International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Integrating Simulink and Arduino for Optimized Solar Tracking Systems: A Methodological Approach for Enhanced Renewable Energy Utilization

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DOI: https://doi.org/10.55248/gengpi.5.0424.0920

A B S T R A C T

This research offers a complete approach to integrating Simulink and Arduino in the context of solar tracking systems. The methodology encompasses several systematic steps that seek to achieve precise orientation of solar panels and efficient energy capture. Commencing from data acquisition in real time involving measurement of azimuth and elevation angles by sensors, it proceeds to develop a Simulink model, including solar position algorithms. This model produces reference signals for a Proportional-Integral (PI) controller, which directs the positioning of solar panels. By integrating with an Arduino microcontroller, it becomes possible to achieve accurate motor control, thus allowing continual adjustment of panel orientation according to signals generated by Simulink. In addition, equations for torque calculation and motor control are used to effect proper alignment with the sun's trajectory.

Moreover, this methodology also addresses how cleaning mechanisms such as air blowers or water sprayers can be integrated to maintain optimal panel efficiency. To evaluate the effectiveness of an integrated system, thorough testing and validation, including simulating Simulink and real-world experimentations, are done. Continuous optimization efforts seek to improve tracking accuracy, energy efficiency, and cleaning performance step-by-step. This methodology, on the whole, is helpful as it offers systematic steps to develop and optimize solar tracking systems and provides direction for using Simulink/Arduino to enhance renewable energy utilization.

Keywords: Solar panels, Maintenance system, Sun tracking, Arduino, Automated cleaning

1. Introduction

It has been shown that solar tracking systems are essential in maximizing the efficiency of PV panels by ensuring they face the sun's position throughout the day. The development of complex tracking systems that boost energy capturing and exploitation is made easier by merging advanced controls with developing technologies. This report demonstrates how Simulink can be used with Arduino to design a solar tracking system that ensures accurate panel orientation and efficient energy conversion.

The methodology presented in this paper consists of a series of structured steps to integrate sensor data acquisition, control algorithm design, motor control, torque calculation, and cleaning mechanism integration under one framework. Accurate control over panel orientation and cleaning mechanisms can be achieved using Simulink, a robust simulation and modeling tool, together with Arduino microcontrollers. The integrated system's effectiveness is then assessed using rigorous testing and validation processes; thus, efforts towards improved accuracy in tracking, energy efficiency, and better cleaning results continue.

The paper, therefore, includes detailed methods that are concerned with data collection and utilization of senses, building a Simulink model, designing PI controller, controlling motors using Arduino boards, calculating torque and its control mechanisms, combining cleaning systems into one module then testing its functionality as well as refining it to operate more effectively. This research explains every step of the methodology in allowing the solar tracker to develop into an effective solution for renewable energy by offering information on how Simulink and Arduino can be adopted in solar power technology.

2. Review of Literature

Md. Rawshan Habib [1] In this paper, an Arduino-based solar panel cleaning system is designed and implemented for dust removal. The proposed solar panel cleaner is waterless, economical, and automatic. A two-step mechanism in this system consists of an exhaust fan, which works as an air blower and a wiper to swipe the dust from the panel surface. A dc motor is used to power the wiper. Since the system does not need water to clean solar panels, it avoids water wastage and is effective in desert areas. Experimental results show that the proposed cleaning system can operate with an efficiency of 87-96% for different types of sand.

Nurul F. Zainuddin [2] In this study, a flexible cleaning gadget is developed, which ventures into every part of the whole length of the solar panel. The technique presented also monitors the electrical power generated from the solar cells, and instructions for cleaning solar cell photovoltaic surfaces can be activated when required by using Internet of Things (IoT) mobile applications. The results revealed that the external resistance could reduce the solar panel's performance by up to 22%.

Faridah Hanim Mohd Noh [3] In this paper, a fully automatic solar panel cleaning system with/without water is proposed. Hence, in this paper, the design of a robot for automated cleaning of the surface of PV panels is presented. The design utilizes an Arduino controller system to control the robot's movement during cleaning. In addition, it is equipped with two rough sponges and a water pump system that can be used to clean dust or debris found on PV panel surfaces. The efficiency of the PV panels before and after the cleaning process is also observed. The result shows that the developed solar panel cleaning robot can clean the panel effectively and increase the output current and the maximum power of the panel by 50% after the dust on the PV panel is cleaned.

Ajay Suri [4] This paper discusses the introduction of the various technologies used for solar panel cleaning, the factor regarding efficiency due to nature, and the varied problems involved with solar panel cleaning.

Abhishek Kumar Tripathi [5] In this paper, In order to improve the performance of the PV panel, an automatic microcontroller-driven dust cleaning technique is developed, capable of removing the accumulated dust particles from the PV panel surface. Moreover, an experimental study has been performed to analyze the efficiency of this developed technique. The developed cleaning system showed an improvement of 27.98% in the output power of the PV panel when compared to the dusty panel.

Manoj Kumar Swain [6] This paper proposes that this work is carried out with the help of the Arduino Uno microcontroller board, which effortlessly controls all the connected devices. The experimental results clearly show a substantial increase in the efficiency of the SPV panel. Moreover, the proposed work has been carried out by considering the following aspects: (i) efficacy of anti-soiling, (ii) frequency of cleaning, and (iii) energy saving (observation on a daily, weekly, and monthly basis).

Laurentiu Alboteanu [7] This paper presents aspects of designing an automaton for a PV panel tracking system fitted with low sunlight concentrating elements. The tracking systems use controlled mechanisms that maximize direct regular sunlight received on PV panels.

Nasib Khadka [8] In this paper, the sensing unit added with the regression model is named an autonomous unit, which predicts the suitable time for cleaning action. According to the system evaluation done on a demonstration PV module, it was found that the designed system can clean dry dust accumulated over the panel's surface. Moreover, by attaching the metal rail tracks to a long solar array, the system seems to be implementable on a large-scale solar farm.

Sathish Singarapu [9] In this study, we propose a timed system that uses water and wipers to clean solar panels. Internet of Things (IoT) technology is used to operate. The microcontroller and several sensor modules will undoubtedly handle system management. The Android application may be used to control the system. The system sends the consumer a notification informing them of the various processes. The system may be made transportable to be deployed in various settings. A 5V, 500mA controlled power supply is used in this project. For voltage regulation, the 78053 authority is used, which is incurable. A full wave bridge rectifier rectifies the second 230V to 12V step-down transformer's AC output.

In this paper, N Sugiartha [10], The experimental tests are conducted to obtain the solar panel performance, namely output voltage, output current, output power, and panel efficiency under clean and dusty conditions. A comparison of both conditions was made to determine the cleaning effectiveness of the proposed prototype. The test results show that the wiper-swept repetition of 10, 20, and 30 times delivers 57.0 percent, 79.1 percent, and 86.7 percent of the performance of the initial clean surface condition, respectively.

NASIB KHADKA [11] This paper presents The authors finally suggest a schematic of a decision-making model that uses probable parameters, data processing techniques, and machine learning tools. Implementing data science and machine learning in a solar PV panel cleaning system could be a remarkable advancement in the field of renewable energy.

Najmi, N [12] This paper provides an overview of the cleaning aspects of solar panels. We first discuss the drawbacks of unwanted deposits on solar panels in terms of energy production and efficiency. Existing cleaning practices and technologies are then presented with an emphasis on factors such as the size of the facility, location, cost, and available resources. Finally, a comparative cost–benefit analysis is carried out using decision support tools and considering different relevant criteria to support users in choosing the proper cleaning maintenance for their specific solar installation.

Bandam Abhilash [13] This paper presents the idea that to make solar energy more fruitful, the efficiency of solar array systems must be maximized [2] for the efficiency evaluation of PV panels, which has been discussed with particular attention to the presence of dust and maximum intensity of light on the panel surface. The effects of dust and intensity of light on the efficiency of PV panels have been highlighted. This paper briefly describes the design and construction of a microcontroller-based cleaning and tracking system.

G Anilkumar [14] This paper proposes That an attempt had been made to bring in an automated robot cleaning system using a power vast area network (LPWAN) based on a network of ESP 8266 Node MCUs associated with a set of sensors under different configurations which showed successful results for implementation in industrial scale large solar PV power plants.

Benjamin Oluwamuyiwa Olorunfemi [15] This paper provides real-time monitoring and cleaning of the solar panel to improve its output power with integrated intelligent systems. It helps users get real-time updates of the solar panel's condition and control actions from distant locations. A critical limitation of this research is the insufficient empirical analysis of existing intelligent systems, which should be thoroughly examined to allow further generalization of theoretical findings.

3. Methodology

3.1 Data Acquisition with Sensors

In this step, sensors are employed to capture real-time data regarding the azimuth and elevation angles of the sun. These sensors may include photodiodes, photovoltaic cells, or other solar tracking sensors. The azimuth angle represents the horizontal angle between the true north and the sun's direction. In contrast, the elevation angle represents the vertical angle above the horizon. By accurately measuring these angles, the control system can determine the sun's position relative to the solar panels.

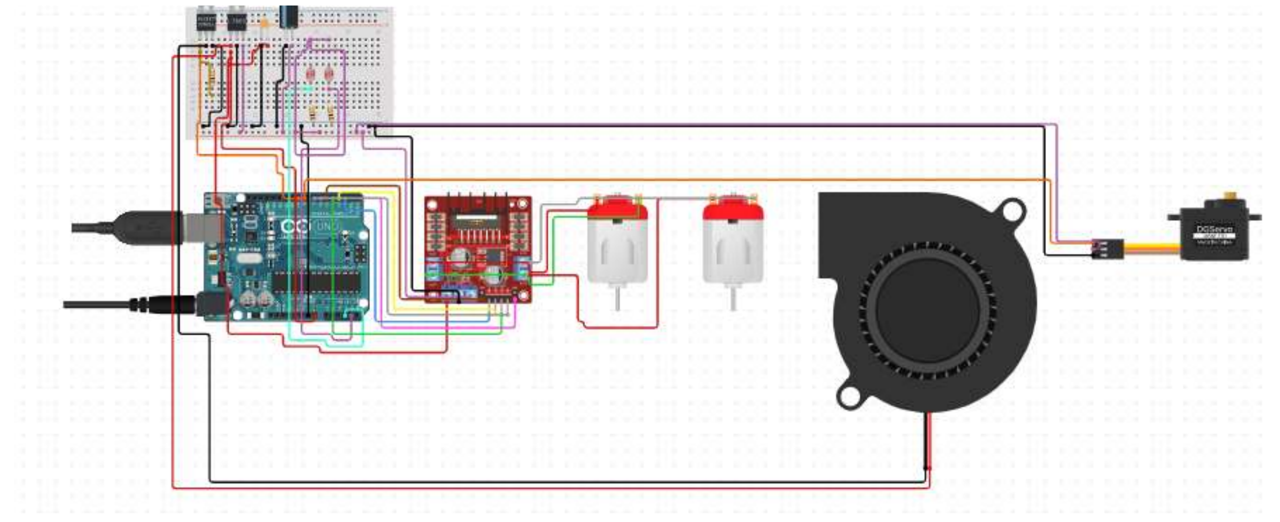

Fig. 1 – Prototype Model of the Proposed Work

3.2 Simulink Model Development

In this model, Simulink is used to incorporate solar position algorithms. The inputs into these algorithms are dates, times, and geographical coordinates, which come out with the desired azimuth and elevation angles for optimum solar tracking. In a control system's heart, the Simulink model generates reference signals for positioning solar panels all over a day.

3.3 PI Controller Design

A Proportional-Integral (PI) controller is implemented within the Simulink environment to regulate the azimuth and elevation angles of the solar panels. The PI controller adjusts the orientation of the panels based on the disparity between the desired angles calculated by the Simulink model and the actual angles measured by the sensors. Through careful tuning of controller gains, the system can balance response speed and stability, ensuring smooth and accurate sun tracking.

3.4 Motor Control with Arduino

The Simulink model is integrated with an Arduino microcontroller to facilitate motor control. DC gear motors are utilized to adjust the orientation of the solar panels based on the reference signals generated by the Simulink model. The Arduino receives these signals and translates them into commands to actuate the motors, ensuring the panels are continuously aligned with the sun's position.

3.5 Torque Calculation and Control

Equations for calculating motor torque and controlling motor position are implemented within the Simulink environment. These equations account for panel weight, friction, and wind resistance to determine the torque required to adjust the panel orientation accurately. By dynamically controlling motor position, the system ensures precise alignment with the sun's trajectory, maximizing energy capture.

3.6 Integration of Air Blower and Water Sprayer

In environments where dust or debris accumulation may hinder solar panel performance, air blowers and water spray control systems can be integrated into the overall system. Additional control logic is developed within the Simulink model to activate these systems based on environmental conditions or predefined cleaning schedules. By periodically removing debris from the panels, the system maintains optimal efficiency and prolongs the lifespan of the solar array.

3.7 Testing and Validation

The integrated system undergoes comprehensive testing to validate its performance. Simulation in Simulink allows for a thorough analysis of system behavior under various conditions. At the same time, real-world experimentation provides empirical verification of tracking accuracy and cleaning effectiveness. Testing efforts aim to identify any potential issues or areas for improvement, ensuring that the system meets the desired performance requirements.

3.8 Optimization and Fine-Tuning

Continuous optimization of control algorithms and system parameters is conducted based on feedback obtained from testing. The system can further enhance tracking accuracy, energy efficiency, and cleaning performance by iteratively refining the Simulink model and Arduino code. Optimization efforts focus on maximizing solar energy capture while minimizing energy consumption and maintenance requirements, ultimately enhancing the overall effectiveness of the solar tracking system.

4. Results

Result 1

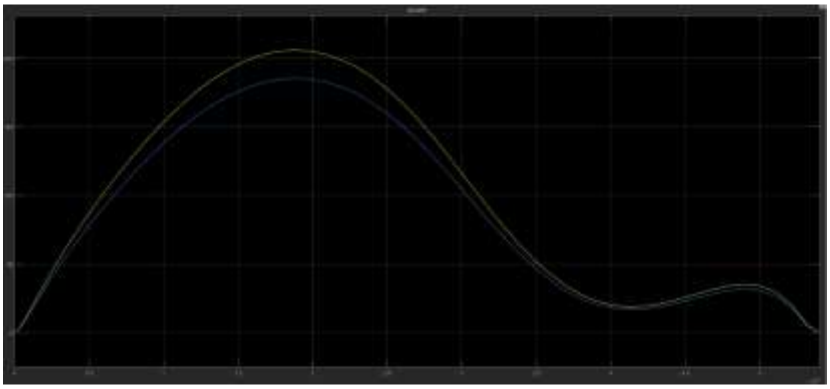

Fig. 2 – Power Loss Waveform at 10%

This image illustrates the deviation in energy output observed by the Smart Solar Panel Maintenance System when a 10% loss in efficiency occurs. The graph plots the measured energy output over time, showing a noticeable decline from the expected output level. The system's monitoring mechanism, utilizing Light Dependent Resistors (LDRs), accurately detects this deviation, activating the appropriate cleaning mechanism to restore optimal performance.

This real-time monitoring and intervention capability demonstrates the effectiveness of the proposed system in maintaining the peak energy efficiency of solar panels, thereby minimizing energy loss and maximizing overall system productivity.

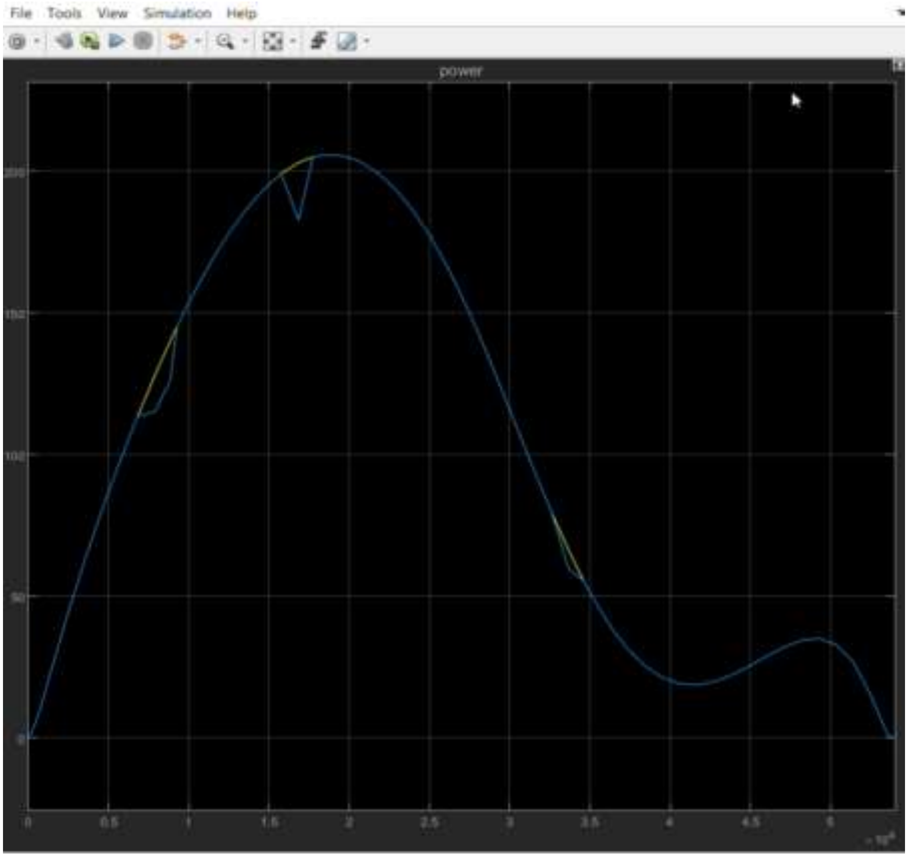

Fig. 3 – Retrieved Power Loss Waveform at 10%

Result 2

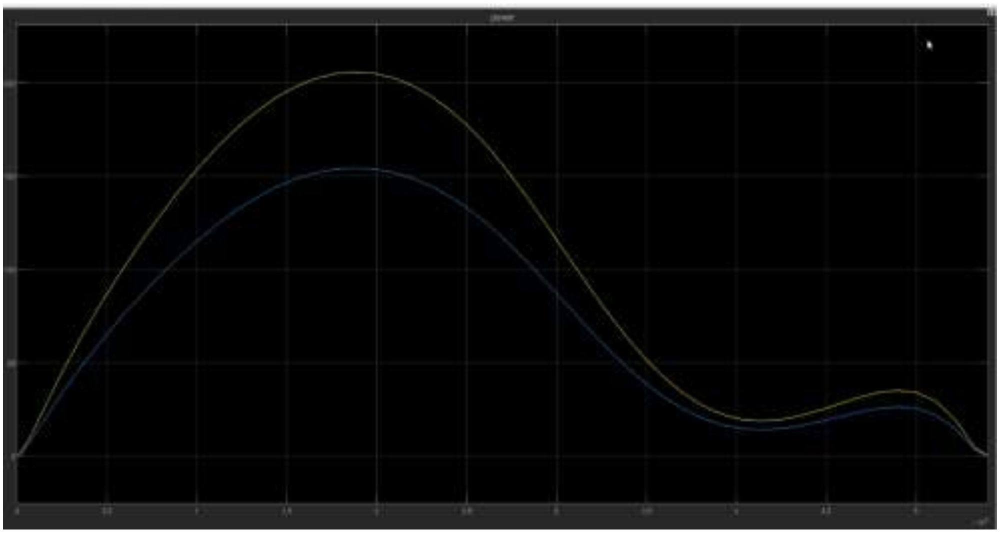

Fig. 4 – Power Loss Waveform at 20%

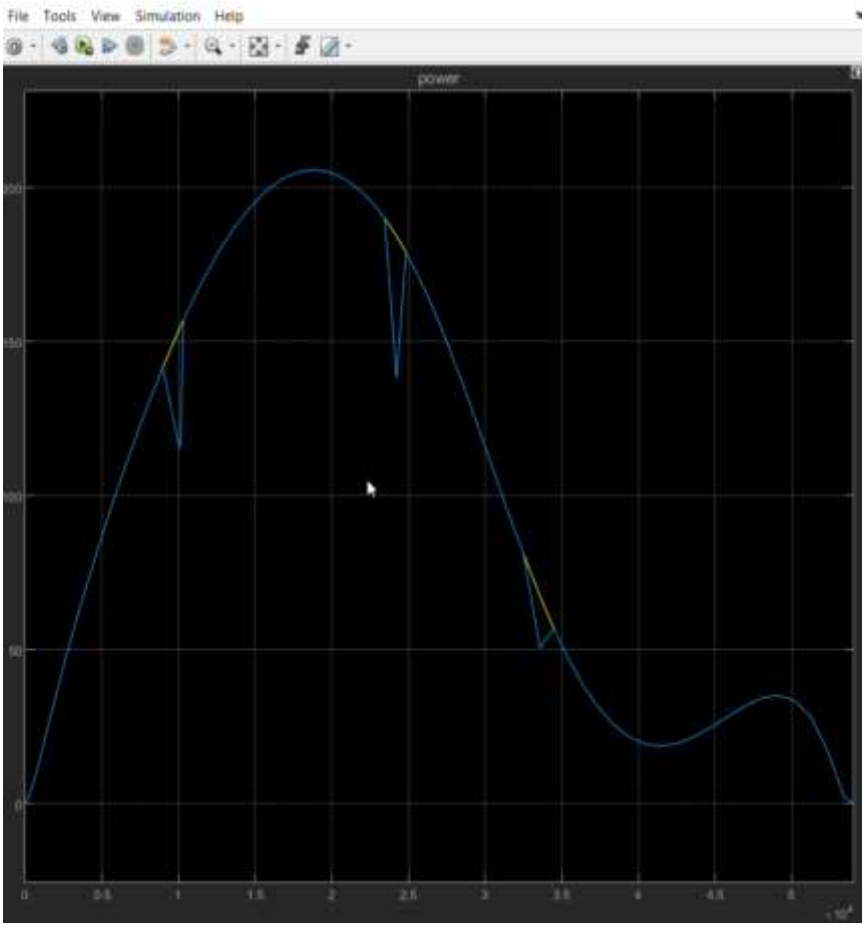

Fig. 5 - Retrieved Power Loss Waveform at 20%

This image depicts the deviation in energy output recorded by the Smart Solar Panel Maintenance System when a 20% loss in efficiency occurs. The graph visually represents the measured energy output over a specific period, indicating a substantial decline compared to the expected output level. The sophisticated monitoring system, utilizing Light Dependent Resistors (LDRs), accurately identifies this deviation and activates the appropriate cleaning mechanism. In response to this significant loss, the system deploys a water sprayer to remove contaminants and restore optimal performance. This real-time monitoring and intervention capability highlights the system's ability to maintain the efficiency and productivity of solar panels, thereby minimizing energy loss and enhancing overall system reliability.

Result 3

This image illustrates the significant deviation in energy output observed by the Smart Solar Panel Maintenance System when a 30% loss in efficiency occurs. The graph displays the measured energy output over a specified time frame, demonstrating a notable decline compared to the expected output level. The system's precise monitoring mechanism, utilizing Light Dependent Resistors (LDRs), accurately detects this deviation and triggers the activation of the appropriate cleaning mechanism. In response to this considerable loss, the system uses a wiper mechanism to remove accumulated debris and thoroughly restore optimal performance. This real-time monitoring and intervention capability underscores the system's ability to mitigate the impact of efficiency losses on solar panel productivity, ensuring consistent energy generation and maximizing overall system efficiency.

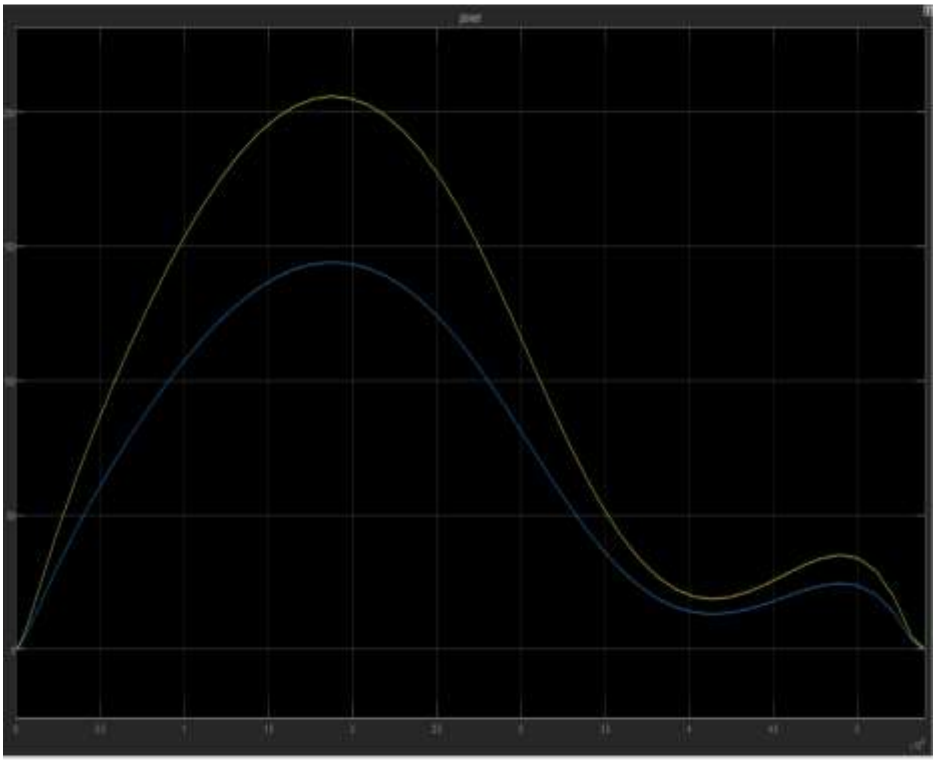

Fig. 6 - Power Loss Waveform at 30%

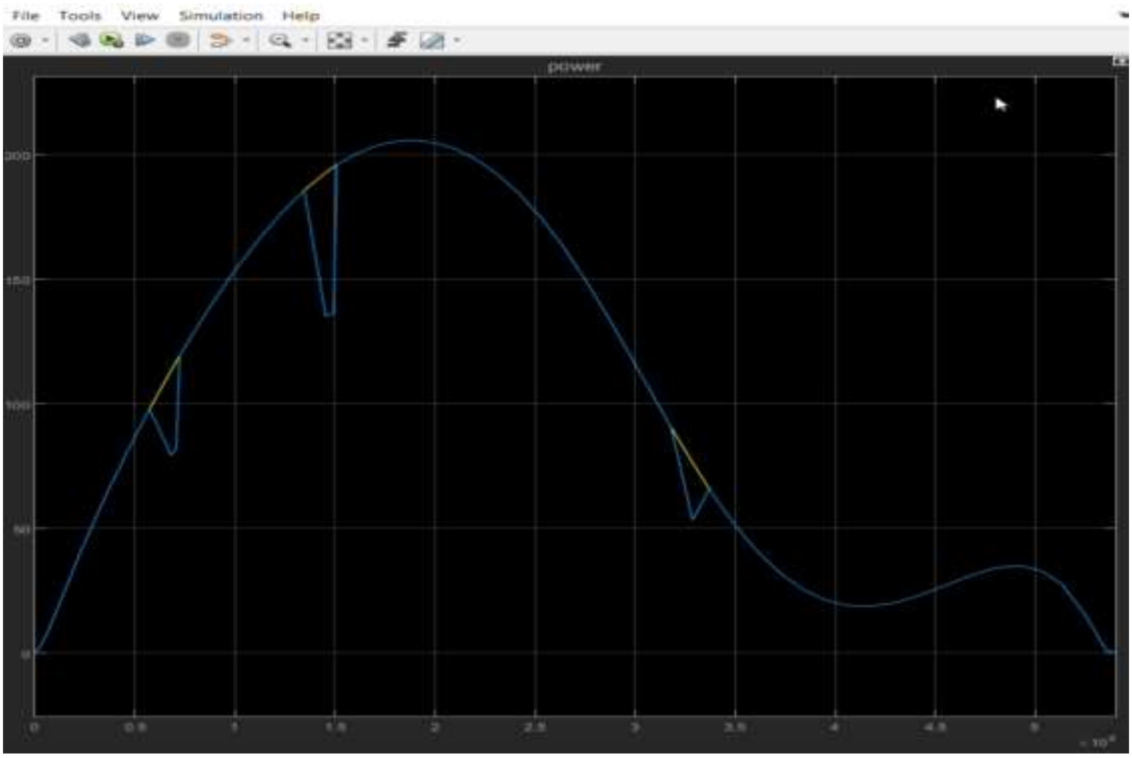

Fig. 7 - Retrieved Power Loss Waveform at 30%

5. Discussion

A significant advancement in many areas was achieved by implementing the proposed methodology for solar tracking and cleaning system integration. The system used exact sensor data and a Simulink model with solar position algorithms to accomplish excellent tracking accuracy, ensuring optimal sun panel alignment. In addition, efficient energy use was facilitated by the incorporation of motor control. At the same time, dust and debris build-up has been maintained by adding cleaning systems, which contributed to improved maintenance efficiency. Rigorous testing and validation processes have established that the integrated system is robust and effective, leading to continuous optimization and improvement activities. Generally, this method provides an all-around approach toward energy capture maximization and panel efficiency sustainability. At the same time, future research would concentrate on further optimizations and explore advanced technologies for better functioning and adaptability across different environments.

6. Conclusion

The integration of solar tracking and cleaning systems, as outlined in the methodology, has yielded significant advancements in energy capture and panel efficiency. The system achieves exceptional tracking accuracy by leveraging precise sensor data and a sophisticated Simulink model, optimizing solar panel alignment with the sun's trajectory. Motor control mechanisms ensure efficient energy utilization, while cleaning systems effectively mitigate dust and debris accumulation, enhancing maintenance efficiency and sustainability. Rigorous testing validates the system's robustness, and ongoing optimization efforts promise further energy capture and efficiency improvements. Future research will focus on refining the system and exploring advanced technologies to enhance functionality across diverse environments, ultimately maximizing solar energy utilization.

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