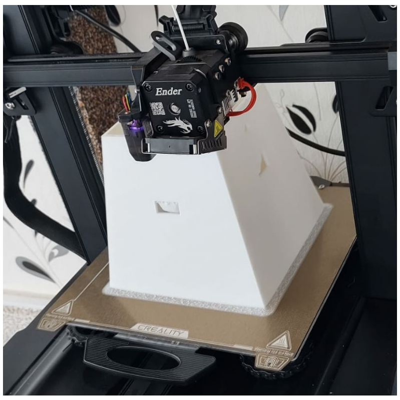

Figure 13. Printing the case.

The system was subsequently tested using the sun as the power source. The values displayed on the screen were: a supply voltage of 7V, a current generated by the solar panel of -0.2mA, with the calculated power shown below these two values, and on the last line, the energy stored since the system turned on. The negative current value is because, at this moment, no battery was connected to store solar energy and there was no consumer, so the panel functioned as the consumer itself (Figure 14).

Figure 14. The values displayed by the system - direct sunlight case.

Power is the result of the calculation:

7V × (-0.2) mA = -1.4mW.

I took advantage of the moment and observed a cloud passing in front of the sun, and I noticed that the panel voltage changed, decreasing to 5.19V (Figure 15).

Figure 15. The voltage displayed by the system when it is cloudy.

I mounted a battery to the system to store solar energy and conducted further tests. In the first test, I placed the system in direct sunlight and allowed the sensors to orient the panel directly towards the sun. The results obtained appear in Figure 16.

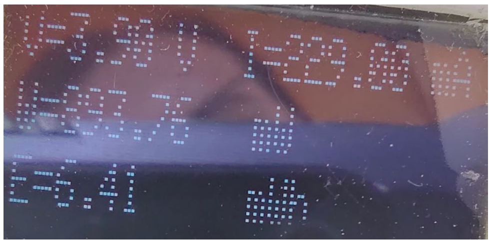

Figure 16. The values obtained when the system was in the sun, with the battery.

From Figure 16, we can see that the panel now produces 229mA and a voltage of 3.9V. The voltage has decreased because all the energy is stored in the battery. The power calculation is as follows: 3.9V × 229mA = 893.1mW. Both the calculation and the displayed value show a discrepancy of 0.66mW. This is due to the loss of a part of the current (0.16mA).

On the last line of the screen, the energy calculated in mWh appears. This is determined by adding the previous value to the power divided by 3600, as it represents energy per hour. For example, from Figure 16,

E = 6.17mWh + (893.76mW / 3600) = 6.41mWh.

Another test took place during which a cloud appeared, causing a slight decrease in voltage and halving the current, as shown in Figure 17.

Figure 17. The values obtained when it is cloudy.

From Figure 17, it is evident that the voltage dropped from 3.9V to 3.78V, and the current decreased from 229mA to 122.4mA. By calculating the power: 3.78V × 122.4mA = 462.67mW. Once again, there is a small error of 0.51mW. The energy calculated is:

E = 14.2mWh + (463.18mW / 3600) = 15.49mWh.

Another test took place during the evening, and as shown in Figure 18, the current decreased significantly compared to the daytime values.

Figure 18. Evaluate during evening.

In the evening, the voltage is 3.98V; this value is higher because the battery has stored energy, and the current is 44.7mA. By calculating the power: 3.98V × 44.7mA = 177.906mW, an error of 0.014mW can be seen.

E = 0.09mWh + (44.7mW / 3600) = 0.14mWh.

The next day, I performed additional tests for comparison purposes. In the following test, I left the system in the sun and made measurements (Figure 19).

Figure 19. Measurements taken the next day in the sun.

From this test, the voltage is at a high value (4.02V) compared to previous measurements (maximum 3.98V), but the current is low (39.8mA). This happens because the battery has stored enough energy, and the module responsible for charging does not allow storing more. From the calculations, 4.02V × 39.8mA = 159.996mW. In this case, there is also an error of 0.164mW.

E = 0.125mWh + (39.8mW / 3600) = 0.17mWh.

I made a final measurement using the implemented system at noon when the sun was at its strongest (Figure 20).

Figure 20. Measurements taken the next day, at noon.

The results show a slight increase in voltage (4.05V compared to 4.02V) and current (44.00mA compared to 39.80mA). The system's battery had a measured voltage of 3.98V, indicating that it was fully charged. The low current is due to the charging module restricting the charge. The calculation gives:

$$4.05V \times 44mA = 178.2mW$$

with an error of 0.11mW.

E = 0.081mWh+(44.0mW/3600) = 0.13mWh.

Operates within a specified temperature range, with specific versions including thermal protection to prevent overheating. A probe was positioned on the output of the solar panel, and another was connected to the battery. I then compared the data shown on the oscilloscope with the information displayed on the system screen (Figure 21).

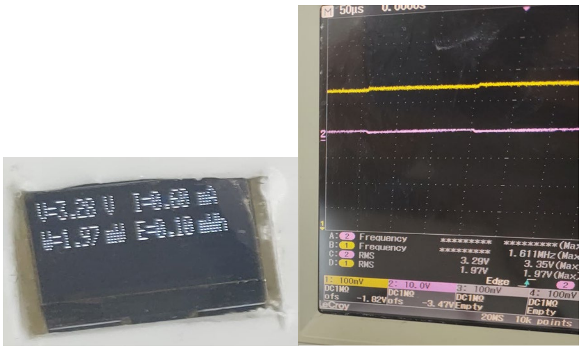

Figure 21. Comparison of results obtained from the system with results provided by the oscilloscope.

In Figure 21, I made a comparison between the voltage displayed on the system's screen and the oscilloscope. The yellow line represents the battery voltage, and the pink line represents the voltage from the panel. At the bottom of the oscilloscope, channels A and B show the analysis in the frequency domain, while channels C and D display the RMS voltage. From the results obtained, the system screen displays a voltage of 3.28V, while the oscilloscope screen shows a voltage of 3.29V. The values are close, with a difference of 0.01V.

$$E = 0.1\text{mWh} + (1.96\text{mW} / 3600) = 0.10\text{mWh}.$$

To determine the current, I used an ammeter connected to the panel's output. The results appear in Figure 22.

Figure 22. Comparison of the current result provided by the system with the one provided by the ammeter.

In Figure 22, when the picture was taken, it can be observed that the last digit had just changed from 0.48mA to 0.44mA. Compared to the current value displayed on the screen of the built system, which shows 0.5mA, the value of 0.48mA is close.

$$E = 0.22\text{mWh}+(1.65\text{mW}/3600) = 0.22\text{mWh}.$$

I set the oscilloscope to capture data over a 5-second period and moved my hand in front of the panel during the measurement (Figure 23).

Figure 23. Analysis of the signals from the system simulating the shading phenomenon.

From Figure 23, the yellow signal, which represents the voltage from the solar panel, decreased each time the hand passed in front of the system, simulating shading. This could also be seen on the oscilloscope screen, where the yellow voltage signal dropped.

Figure 24 shows the data acquisition for current and voltage using the Serial Plotter available in the Arduino IDE [19].

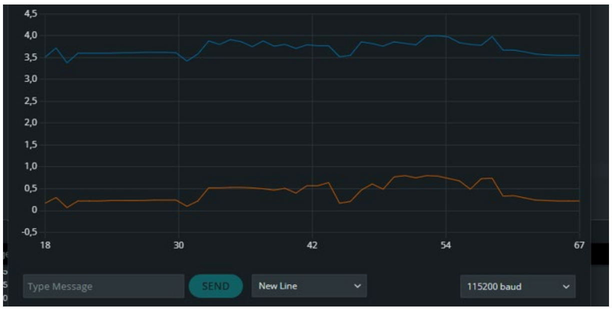

Figure 24. Data acquisition for current and voltage in Arduino IDE – Case 1.

From Figure 24, when the voltage increased, the current followed the same path. At a voltage of 3.9V, the current was approximately 0.7A because the battery had been discharged and had space to store energy.

Figure 25 shows the data acquisition for current and voltage using the Serial Plotter available in the Arduino IDE when the implemented system was placed in the sun.

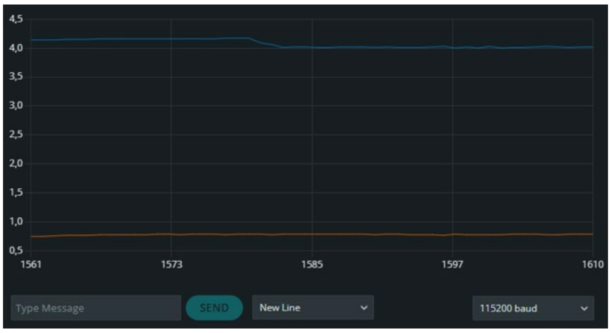

Figure 25. Data acquisition for current and voltage in Arduino IDE – Case 2.

From the previous study (Figure 25), everything is linear, with the current stabilizing at 0.7A and the voltage at 4.1-4V, indicating that the battery is charging.

As a result of the tests performed, I obtained the results presented in Table 2 and Figure 26 (the results obtained using Python [20]):

Table 2. Results obtained in Proteus.

	Voltage (V)	Current (mA)	Power (mW)
Test 1	5	50	250
Test 2	5	16.7	83.5
Test 3	5	10	50
Test 4	5	6.3	31.5

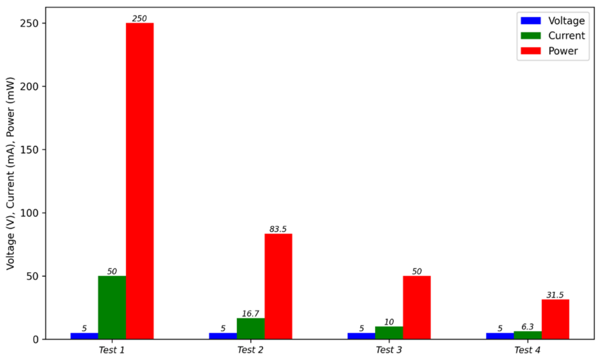

Figure 26. Analysis of the data obtained in Proteus using Python.

From Table 2, the calculation relationships used, and Figure 26, it can be inferred that the results are accurate, and the circuit is functioning properly.

Also, during the simulation, I performed five tests for the solar panel by simulating the operation of the servo motors. I set the sensors one by one as if they were shading and recording the results (Table 3).

Table 3. Sensor values and servo motor positions using Proteus.

	Test 1	Test 2	Test 3	Test 4	Test 5
Val. sensor 1 (Ω)	0,1	0,1	0,1	0,1	1,1
Val. sensor 2 (Ω)	0,1	0,1	0,1	1,1	0,1
Val. sensor 3 (Ω)	0,1	0,1	2,1	0,1	0,1
Val. sensor 4 (Ω)	1,1	0,1	1,1	0,1	0,1
Servo 1 (grade)	-90	-90	-90	+90	+90
Servo 2 (grade)	+90	-90	-90	-90	+90

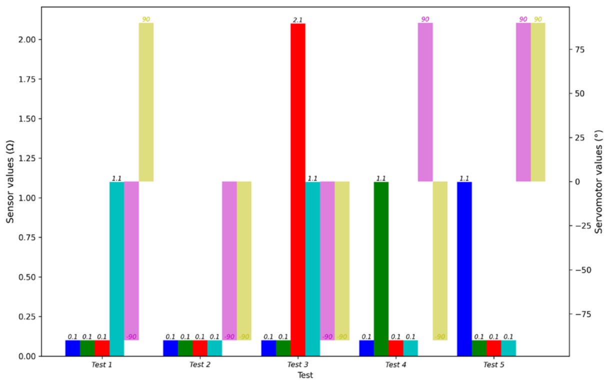

Figure 27. Analysis of the data obtained in Proteus using Python.

From the results obtained (Table 3) and Figure 27 (results obtained using Python), the servo motors respond appropriately based on the data received from the sensors and will move the panel according to the sun's position.

Regarding the practical aspect, the analysis of the implemented system, I placed the system in direct sunlight, taking advantage of the presence of a seven test in clouds in the sky, and recorded the data (Table 4 and Figure 28).

Table 4. Values obtained in the case of the implemented system, under direct sunlight and clouds.

	Voltage (V)	Current (mA)	Power (mW)
Test 1 sun - without battery	7	-0.20	-1.4
Test 2 sun - with battery	5.19	-0.30	-1.57
Test 3 cloud - without battery	3.9	220	893.76
Test 4 cloud - with battery	3.78	122.4	463.18
Test 5 evening - full battery	3.98	44.7	177.92
Test 6 sun - full battery	4.02	39.8	160.16
Test 7 sun - full battery	4.05	44	178.31

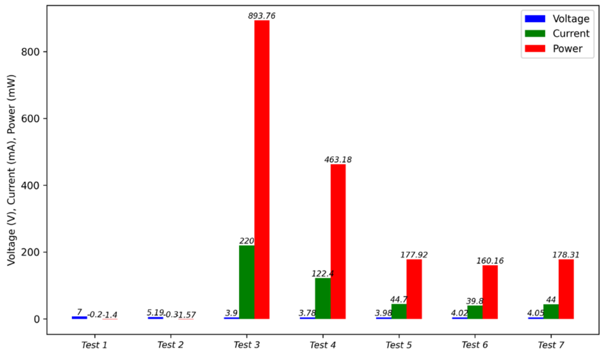

Figure 28. Analysis of the data obtained in Proteus using Python.

From Table 4 and Figure 28, the system reacts to direct sunlight and clouds. The current values obtained in direct sunlight are higher only when the battery is empty, allowing it to receive all the current provided. When the battery is full, the current is lower (from 39.8 mA to 44.7 mA), and the voltage increases (from 160.16 mW to 178.31 mW).

5. CONCLUSIONS

As a result of the tests conducted, it has been demonstrated that the developed system is capable of efficiently monitoring relevant parameters such as voltage, current, and power generated by the solar panel, adapting to changing lighting conditions, such as the presence of clouds or variations in solar light intensity.

The comparison of the results obtained in Proteus, Python, and with the help of measurement instruments (oscilloscope and ammeter) confirmed the system's accuracy, with recorded differences being minimal (in the case of voltage, a difference of 0.01V was obtained, while in the case of current, the difference was 0.02mA), suggesting that the implementation is correct and reliable.

Additionally, the integration of a current sensor enabled precise monitoring of current and power, and the use of a battery for energy storage contributed to the system's efficiency, even under varying lighting conditions. Overall, the project demonstrated the functionality of a solar tracking system with a solar power supply, showing potential for use in renewable energy applications.

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