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PID CONTROLLER DESIGN FOR SOLAR TRACKING SYSTEM

Dr. V Siva Nagaraju, Assistant Professor, ECE, IARE

G.Sathwika ECE & IARE
M.Prajwala ECE & IARE

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Abstract –The aim of this research is to design solar tracking in order to orientate the solar panel to the maximum radiation at all times. In the present work, designing of an optimum proportional-integral-derivative (PID) controller is used to control a dual axis solar tracker system, namely: rotation and elevation. To obtain the optimum result, two kinds of testing were conducted, namely, testing of mechanical design and PID parameters. As a result, the mechanical testing indicated that this system can work properly based on the parameters input. Similar to the PID testing, the response of PID set point with set position rotation and elevation according to the parameters input. In addition, this research was conducted in an electrical power system Laboratory in the State Polytechnic of Ujung Pandang, Makassar, Indonesia.

Key Words: Control; design; PID ; Solar; Tracking

1.INTRODUCTION

A solar tracking system is a mechanism designed to optimize the alignment of solar panels with the sun's position, maximizing energy output throughout the day. Unlike fixed solar panels, tracking systems reduce the angle of incidence between sunlight and the panel surface, significantly increasing efficiency.
Proportional-Integral-Derivative (PID) control is a widely used method for solar tracking due to its precision and adaptability. PID controllers adjust the position of the solar panel by calculating the error between the desired sun position and the panel's actual position. By minimizing this error, the system ensures continuous alignment with the sun. The proportional term addresses the immediate error, the integral term accumulates past errors, and the derivative term anticipates future errors, creating a balanced and responsive control system.

2. Body of Paper

Renewable energy sources are critical for addressing global energy challenges. Among these, solar energy offers a sustainable and efficient alternative to traditional fossil fuels. To maximize the efficiency of solar energy systems, solar tracking systems are employed. These systems align solar panels with the sun's position, minimizing the angle of incidence and optimizing energy output.
This paper focuses on a dual-axis solar tracking system utilizing a Proportional-Integral-Derivative (PID) controller. The PID controller ensures accurate positioning by continuously adjusting panel orientation based on feedback. The objective of this research is to design and analyze a solar tracking system that operates efficiently under varying environmental conditions.

Literature Review

Numerous studies have explored solar tracking methodologies. For instance, in Sec. 2.1, methods like coordinate rotation and transformation were applied to enhance solar receiver efficiency (Ref. [Hu et al., 2018]). Dual-axis systems, as discussed in Sec. 2.2, demonstrated higher energy output compared to fixed-tilt panels, with some studies integrating Programmable Logic Controllers (PLCs) or microcontrollers for better control (Ref. [Singh et al., 2018]).
However, many of these approaches lacked the implementation of a PID controller. As illustrated in Sec. 2.3, a PID-based system offers precise trajectory tracking, reducing error and improving overall efficiency. This highlights the gap addressed by the current study.

Figure 4: Tracking Control Box

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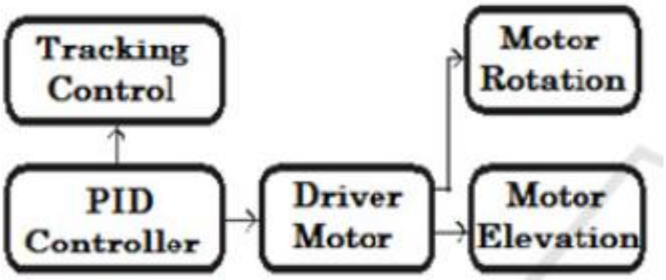

Figure 3: Mechanical Design for solar Tracking

Figure 5: Mechanical Design of Solar tracking-elevation motor.

1. **Elevation Motor**: This motor is responsible for elevating the solar panels when commanded by the tracking control, ensuring optimal positioning relative to the sun.
2. **Rotation Motor**: Similar to the elevation motor, the rotation motor adjusts the panels' horizontal position based on commands from the tracking control.

Overall, the design emphasizes user-friendliness and efficiency in maximizing solar energy capture through precise tracking of the sun's position.

Research Methodology

In this study, a dual-axis solar tracking system was designed and tested. The system includes the following components:

- Mechanical Design: Solar panels are mounted on a dual-axis structure, allowing rotation and elevation adjustments (see Fig. 3).
- PID Control Mechanism: The PID controller minimizes the error between the panel's position and the sun's location. The controller uses proportional integral and derivative gains for precise control.
- Control Box: The control box allows manual and automatic operation (see Fig. 4). Manual controls include directional adjustments (e.g., left, right, up, down) and run/stop buttons.

The methodology emphasizes testing both mechanical and control system performance under varying conditions.

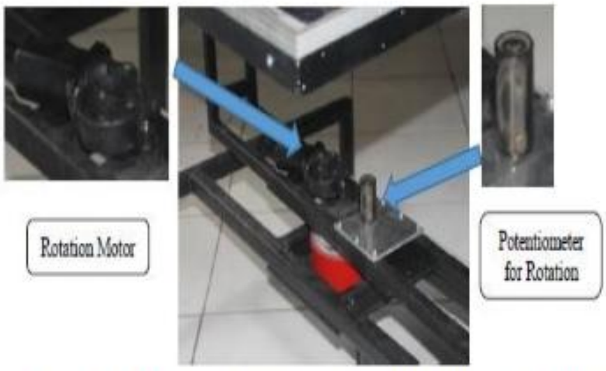

Figure 6: Mechanical Design of Solar tracking-rotation motor.

1. **Real-Time Sun Position Tracking**: Incorporate sensors that continuously monitor the sun's position in real-time, allowing for dynamic adjustments to the solar panels throughout the day.
2. **Weather Resistance**: Design the mechanical components to withstand various weather conditions, such as rain, snow, and high winds, ensuring durability and reliability.
3. **Energy Monitoring System**: Integrate a monitoring system that tracks the energy output

of the solar panels, providing users with data on performance and efficiency.

4. **Remote Control and Monitoring**: Enable remote access to the tracking system via a mobile app or web interface, allowing users to control and monitor the system from anywhere.
5. **Automatic Calibration**: Implement an automatic calibration feature that adjusts the system based on seasonal changes in the sun's path, optimizing performance year-round.
6. **Safety Features**: Include safety mechanisms such as limit switches to prevent over-rotation or elevation, protecting the system from mechanical failure.
7. **User -Friendly Interface**: Develop an intuitive user interface for the tracking control box, featuring a touchscreen display that provides real-time data and easy access to settings.
8. **Energy Storage Integration**: Allow for integration with battery storage systems, enabling users to store excess energy generated during peak sunlight hours for use during low sunlight periods.
9. **Solar Panel Cleaning Mechanism**: Consider adding a cleaning system that automatically cleans the solar panels to maintain efficiency, especially in dusty or polluted environments.
10. **Data Logging and Analytics**: Provide a data logging feature that records performance metrics over time, allowing users to analyze trends and make informed decisions about energy usage.
11. **Multi-Panel Configuration**: Design the system to support multiple solar panels, allowing users to expand their solar energy capacity as needed.
12. **Integration with Smart Home Systems**: Enable compatibility with smart home systems, allowing users to automate energy usage based on solar production.
13. **User Customization Options**: Allow users to customize settings based on their specific needs, such as adjusting sensitivity levels for tracking or setting energy usage preferences.
14. **Maintenance Alerts**: Implement a notification system that alerts users when maintenance is required, such as checking the motors or cleaning the panels.
15. **Sustainability Features**: Use eco-friendly materials in the construction of the tracking system to promote sustainability and reduce environmental impact.

These features can enhance the functionality, usability, and efficiency of the solar tracking system, making it more appealing to consumers and improving overall performance.

Figure 7: Standard Position of elevation

Figure 8: Position of solar panel with -30°C from standard elevation

Results and Analysis

Mechanical testing:
Mechanical testing confirmed the system’s ability to align solar panels accurately. The standard elevation and rotation positions are depicted in Figs. 7 and 9, respectively. As demonstrated in Sec. 4.1.1, the system adjusted panel orientation smoothly, achieving desired angles with minimal delay.

PID Performance Testing:

The PID controller was tuned with the parameters the response to a 10° setpoint was achieved within 4 seconds (see Fig. 11). For a 20° setpoint, as illustrated in Sec. 4.2.2, the response time was reduced to 2 seconds (see Fig. 12). These results validate the PID controller's efficiency in minimizing errors and maintaining precise alignment.

Testing of Mechanical Design

The mechanical design of the solar tracking system was tested to evaluate its performance in different positions.

- **Standard Elevation Position**: Figure 7 shows the solar panel in its standard elevation position, which is optimized to face directly towards the sun for maximum energy capture.
- **Adjusted Elevation Position**: Figure 8 illustrates the solar panel positioned at -30 degrees from the standard elevation. This adjustment can be easily made by the user through the tracking control system.
- **Standard Rotation Position**: Figure 9 depicts the standard rotation position set at 90 degrees. This position serves as a reference point for the rotation functionality of the system.
- **Adjusted Rotation Position**: Figure 10 shows the solar panel at -30 degrees from the standard rotation position, demonstrating that the rotation function is working correctly.

4.2 Testing of PID Parameters

The system offers two operational modes: manual and automatic. For testing purposes, the manual setting was selected to evaluate the PID (Proportional-Integral-Derivative) control method.

- **PID Parameter Values**: The PID controller requires three parameters the values were set to K p = 20, Ki = 5, and K d = 10.
- **Response Time Analysis**: The purpose of testing the PID parameters was to assess how well the system responds to changes in the set angle. Figure 11 shows the response of the PID controller when the set point for both rotation and elevation was 10 degrees. The system achieved this position in 4 seconds.
- **Further Response Testing**: Figure 12 illustrates the response when the set position was adjusted to 20 degrees for both rotation and elevation. In this case, the system responded more quickly, reaching the desired position in just 2 seconds.

Overall, the results indicate that the PID parameters effectively control the system's response to changes in position. However, it was noted that the graphic response for rotation was less precise compared to elevation, as shown in Figure 11.

Figure 9: Standard Position of rotation

The mechanical design and PID control of the solar tracking system were tested successfully, demonstrating the system's ability to adjust the solar panels accurately to optimize energy Delivery

Figure 10: Position of solar panel with -30°C from standard rotation

PID Control Testing

1. Operational Modes: The system can operate in manual or automatic modes. Manual mode was used for testing.
2. PID Parameters: The PID controller uses three parameters: K p (20), Ki (5), and K d (10) to manage the system's response.
3. Response Time:
    - When the set point was 10 degrees, the system took 4 seconds to respond.
    - When the set point was increased to 20 degrees, the response time improved to 2 seconds**.**

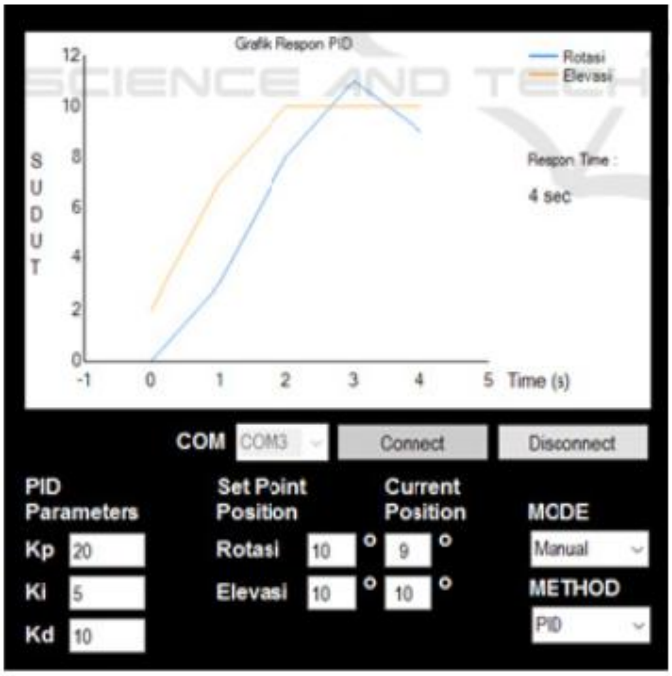

Figure 11: Response of PID set point

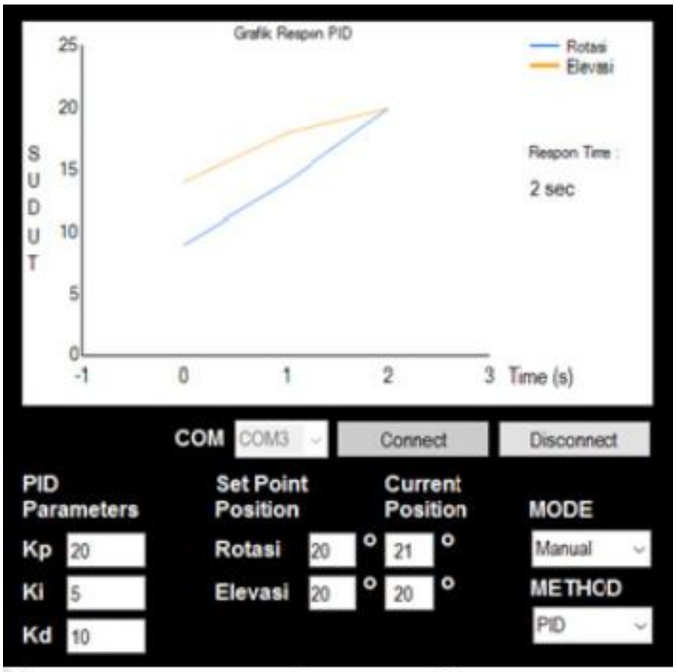

Figure 12: Response of PID set point

Applications of Solar Tracking Systems Using PID Control

1. Residential Solar Installations: Homeowners can implement PID-controlled solar tracking systems to optimize energy capture from rooftop solar panels, leading to increased electricity generation and reduced energy costs.
2. Commercial Solar Power: Businesses can use PID-controlled tracking systems to enhance the efficiency of solar arrays, making solar energy a more viable and cost-effective option for commercial energy needs.
3. Utility-Scale Solar Farms: Large solar farms can benefit from PID control to maximize energy output, allowing for better management of large arrays and improving the overall return on investment.
4. Remote and Off-Grid Applications: PID-controlled solar tracking systems can be deployed in remote areas to provide reliable power for telecommunications, water pumping, and other off-grid applications, ensuring optimal energy production.
5. Agricultural Energy Solutions: Farmers can use PID-controlled solar tracking systems to power irrigation systems, greenhouses, or other agricultural equipment, promoting sustainable farming practices and reducing operational costs.
6. Research and Development: PID-controlled solar tracking systems can be used in research settings to study the effects of tracking algorithms on solar energy efficiency and to develop new control strategies.
7. Integration with Smart Grids: PID-controlled solar tracking systems can be integrated into smart grid technologies, allowing for better energy management and distribution based on real-time data.

Advantages of Solar Tracking Systems Using PID Control

1. Enhanced Precision: PID control provides precise adjustments to the position of solar panels, ensuring they are optimally aligned with the sun throughout the day, which maximizes energy capture.
2. Improved Response Time: The PID controller can quickly respond to changes in the sun's position, allowing for real-time adjustments that enhance the system's overall efficiency.
3. Increased Energy Output: By maintaining optimal panel orientation, PID-controlled solar tracking systems can increase energy production by 20% to 50% compared to fixed installations.
4. Adaptive Control: PID controllers can adapt to varying environmental conditions, such as changes in sunlight intensity or weather, ensuring consistent performance and energy generation.
5. Reduced Mechanical Wear: The smooth and precise movements provided by PID control can reduce mechanical stress on the tracking system, leading to lower maintenance costs and longer system lifespan.

6. User -Friendly Operation: PID-controlled systems can be designed with user-friendly interfaces, allowing for easy manual adjustments and monitoring of performance metrics.
7. Data Logging and Analysis: Many PID-controlled systems can incorporate data logging features, enabling users to analyze performance over time and make informed decisions about energy usage and system adjustments.
8. Scalability: PID control can be applied to both small-scale residential systems and large-scale commercial installations, making it a versatile solution for various applications.
9. Integration with Other Technologies: PID-controlled solar tracking systems can be integrated with other renewable energy sources or energy storage systems, optimizing overall energy management.

CONCLUSIONS

This research illustrates the design of a sun tracking system by a PID controller. In order to orientate the solar panel to the maximum radiation at all times, this system is designed with dual axis control, such as: rotation and elevation. According to the mechanical test, the function of rotation and elevation can work properly based on the parameters input. In addition, the PID parameters give a response precisely based on the parameters input. Consequently, the solar tracking can recognize the position of the sun more accurately.

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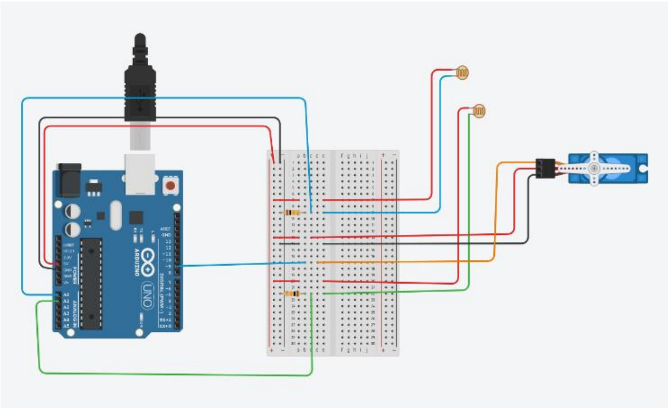

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