

DECARBONIZING NIGERIA'S POWER SECTOR THROUGH AI-OPTIMIZED WIND-SOLAR HYBRID SYSTEMS IN SMART GRIDS

Sabo Aliyu^{a*}, Dahiru Dauda^b, Olutosin Adebayo Ogunleye^c

^{abc} Department of Electrical and Electronics Engineering, Faculty of Engineering and Engineering Technology,

Nigerian Defence Academy (NDA), Kaduna, Nigeria.s.

*Corresponding author Email: aliyu@nda.edu.ng

Received: 2nd April, 2025

Reviewed: 22nd April, 2025

Accepted: 25th April, 2025

ABSTRACT:

This research looks into Using renewable energy sources like wind and solar photovoltaic (PV) systems is crucial to achieving a sustainable, low-carbon energy future. These systems are becoming more and more feasible because of their scalability and affordability. However, because of their intrinsic unpredictability, it is difficult to manage energy distribution, balance supply and demand, and preserve grid stability. Advanced control technologies including Phasor Measurement Units (PMUs), energy storage systems (ESS), and artificial intelligence (AI) can help wind and solar PV work together to maximize power generation, reduce waste, and improve grid resilience. Nigeria's energy landscape offers insights on the unrealized promise of renewable energy, especially in areas that continue to rely on fossil fuels. The study also looks at modern control strategies, such as machine learning and AI-based energy management, to reduce intermittency and increase operational effectiveness. The findings demonstrate how different technologies must be integrated in order to create a reliable and sustainable energy system.

Keywords: Wind Energy, Solar Energy, Power Electronics, AI, Grid stability

I. INTRODUCTION

Achieving a sustainable and low-carbon energy system requires a growing proportion of electricity generation from renewable energy sources (Meister et al., 2025). Wind power and solar energy systems are two of the most popular renewable energy technologies because of their accessibility, scalability, and declining costs. Nevertheless, the power grid has difficulties in balancing supply and demand due to the stochastic production patterns of both sources. Optimizing energy generation, reducing curtailment, and guaranteeing a steady supply of electricity all

depend on an understanding of the link between these two sources (Meister et al., 2025). Because wind and solar energy have so many benefits, they are developing quickly and gradually replacing fossil fuel. Figure 1 shows the yearly variations in energy generation per source, expressed in terawatt-hours (TWh), between 2019 and 2025. It shows a substantial fall in coal generation, especially in 2020, and a notable growth in renewable energy generation, particularly after 2021 (IEA,2023). In Nigeria, where gas, coal, and oil now make up the majority of the energy mix, there is a growing trend toward renewable energy sources. With abundant solar, wind, hydro, and

biomass resources, the country is well-positioned to address its energy challenges and transition to a more sustainable future (Adeshina et al., 2024). Nigeria possesses substantial renewable energy resources, with an estimated annual solar power potential exceeding 427,000 GWh. The country receives abundant solar irradiation, ranging from 4.0 to 6.5 kWh/m²/day across different regions (Adeshina et al., 2024). For wind energy, northern states including Sokoto and Katsina show promising average wind speeds of 5.0–7.0 m/s, which are technically viable for power generation (Adeshina et al., 2024). To enhance renewable energy adoption in Nigeria, tailored solutions such as rural microgrids and urban financing models are essential. In remote communities where extending the national grid is impractical, hybrid solar-diesel-battery microgrids have proven effective in providing reliable electricity, as seen in places like Torankawa, Sokoto State. For urban areas, alternative financing options like renewable energy leasing and collaborations between the public and private sectors have facilitated broader access to solar technologies by lowering initial investment barriers. These strategies support Nigeria’s transition to clean energy while promoting inclusive energy access and strengthening the resilience of the power system (Ukoba et al., 2024a). The integration of PV and wind energy systems is justified by their potential to significantly reduce dependence on fossil fuels, lower greenhouse gas emissions, and promote long-term energy sustainability. Although these renewable sources are inherently variable and can create supply-demand imbalances, advancements in technology, energy storage solutions, and smart grid systems are actively addressing these issues. Furthermore, diversifying energy sources enhances grid resilience and reliability. Thus, the benefits of integrating PV and wind energy far outweigh the challenges, making them a critical part of the global transition to clean energy (Al-Fatlawy et al., 2024). Even though we are not producing as much renewable energy as we should, Nigeria has a wealth of energy resources, particularly wind and photovoltaics. Control devices are incorporated into the system to increase efficiency and economic benefits, and modern power grids are highly networked with cutting-edge technologies (Ali et al., 2021). Planning an energy system now heavily considers the balance between solar and wind output, especially in areas where variable renewable energy is widely used. Wind and solar PV are somewhat complementary, but in order to find the best combination that increases energy generation while

minimizing reserve deficiencies, their combined production characteristics must be carefully examined. The primary obstacle stems from these energy sources' sporadic character, necessitating efficient methods to improve grid stability, regulate (Rekioua, 2023a)em and Phasor Measurement Units.

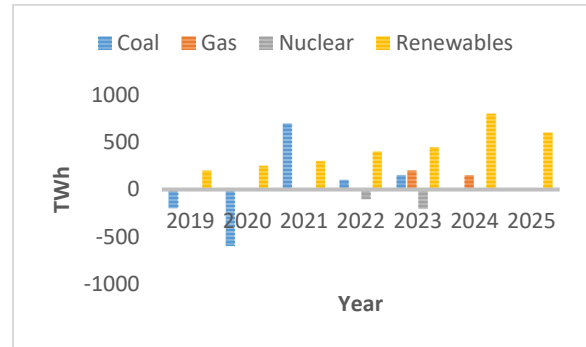


Figure 1: Global change of energy generation (IEA, 2023)

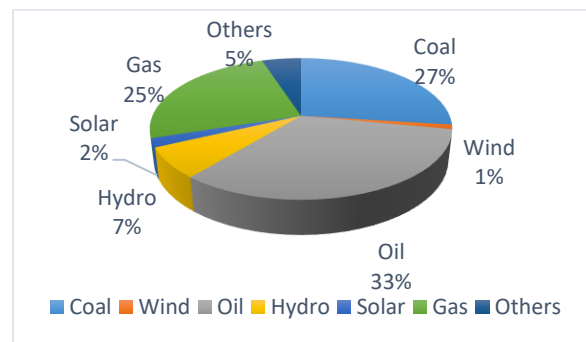


Figure 2: Sources of energy generation in Nigeria (Jäger-Waldau, 2020).

II. MODERN TECHNOLOGY OF RE AND CONTROL STRATEGIES

Developments in power electronics devices guarantee the quality of electricity and allow WECS and PV energy generation. To meet the demands of the wind energy sector in the future, however, more research on different kinds of electric generators such as double fed induction generator (DFIG) and permanent magnet synchronous generator (PMSG) is required (Dani et al., 2024). In order to provide mission-critical data on voltage, current, frequency, and phase in the grid, smart grids nowadays rely on Phase Measuring Units. PMU monitor the power system data in real time. Although wind energy is a known source of unpredictability, Static Synchronous Compensator (STATCOM) is also the best control system.

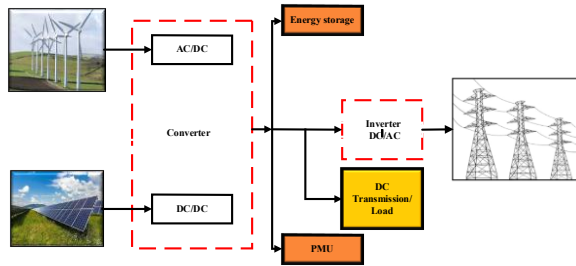


Figure 3: Schematic representation of integrated RE power plant

A. AI-Application in RE

AI approaches are used to analyze real-time data and optimize energy production, distribution, and consumption. Integrated Energy Management Systems estimate energy demand and supply, schedule generation and transmission activities, and balance load and generation in real time. The system can also incorporate customer preferences and demand response programs to enable more flexible and efficient energy consumption. Recently, researchers have focused on AI-based IEMS for improving the optimization process in SG, Virtual Power Plant. Moreover, IEMS has also been implemented in different systems, such as SBs, smart home, smart industry, and RES (Ukoba et al., 2024a).

AI can also be a key component in creating solutions that give underserved populations access to inexpensive, clean energy. Data-driven research and AI predictive modeling can also help the tidal and wave energy, as these renewable energy sources are frequently disregarded but have great potential (Bennagi et al., 2024). AI applications make it simple to identify system failures and offer real-time monitoring, the AI application explain in figure 4. the classification of AI-based methods and algorithms. Almost all RE systems, including hydro, wind, geothermal, solar, and ocean systems, as well as solar photovoltaic systems, have adopted smarter systems like artificial intelligence (AI) to make them more robust and responsive. As a result, RE-based technologies are becoming more sophisticated (Bennagi et al., 2024).

AI algorithms such as Artificial Neural Networks (ANN), Support Vector Machines (SVM), and Deep Reinforcement Learning (DRL) have been employed in hybrid energy systems for optimal energy dispatch, load forecasting, and fault detection. For instance, ANN models trained on solar irradiance and load demand data have achieved forecasting accuracies

above 95%, enabling real-time control through predictive modeling (Ukoba et al., 2024b).

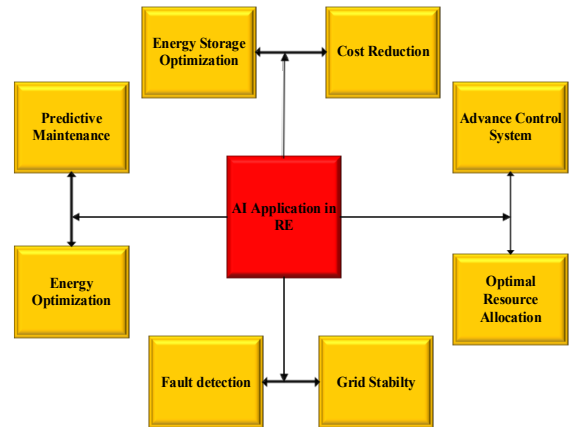


Figure 4: Application of AI in RE (Ukoba et al., 2024a)

B. PMU

High-speed sensors known as phasor measuring units detect the power system's voltage and current synchro phasors with an accuracy of one microsecond, (Appasani & Mohanta, 2019). Large numbers of PMU and the capacity to compare voltage phase angles at strategic grid locations could enable automated systems to transform power system management by quickly and dynamically reacting to system conditions (Appasani & Mohanta, 2019). Using the Global Positioning System (GPS), which has exact reference timing signals, PMU can attain accuracy and precision. The voltage and current phasors are measured in unison thanks to this timing. The use of PMU has grown quickly in order to enhance power grid monitoring. The number and placement of PMU must be optimized, because they are expensive devices. PMU can be deployed on specific buses utilizing optimization methods to make the system observable with the fewest possible PMU, as opposed to installing these devices on every bus to improve full observability in the power system (Sefid & Rihan, 2019).

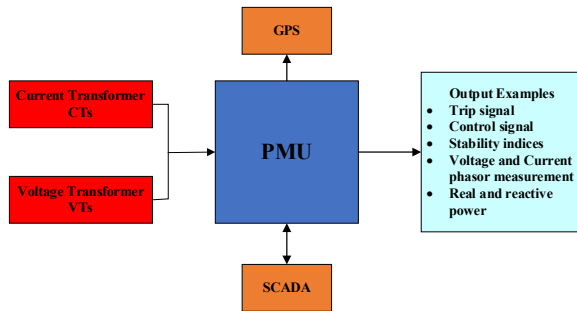


Figure 5: PMU technology (Samuelsson et al., n.d.)

C. Energy Storage System

ESS technologies, especially Lithium-ion batteries and Flywheels, help balance generation and load while enhancing grid stability and inertia (Rekioua, 2023b). In hybrid solar and wind systems, energy storage devices are essential for guaranteeing a steady power supply. During periods of strong production, they store excess energy, which they then release when output is low or demand is high. Advanced energy management systems and smart grid technologies provide smooth integration with the main grid, improving energy flow and stability (Nwagu et al., 2025).

1) Batteries Energy Storage Systems

Batteries generate a flow of electrons through a chemical reaction that can be used to power electrical loads such as electronic devices. Energy storage devices use several different kinds of batteries. The BESS are categorized according to life cycle, cost, efficiency, energy density, and technology (Rekioua, 2023b).

2) Flywheel Energy Storage (FES)

High-speed rotating flywheels composed of lightweight materials, such as carbon fiber, are used in Flywheel Energy Storage (FES) systems to store and release energy. They are perfect for uninterruptible power supplies and grid stabilization because of their extended lifespans, great efficiency, and quick reaction times. However, because they gradually lose energy over time, they are less appropriate for long-term storage (Rekioua, 2023b) and other ESS are studies in (Dunn et al., 2011; Elalfy et al., 2024).

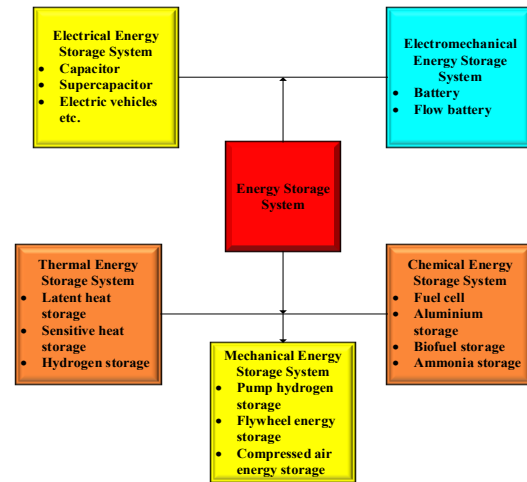


Figure 6: Types of ESS (Rekioua, 2023a)

III. FACTORS EFFECTING RE INTEGRATION

Because wind and solar PV power are intermittent and can cause grid instability, controlling frequency and voltage is essential for their successful integration into power grids. Robust control strategies are needed to maintain stable frequency and voltage, and the challenges associated with wind and PV integration are covered in detail in (Osman & Alsokhry, 2022)(Sanni et al., 2024). Although the mechanical functioning of wind turbine rotors is not directly impacted by PV integration, it can have an effect on how the wind turbines function within the larger energy generation and grid system. Grid stability, electricity quality, and both wind and PV system operational strategies are the primary areas of impact. Combining PV with wind energy can increase total system efficiency and reliability if these aspects are appropriately managed, but for seamless operation, sophisticated control systems and cautious grid management are needed (Wind/PV Integration Studies, 3rd Edition Task 14 PV in the 100% Renewable Energy System, n.d.).

The total system inertia is decreased when traditional synchronous generators are swapped out for renewable energy sources like wind and solar. The frequency response of the grid is weakened since solar PV has no inertia and wind turbines are connected through power converters. This decreased inertia speeds up frequency changes, increasing the grid's susceptibility to instabilities and causing load shedding even in the event of small disruptions. Frequency stability thus becomes essential to preserving grid resilience (Alam et al., 2023). Controller for the machine similar to 2-fuzzy cascade

It is possible to implement a PI fractional order controller (Sahu & Samantaray, 2023). The frequency deviation equation is given in equation (Sahu & Samantaray, 2023b).

$$J \frac{d\omega}{dt} = T_m - T_e \quad (1)$$

Convert torque to power P

$$P = T_{m,e} \times \omega \quad (2a)$$

multiply through by ω

$$J\omega \frac{d\omega}{dt} = P_m - P_e \quad (2b)$$

J is the moment of inertia in kg·m², ω is th angular velocity in rad/s, T_m is the mechanical torque in N·m and T_e is th electrical torque in N·m.

Using base power

$$\frac{J\omega^2}{s_b} \frac{d\omega}{dt} = (P_m - P_e)_{p.u} \quad (3)$$

$$2H \frac{\omega}{\omega_o^2} \frac{d\omega}{dt} = \Delta P_{p.u} \quad (4)$$

ω_o is the rated angular velocity

$$\frac{J\omega}{2\omega_o^2} = H \quad (5)$$

For small deviations around nominal frequency

$$\omega = 2\pi f \approx 2\pi f_o \quad (6a)$$

$$\frac{d\omega}{dt} \approx 2\pi \frac{df}{dt} \quad (6b)$$

put ω and $\frac{d\omega}{dt}$

$$2H \frac{2\pi f}{(2\pi f_o)^2} \times 2\pi \frac{df}{dt} = \Delta P_{p.u} \quad (7)$$

$$\frac{2H}{f_o} \frac{df}{dt} = \Delta P_{p.u} \quad (8)$$

For suitable imbalance ΔP and frequency stabilize at

$$\frac{df}{dt} = 0$$

$$\Delta f = \frac{\Delta P_{p.u} \times f_o}{\sum S} \quad (9)$$

$$\Delta f = \frac{\Delta P}{\sum S} \frac{f_o}{2H} \quad (10)$$

where, ΔP is the power imbalance between the generation and the load., $\sum S$ summation of apparent power, f is the system's nominal frequency., and H is the system inertia. The system frequency is inversely

proportional to the inertia, as the mathematical definition makes evident.

A. System Frequency Control

With or without supplementary devices, the frequency of high-level renewable energy integrated wind systems is primarily managed. A thorough description of frequency management with various auxiliary devices, such as flywheel energy storage, batteries, supercapacitors, unified power flow controllers, and superconducting magnetic energy storage (SMES), is given in this section.

B. System Voltage control

Voltage control, which is accomplished by methods like reactive power compensation (using devices like Static Var Compensators or SVC) and by controlling the DC-link voltage in the inverter, is essential for stable grid integration in a hybrid wind and PV system (Osman & Alsokhiry, 2022)

IV. CONTROL TECHNOLOGY/DEVICES IN PV AND WIND ENERGY INTEGRATION

In order to regulate unpredictability, guarantee stability, and maximize performance, wind and PV energy sources must be integrated into the power grid using sophisticated management methods and devices. Numerous tactics have been investigated in recent research to accomplish these goals (Osman & Alsokhiry, 2022)(Liang et al., 2024).

A. Power Management in Hybrid Systems

max power point tracking (MPPT) methods for hybrid solar-wind energy systems to maximize power generation. The goal of the project is to integrate the hybrid system with electrical grids and increase the efficiency of power extraction (Salman et al., 2025)

B. Energy Storage Coordination

synchronized control approach for solar energy storage power plants. The strategy is to extend the life of energy storage devices, guarantee steady operation, and improve the coordinated control impact (Salman et al., 2025)

V. CONTROL DEVICES TECHNOLOGIES

Artificial Neural Networks (ANN) Controlled STATCOM. New Advances in Machine Learning Technology. In order to address power quality issues in PV-wind power systems, a new study suggests an ANN-based Distribution Static Synchronous Compensator (DSTATCOM). This method improves

system stability and corrects harmonic distortions (Irfan et al., 2025), nonlinear controllers known as neuro-fuzzy controllers are renowned for their capacity to learn, adapt, and draw conclusions without the use of an exact system model. They are perfect for use in conjunction with traditional controllers because of their robustness, particularly in nonlinear systems with variable parameters and uncertainties (Sabo et al., 2020).

A. Phasor Measurement Units

PMU provide real-time monitoring of voltage and current phasors, aiding in the dynamic observation of the system and early detection of instabilities.

B. Energy Storage Systems

Incorporating ESS, such as batteries and supercapacitors, helps smooth power output, provide grid support, and improve rotor angle stability during disturbances.

VI. CONCLUSION

Combining solar and wind power is essential for moving toward a low-carbon energy future because it can significantly reduce greenhouse gas emissions and reliance on fossil fuels. Although there are difficulties because of their intrinsic variability, these problems are being lessened by developments in energy storage, control technologies, and AI-driven solutions. PMU provides energy storage, a steady power supply, real-time grid monitoring, and AI improves predictive modeling and system optimization. Despite ongoing institutional and infrastructure obstacles, Nigeria, with its wealth of renewable resources, is a prime example of the potential for the adoption of sustainable energy. In addition to increasing grid efficiency and stability, these technologies work together to achieve global energy sustainability goals. Overcoming current constraints and optimizing the advantages of integrating renewable energy requires sustained innovation and strategic execution.

VII. RECOMMENDATIONS

In order to expedite the shift to sustainable energy systems, governments and energy stakeholders should prioritize investments in large-scale energy storage solutions and smart grid technologies; implement policies that encourage the adoption of renewable energy through tax breaks and subsidies; encourage public-private partnerships to finance the development of infrastructure; support research into hybrid

renewable systems and AI-driven grid management; create training programs to increase technical capacity for maintaining modern energy systems; and create regulatory frameworks that make it easier to integrate distributed renewable resources while maintaining grid stability and reliability.

References

- International Energy Agency, I. (n.d.). *Electricity Market Report 2023*. www.iea.org
- Adeshina, M. A., Ogunleye, A. M., Suleiman, H. O., Yakub, A. O., Same, N. N., Suleiman, Z. A., & Huh, J. S. (2024). From Potential to Power: Advancing Nigeria's Energy Sector through Renewable Integration and Policy Reform. In *Sustainability (Switzerland)* (Vol. 16, Issue 20). Multidisciplinary Digital Publishing Institute (MDPI). <https://doi.org/10.3390/su16208803>
- Alam, M. S., Chowdhury, T. A., Dhar, A., Al-Ismael, F. S., Choudhury, M. S. H., Shafiullah, M., Hossain, M. I., Hossain, M. A., Ullah, A., & Rahman, S. M. (2023). Solar and Wind Energy Integrated System Frequency Control: A Critical Review on Recent Developments. In *Energies* (Vol. 16, Issue 2). MDPI. <https://doi.org/10.3390/en16020812>
- Al-Fatlawy, R. R., Subburam, S., Rai, A. K., Chavan, U. S., Jayadurga, R., Khairnar, Y., & Pragathi, B. (2024). Integration of PV and Wind Energy Systems: Strategies for Balancing Energy Supply and Demand. *E3S Web of Conferences*, 591. <https://doi.org/10.1051/e3sconf/202459107002>
- Ali, S. W., Sadiq, M., Terriche, Y., Naqvi, S. A. R., Hoang, L. Q. N., Mutarraf, M. U., Hassan, M. A., Yang, G., Su, C. L., & Guerrero, J. M. (2021). Offshore Wind Farm-Grid Integration: A Review on Infrastructure, Challenges, and Grid Solutions. In *IEEE Access* (Vol. 9, pp. 102811–102827). Institute of Electrical and Electronics Engineers Inc. <https://doi.org/10.1109/ACCESS.2021.3098705>
- Appasani, B., & Mohanta, D. K. (2019). Uncertainty analysis and risk assessment for effective

- decision-making using wide-area synchrophasor measurement system. *Decision Making Applications in Modern Power Systems*, 63–88. <https://doi.org/10.1016/B978-0-12-816445-7.00003-7>
- Bennagi, A., AlHousrya, O., Cotfas, D. T., & Cotfas, P. A. (2024). Comprehensive study of the artificial intelligence applied in renewable energy. *Energy Strategy Reviews*, 54, 101446. <https://doi.org/10.1016/J.ESR.2024.101446>
- Dani, A., Benlamlih, M., Mekrini, Z., El Mrabet, M., & Boulaala, M. (2024). Wind Energy Conversion Technologies and Control Strategies: A Review. In *International Journal of Renewable Energy Research* (Vol. 14, Issue 1, pp. 140–154). Gazi Universitesi. <https://doi.org/10.20508/IJRER.V14I1.14296.G8869>
- Dunn, B., Kamath, H., & Tarascon, J. M. (2011). Electrical energy storage for the grid: A battery of choices. *Science*, 334(6058), 928–935. <https://doi.org/10.1126/SCIENCE.1212741>
- Elalfy, D. A., Gouda, E., Kotb, M. F., Bureš, V., & Sedhom, B. E. (2024). Comprehensive review of energy storage systems technologies, objectives, challenges, and future trends. *Energy Strategy Reviews*, 54, 101482. <https://doi.org/10.1016/J.ESR.2024.101482>
- Irfan, M. M., Alharbi, M., & Basha, C. H. (2025). Artificial neural network controlled DSTATCOM for mitigating power quality concerns in solar PV and wind system. *Scientific Reports*, 15(1). <https://doi.org/10.1038/s41598-025-88540-0>
- Jäger-Waldau, A. (2020). The Untapped Area Potential for Photovoltaic Power in the European Union. *Clean Technologies*, 2(4), 440–446. <https://doi.org/10.3390/cleantechnol2040027>
- Liang, S., Sun, S., & Wang, F. (2024). Coordinated control strategy of photovoltaic energy storage power station based on adaptive dynamic programming. *Frontiers in Energy Research*, 12. <https://doi.org/10.3389/fenrg.2024.1419387>
- Meister, R., Yaïci, W., Moezzi, R., Gheibi, M., Hovi, K., & Annuk, A. (2025). *Evaluating the Balancing Properties of Wind and Solar PV Production*. <https://doi.org/10.20944/preprints202503.0691.v1>
- Nwagu, C. N., Ujah, C. O., Kallon, D. V. V., & Aigbodion, V. S. (2025). Integrating solar and wind energy into the electricity grid for improved power accessibility. *Unconventional Resources*, 5, 100129. <https://doi.org/10.1016/J.UNCRE.2024.100129>
- Osman, A. M., & Alsokhiry, F. (2022). Control design and performance evaluation of a grid connected PV–wind power system: A case study of Dongola, Sudan. *Energy Reports*, 8, 15629–15653. <https://doi.org/10.1016/J.EGYR.2022.11.145>
- Rekioua, D. (2023a). Energy Storage Systems for Photovoltaic and Wind Systems: A Review. In *Energies* (Vol. 16, Issue 9). MDPI. <https://doi.org/10.3390/en16093893>
- Rekioua, D. (2023b). Energy Storage Systems for Photovoltaic and Wind Systems: A Review. In *Energies* (Vol. 16, Issue 9). MDPI. <https://doi.org/10.3390/en16093893>
- Rekioua, D. (2023c). Energy Storage Systems for Photovoltaic and Wind Systems: A Review. In *Energies* (Vol. 16, Issue 9). MDPI. <https://doi.org/10.3390/en16093893>
- Sabo, A., Wahab, N. I. A., Othman, M. L., Jaffar, M. Z. A. M., Acikgoz, H., & Beiranvand, H. (2020). Application of neuro-fuzzy controller to replace smib and interconnected multi-machine power system stabilizers. *Sustainability (Switzerland)*, 12(22), 1–42. <https://doi.org/10.3390/su12229591>
- Sahu, P. C., & Samantaray, S. R. (2023a). Resilient frequency stability of a PV/wind penetrated complex power system with CSA tuned robust Type-2 fuzzy cascade PIF Controller. *Electric Power Systems Research*, 225, 109815. <https://doi.org/10.1016/J.EPSR.2023.109815>
- Sahu, P. C., & Samantaray, S. R. (2023b). Resilient frequency stability of a PV/wind penetrated complex power system with CSA tuned robust Type-2 fuzzy cascade PIF Controller. *Electric Power Systems Research*, 225, 109815. <https://doi.org/10.1016/J.EPSR.2023.109815>

- Salman, M., Kashif, S. A. R., Fakhar, M. S., Rasool, A., & Hussen, A. S. (2025). Optimizing power generation in a hybrid solar wind energy system using a DFIG-based control approach. *Scientific Reports*, 15(1). <https://doi.org/10.1038/s41598-025-95248-8>
- Samuelsson, O., Samuelsson, O., Jóhannsdóttir, H., Gustavsson, N., Karlsson, D., Kockott, M., Arve, J. S., & Abb, S. (n.d.). *Power system damping in Iceland based on phasor measurements*. <https://www.researchgate.net/publication/228915056>
- Sanni, S. O., Abdullateef, A. I., Mohammed, O. O., Aman, M. N., Raji, A. K., & Fajuke, I. D. (2024). Investigating the impact of solar PV and wind energy systems on the strength of a longitudinal power grid. *E-Prime - Advances in Electrical Engineering, Electronics and Energy*, 8, 100593. <https://doi.org/10.1016/J.PRIME.2024.100593>
- Sefid, M., & Rihan, M. (2019). Optimal PMU placement in a smart grid: An updated review. *International Journal of Smart Grid and Clean Energy*, 8(1), 59–69. <https://doi.org/10.12720/sgce.8.1.59-69>
- Ukoba, K., Olatunji, K. O., Adeoye, E., Jen, T. C., & Madyira, D. M. (2024a). Optimizing renewable energy systems through artificial intelligence: Review and future prospects. In *Energy and Environment*. SAGE Publications Inc. <https://doi.org/10.1177/0958305X241256293>
- Ukoba, K., Olatunji, K. O., Adeoye, E., Jen, T. C., & Madyira, D. M. (2024b). Optimizing renewable energy systems through artificial intelligence: Review and future prospects. In *Energy and Environment*. SAGE Publications Inc. <https://doi.org/10.1177/0958305X241256293>
- Wind/PV Integration Studies, 3rd Edition Task 14 PV in the 100% Renewable Energy System*. (n.d.).