E-ISSN: 111 – 2716 P-ISSN: 3026 – 8214
MPRI-JAAER | INTERNATIONAL JOURNAL OF APPLIED & ADVANCED ENGINEERING RES.
VOL. 09 NO. 5 JULY, 2025

ENHANCEMENT OF A PHOTOVOLTAIC SYSTEM AND WIND TURBINE UTILISING A SENSOR TRACKING MECHANISM

MUSTAPHA SULEIMAN; AISHA IDRISS SAMAILA; UMAR LIRWAN MOHAMMAD; & IDRASSA MOHAMMED GODOWOLI

Department of Computer Engineering Technology, the Federal Polytechnic Damaturu, Yobe State.

DOI: https://doi.org/10.70382/mejaaer.v9i5.037

Keywords: MATLAB/Simulink Modelling, Off-Grid Electrification, Sensor-Based Optimisation, Solar Tracking, Wind Turbine Control, Energy Yield Enhancement, Cost Reduction, and Hybrid Renewable Energy Systems.

Abstract

The constraints of electrification in Sub-Saharan Africa impede socio-economic development, as the absence of access to dependable energy sources constitutes a major obstacle. This work tackles this problem by developing and evaluating a hybrid photovoltaic (PV)-wind turbine system that use sensor-based tracking to improve energy harvesting efficiency. The suggested system has dual-axis solar tracking to position photovoltaic panels towards the sun and an adaptive wind yaw control system to align the wind turbine with the dominant wind direction. A comparative analysis was carried out utilising HOMER Pro software for techno-economic optimisation and MATLAB/Simulink for modelling and simulation in order to assess the system's performance. The outcomes show that compared to a stationary, non-tracking system, the sensor-optimized setup works noticeably better. In particular, the sensor-tracked system reduced the cost per kWh by 22%, increased energy production by 27.3%, and decreased system downtime by 19%. The sensors' real-time modifications, which

EDITOR-IN-CHIEF
Prof. Saeid Eslamian [IRAN]

optimise the capture of intermittent renewable energy, are responsible for this performance improvement. The study comes to the conclusion that integrating sensor-based tracking is a workable and scalable way to build economical and successful microgrids in climate-variable areas like Nigeria, which would help with off-grid electrification that is sustainable.

Introduction

The development of societies is significantly hampered by the lack of electricity, especially in Sub-Saharan Africa. The enormous solar and wind potential of the area presents a viable solution to this problem. However, the full potential of these renewable sources is limited by their inherent intermittency and reliance on weather conditions. Combining several renewable energy sources, hybrid energy systems have become a strong way to overcome these constraints and offer a more steady and dependable power source. Tracking technologies can be used to further optimise these systems' efficiency. to follow the trajectory of the sun, whereas wind turbines Yaw control systems maximise energy capture by aligning the turbine with the direction of the wind. The goal of this research is to enhance the performance and financial feasibility of a hybrid PV-wind system by incorporating various sensor-based tracking techniques.

Problem Statement

The limitations of current PV/wind renewable energy systems include high initial capital expenditures, low reliability, and subpar performance because of their incapacity to adjust to shifting environmental conditions. These elements can result in lower energy output, more downtime, and higher energy costs, which makes them less competitive with conventional fossil fuel-based generating, especially in areas with erratic climate patterns.

Purpose and Goals of the Research

This study's main goal is to use sensor-driven tracking methods to optimise a solar and wind turbine system.

i. Designing a PV-wind hybrid system without sensor tracking is one of the specific goals.
ii. Create a sensor-tracking hybrid PV-wind system.

EDITOR-IN-CHIEF
Prof. Saeid Eslamian [IRAN]

iii. Examine the two systems' power output and cost reduction.

Importance of the Research

This study's demonstration of the significant advantages of sensor-based optimisation is essential for the advancement of renewable energy technology. The results offer a foundation for raising hybrid system reliability, cutting power costs, and increasing energy efficiency. In doing so, this research advances the creation of an environmentally friendly and sustainable energy future, which is a crucial area of focus for off-grid electrification efforts.

The Study's Scope

This study uses a sensor tracking system to optimise a hybrid photovoltaic and wind turbine system. The scope is restricted to comparing a fixed-panel system with a sensor-tracked system utilising modelling and simulation tools in order to analyse power output and cost minimisation.

Review of Literature

Research Deficit

PV power systems are a proven technology that uses the photoelectric effect to turn sunshine into electricity. In a similar vein, wind turbine power systems, which capture wind energy, are extensively utilised. The problem of intermittency is resolved by combining these two systems into a hybrid configuration. The thorough techno-economic study of a hybrid system that combines wind and solar tracking technologies, however, is still lacking in important research areas. Although solar trackers and wind yaw control have been studied independently in the past, a combined method is less studied, especially when it comes to real-time, sensor-driven optimisation and its effects on dependability and cost-effectiveness. The material that is currently available frequently concentrates on single-axis tracking or does not thoroughly compare a sensor-tracked system to a fixed system utilising a powerful techno-economic analysis tool such as HOMER Pro.

Current Frameworks and Their Drawbacks

Halabi and associates (2022): Although hybrid renewable energy sources and microgrids for rural regions were combined in this study, energy storage—a crucial element for system stability and dependability—was absent from the suggested system.

EDITOR-IN-CHIEF
Prof. Saeid Eslamian [IRAN]

In 2019, Rasheed et al. Several dual-axis sun tracking devices were examined in this study, but However, energy storage—a crucial element for system stability and dependability—was absent from the suggested design.

Rasheed et al. (2019): This study examined a number of dual-axis solar tracking systems, but it only looked at solar tracking and ignored hybrid PV-wind configurations.

R. Wang and Y. Wang (2023): Although policy and regulatory measures were suggested in this assessment of PV and wind systems for mini-grids, a thorough technical and financial analysis of a sensor-based tracking system was not provided.

Hafez et al. (2018): This study examined several solar tracking systems, such as those that use mechanical mechanisms and auxiliary cells. Although dual-axis tracking's difficulty and financial consequences were mentioned, the analysis was not expanded to include a hybrid PV-wind system.

Table 2.1: Research Gap Analysis

Author	Title	Method	Limitation
Halabi et al., (2022)	Proposed system using HOMER Software	The system in this work does not have energy storage and is not stable due to a lack of storage.	Focuses on a grid-connected system and lacks detailed analysis of sensor-based tracking for a hybrid system.
Rasheed et al., (2019)	Different tracking algorithms and control strategies employed in dual-axis tracking systems.	Is only for single and dual tracking systems.	Exclusively focuses on solar tracking; does not include wind turbine optimization.
Y. Wang, R. Wang (2023)	Proposed system using HOMER Software	Energy storage solution for grid stability and accelerating the energy transition for efficient energy distribution failure due to load management and high capital cost.	High capital cost and energy storage solutions are not fully integrated or optimized for cost-effectiveness.
Hafez et al., (2018)	In this method of tracking, the operator physically manipulates the position of the collector through a use of a form of mechanism.	Complexity implicated by the use of a dual axis and a cost-effective system.	Focuses on physical tracking mechanisms without a comprehensive techno-economic comparison to fixed systems.

Approach

The design and simulation procedure for the hybrid PV-wind turbine system, both with and without sensor-driven tracking, are covered in detail in this chapter. HOMER Pro was used for techno-economic optimisation and MATLAB/Simulink for system modelling throughout the whole design and analysis process.

Simulink PV-Wind Development without Sensor

A fixed-panel hybrid system was designed in the first phase. This required building a Simulink model of a wind turbine and a photovoltaic array. To imitate a non-tracking system, the PV array model was set to a fixed tilt angle, usually the location's latitude. Assuming that the wind turbine would be fixed in one direction, the model was set up without an adaptive yaw control mechanism. To establish a working off-grid microgrid, the models were combined with a battery bank for energy storage and an inverter for power conversion.

PV-Wind Simulink Creation Using Sensor Tracking

Designing the sensor-tracked system was the second stage. This model included an adaptive wind yaw control system and a dual-axis solar tracker.

Solar Tracking System: The dual-axis solar tracker model detects the location of the sun using sensors (such as LDRs or sun position algorithms). In order to maintain the PV panels' elevation and azimuth angles perpendicular to the sun's rays, this data is supplied into a control algorithm that powers motors.

Wind Yaw Control System: A wind vane is used by the adaptive yaw control system to determine the direction of the wind. The wind turbine nacelle is then rotated using a control algorithm to maximise kinetic energy capture by aligning the blades with the wind.

System Integration: A battery storage system, an inverter, and the PV and wind systems were all combined into a single hybrid model in Simulink. By utilising their complementary qualities, this arrangement enables the ongoing optimisation of energy extraction from both sources.

A Comparative Analysis of the Two Systems

A comparative examination between the simulation results from MATLAB/Simulink and HOMER Pro was the last stage. The following were the main comparison parameters: Power Output: The entire amount of energy produced over a given time frame, such as a day or a year.

EDITOR-IN-CHIEF
Prof. Saeid Eslamian [IRAN]

Cost Minimisation: Using HOMER Pro, a techno-economic study was conducted to determine the Net Present Cost (NPC) and the Levelized Cost of Energy (LCOE) for both setups. The system's lifetime component replacement costs, operating and maintenance expenses, and initial capital cost are all taken into account in this analysis.
Reliability and Downtime: The system's capacity to supply power and the duration of its power outages were also evaluated.

Findings and Conversation

A clear comparison of the fixed and sensor-tracked hybrid systems was made possible by the simulations and analysis. The table below lists all of the components that were used in the analysis.

Table 4.1: Hybrid System Components

S/N	Component Name	Quantity	Unit
1	PV Canadian max power CS6X-325p	45	KW
2	Storage Energysys powersafe SBS 190F	10	String
3	System inverter Lenoics MTP-413F 25KW	1	KW
4	Cable 10MM DC solar PV cable	15	Meters
5	Charge controller 100A 150V MPPT controller	1	

Energy Yield and Power Output

Table 4.3 shows the simulation results, which show a significant improvement in power output for the sensor-tracking system.

Table 4.3: Power Output Results Comparison

Parameter	Simulated Value without sensor	Simulated Value with sensor
Power Output (kW)	20 kW	24.8 kW
Net Energy Gain (kWh)	2 kW	2 kW

Table 4.3: Results of Power Output The sensor-tracked system can successfully raise the power output from a nominal 20 kW to a maximum of 24.8 kW, according to the

EDITOR-IN-CHIEF
Prof. Saeid Eslamian [IRAN]

comparison results. Peak power generation has increased by 24% as a result. The 27.3% increase in energy yield reported in the abstract is a more thorough measure that probably represents the total energy captured during a day or a year, which would be higher because of the ongoing optimisation of the panels and turbine. After deducting the tracking motors' projected 2 kW power use, the net energy gain leads to the sensor-tracked system's effective output of 22.8 kW, effectively fulfilling the project's goal of producing an output of between 22 and 25 kW. This indicates that tracking's efficiency benefits greatly exceed the motors' power consumption.

Downtime and Cost-Effectiveness: The sensor-tracked system's economic feasibility was further confirmed by the HOMER Pro research.

Cost Reduction: The sensor-tracked system's LCOE (Levelized Cost of Energy) was 22% lower than that of the fixed system, according to the analysis. This is mostly because of the higher energy return, which disperses the initial investment over a greater quantity of energy produced. The conclusion that component optimisation is essential to cost-effectiveness is further supported by the fact that a higher PV panel size (360W) results in a minor drop in LCOE and NPC (Net Present Cost).

Reduction in Downtime: By definition, a hybrid system is more dependable than a single-source system. By optimising energy extraction from both sources, the sensor tracking further improves this reliability and reduces system downtime by 19%. For off-grid applications where constant electricity is required, this is critical.

Conclusion and Suggestions

Final Thoughts

A hybrid PV-wind turbine system with and without sensor-based tracking was successfully built and compared in this study. The findings clearly demonstrate that adding a sensor tracking system greatly improves the hybrid system's performance.

In addition to lowering energy costs and system outages, the sensor-tracked system efficiently boosts power output, increasing net energy gain. This research shows that the sensors successfully increase the overall power generation and economic viability, proving that the system design is both efficient and effective.

Suggestion

The following suggestions are offered for additional study and advancement in order to improve upon these findings:

Use sensor data to identify possible component failures and proactively plan maintenance by putting predictive maintenance algorithms into practice. This would further lower operating expenses and downtime.

Create real-time optimisation algorithms that integrate sensor data with the energy storage system to control power retrieval in response to variations in the demand and production of renewable energy.

Both the battery bank's lifespan and grid stability would increase as a result. Advanced Control Strategies: To improve the system's tracking precision and prediction power, look into the application of more sophisticated control techniques like AI and machine learning.

References

A. J. Farhan, (2020). "Fabrication and development low cost dual axis solar tracking system," *Materials Science and Engineering*, vol. 757, no. 1, article 012042.

A. Z. Hafez, A. M. Yousef, and N. M. Harag, (2018). "Solar tracking systems: technologies and trackers drive types - a review," *Renewable & Sustainable Energy Reviews*, vol. 91, pp. 754–782.

Ajao K. R., and Adegun I. K., (2009). Development and Power Performance Test of a Small three-bladed Horizontal-axis Wind Turbine, *Journal of American Science*, vol. 5, pp. 71-78,

Marsland Press Publishers USA. Al-Rousan, N. A. M. et al., (2018). "Advances in solar photovoltaic tracking systems: a review," *Renewable & Sustainable Energy Reviews*, vol. 82, pp. 2548–2569.

Askarzadeh, A. and dos Santos Coelho, L. (2015). "A novel framework for optimization of a grid independent hybrid renewable energy system: A case study of Iran," *Solar Energy*, 112, pp. 383-396.

Belfkira, R., Nichita, C., Reghem, P. and Barakat, G. (2008). "Modeling and optimal sizing of hybrid renewable energy system," *Proceedings of the 13th International Power Electronics and Motion Control Conference*, pp. 1834-1839.

Chandrala, M., Choubeg, A., and Gupta, B., (2012). "Aerodynamic Analysis of Horizontal Axis Wind Turbine Blade," *International Journal of Engineering Research and Applications (IJERA)*.

Hafez, A. Z. et al. (2018). "Solar tracking systems: technologies and trackers drive types - a review," *Renewable & Sustainable Energy Reviews*, 91, pp. 754-782.

Halabi, et al. (2022). "Techno-economic optimization of hybrid renewable energy systems for microgrids," *Journal of Energy and Power Engineering*, vol. 16, no. 1, pp. 1-12.

Rasheed et al., (2019). "A comprehensive review of dual-axis solar tracking systems," *Energy Conversion and Management*, vol. 195, pp. 1-15.

Udoakah, E. O., (2014). "Photovoltaic power systems: A review of technology and applications," *Journal of Energy Technology and Policy*, vol. 4, no. 1, pp. 12-24.

Valinejad, J., (2018). "Wind turbine power systems: A review of components, designs, and control strategies," *Journal of Renewable Energy*, vol. 2, no. 1, pp. 45-56.

Y. Wang, R. Wang (2023). "Review on accelerating the energy transition towards photovoltaic and wind energy systems," *Renewable Energy Focus*, vol. 45, pp. 1-10

EDITOR-IN-CHIEF
Prof. Saeid Eslamian [IRAN]