Harnessing the Power of Renewables: A Review of Recent Developments in Solar and Wind Energy Technologies (2022-2023)

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Introduction

The global energy landscape has been undergoing a paradigm shift towards sustainable and environmentally friendly sources of power. Solar and wind energy, as leading renewable alternatives to traditional fossil fuels, have seen rapid advancements in both technological innovations and widespread implementation. The period between 2022 and 2023 has been particularly significant, marked by numerous breakthroughs in the domains of solar photovoltaics, wind turbines, and the incorporation of artificial intelligence (AI) to improve maintenance and functionality. This paper aims to provide a comprehensive summary of the most relevant and recent articles in these areas, shedding light on the current state of renewable energy technologies and their potential to reshape the future of energy generation.

We will explore cutting-edge developments in solar and wind energy, including advancements in efficiency, cost-effectiveness, and integration into existing power grids. Furthermore, we will delve into the emerging role of AI in optimizing the performance of these renewable energy systems, focusing on its applications in predictive maintenance, fault detection, and overall system management. By reviewing and synthesizing the latest research, we hope to provide a valuable resource for researchers, policymakers, and industry professionals working to accelerate the global transition towards a more sustainable and clean energy future.

AI and Dust Detection on Solar Panels - 1

This paper presents a deep belief network model to accurately monitor and predict dust accumulation on photovoltaic (PV) solar panels. Dust accumulation is a significant challenge for PV-based systems as it leads to a substantial reduction in energy production. Timely and effective cleaning of solar panels is essential, especially in regions with low wind velocity and rainfall.

The proposed model considers various input metrics, such as solar irradiance, temperature level, and dust level on the panels, to estimate the amount of dust in the atmosphere and determine appropriate cleaning intervals for the panels. This approach helps to reduce maintenance costs and optimize power output. The authors conducted simulations to test the efficacy of the model in cleaning the panels, evaluating the results in terms of accuracy, precision, recall, and F-measure.

The simulation results demonstrated that the proposed deep belief network model achieved a higher accuracy rate of more than 99% compared to other methods. Accurate forecasting of solar panel dust accumulation is vital for both investors and grid operators, as it directly impacts their bottom lines. Machine learning, specifically deep belief network models, has proven to be an effective approach for developing a dust detection system for PV panels.

Impact:
This paper presents a deep belief network model to accurately monitor and predict dust accumulation on PV solar panels, which helps optimize power output, reduce maintenance costs, and improve the bottom line for investors and grid operators. The proposed model achieved a high accuracy rate of over 99% in simulations, making it an effective dust detection system for PV panels using machine learning.

Using AI for Scaling Solar Power Systems - 2
This study investigates the application of artificial intelligence (AI) methods for scaling solar power systems, such as standalone, grid-connected, and hybrid photovoltaic (PV) systems, to minimize their environmental impact. The proposed AI model employs multilayered perceptrons for sizing solar systems, operating on current PV modules that integrate hybrid-sizing models. The objective is to enhance energy levels and improve PV panel capacity management using AI-based smart deep learning approaches.

The research emphasizes the importance of AI for PV system sizing, as AI techniques have proven to be effective in accurately sizing PV systems based on available data. AI-based solutions for PV system sizing are becoming increasingly popular, particularly in rural areas. AI can be employed as a design tool to assist in determining the proper size of solar PV systems, offering an alternative to conventional sizing methods when data is not available.

Impact:
The application of AI methods in scaling solar power systems is crucial for reducing their environmental impact and improving the efficiency of PV systems. Utilizing AI techniques for PV

system sizing achieves more accurate results, especially when conventional methods are unsuitable due to data unavailability. AI-based solutions are becoming an essential tool in the development and management of solar power systems.

Wind Energy and DFIG - 3

Wind energy conversion systems (WECS) use doubly-fed induction generators (DFIG) to efficiently convert wind energy into electricity. Control strategies for these systems are constantly evolving, seeking to optimize performance and efficiency, while addressing challenges like power fluctuations, grid stability, and harmonic content.

Several innovative control strategies have been proposed, such as the synergetic sliding mode controller (SSMC) for reducing active and reactive power ripples, modified Direct Power Control (DPC) for unbalanced power grids, and stator flux control for grid-forming mode operation. Other strategies focus on transient conditions to mitigate negative impacts on grid stability and improve fault-ride-through capability.

Efficient startup procedures, such as synchronization for low-impact connection to unbalanced grids, and robust estimation of flux and rotor position are also essential. Moreover, sensorless control schemes and condition monitoring are becoming increasingly important, with techniques such as unsupervised k-means clustering for fault detection and non-invasive monitoring for shaft misalignment detection.

Lastly, alternative generator designs, such as brushless doubly-fed induction machines (BDFIMs), eliminate the need for slip rings, reducing maintenance costs and outage times. However, these designs require more complex controllers for effective decoupling of control variables.

Impact:

These advancements in control strategies for DFIG-based WECS aim to enhance efficiency, performance, and grid stability, while addressing challenges like power fluctuations, transient conditions, and fault detection. These strategies are crucial for the widespread adoption and integration of wind energy into the grid.

Turbine Maintenance and Monitoring - 4

This editorial presents a selection of 10 papers in Energies, focusing on wind turbine condition monitoring. The papers are divided into three categories: wind fault detection and diagnosis, wind turbine condition monitoring, and wind turbine maintenance.

Wind fault detection and diagnosis include papers analyzing failures in wind turbine components such as bearings, pitch actuator systems, and gearboxes. Techniques like artificial neural networks (ANN) and interval observer theory are utilized for fault detection and diagnosis.

Wind turbine condition monitoring papers involve systematic literature reviews, comparative studies on anomaly detection techniques, and methodologies for predicting the remaining useful life of wind turbine components. The use of Supervisory Control and Data Acquisition (SCADA) data for wind turbine condition monitoring is emphasized for its economic benefits, eliminating the need for additional sensors or equipment.

Wind turbine maintenance papers aim to reduce the cost of wind turbine maintenance by developing new maintenance strategies. The studies focus on enhancing the prediction accuracy of the remaining useful life (RUL) of wind turbine components and reducing repair costs by employing algorithms for condition-based maintenance.

Impact:

The editorial highlights the ongoing research trends in wind turbine condition monitoring, fault diagnosis, and maintenance, emphasizing the importance of developing advanced methodologies and integrating multiple data sources for accurate and reliable predictions. Future research should address challenges in wind turbine condition monitoring and leverage machine learning and artificial intelligence techniques to improve the performance, extend the lifespan, and reduce downtime and maintenance costs of wind turbines.

AI and Turbine monitoring - 5

The global energy system is undergoing a significant change as renewable energy gains prominence in the pursuit of climate neutrality in Europe by 2050. Wind energy, in particular, plays a crucial role in achieving this goal, with the aim of representing 50% of the energy mix. However, the levelized cost of electricity (LCOE) is a primary obstacle to the growth of the wind industry. Operation and maintenance costs make up 20-30% of LCOE, making it essential to improve maintenance practices.

To enhance efficiency, the wind sector must transition from corrective and preventive maintenance to predictive maintenance. The editorial reviews ten highly cited articles on wind turbine condition monitoring (CM), focusing on the use of vibration signals, supervisory control and data acquisition (SCADA) data, and machine learning algorithms to detect and diagnose faults in wind turbines.

Research topics in this area include automatic input selection for failure prediction algorithms, developing normal behavior models to improve prediction performance, and employing anomaly detection techniques for identifying faults. These approaches utilize techniques such as principal component analysis, clustering, and long-short-term memory networks to enhance the accuracy and efficiency of condition monitoring.

Impact:

As the field progresses, wind turbine digital twins (DT) are expected to gain attention. These real-time representations of wind turbines allow for the prediction of future behavior and help improve maintenance practices. By combining physics-based and data-driven models, DTs can provide a comprehensive understanding of wind turbine performance and facilitate more effective predictive maintenance strategies.

Conclusion

In conclusion, the rapid advancements in solar and wind energy technologies observed between 2022 and 2023, coupled with the integration of artificial intelligence, signify a promising future for renewable energy sources. As the world faces the pressing need to mitigate the impacts of climate change and reduce greenhouse gas emissions, the development and adoption of green energy solutions become ever more critical. By investing in and promoting research and innovation in renewable energy technologies, we can ensure a more sustainable, cleaner, and secure energy future for all. Embracing the potential of solar and wind power, alongside other forms of renewable energy, will not only benefit the environment but also drive economic growth, job creation, and global cooperation in the pursuit of a greener tomorrow.

Sources:

1. Khilar, R., Suba, G. M., Kumar, T. S., Samson Isaac, J., Shinde, S. K., Ramya, S., Prabhu, V., & Erko, K. G. (2022, May 28). *Improving the efficiency of photovoltaic panels using machine learning approach*. International Journal of Photoenergy. Retrieved from https://www.hindawi.com/journals/ijp/2022/4921153/
2. Meena, R. S. (2022, September 17). Artificial Intelligence-Based Deep Learning Model for the Performance Enhancement of Photovoltaic Panels in Solar Energy Systems. https://proxy2.library.illinois.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=asn&AN=159173144
3. Dannier, A., Fedele, E., Spina, I., & Brando, G. (2022, September 1). *Doubly-fed induction generator (DFIG) in connected or weak grids for turbine-based wind energy conversion system*. MDPI. https://www.mdpi.com/1996-1073/15/17/6402
4. Leon-Medina, J. X., & Pozo, F. (2023, March 15). *Moving towards preventive maintenance in wind turbine structural control and Health Monitoring*. MDPI. https://www.mdpi.com/1996-1073/16/6/2730
5. Vidal, Y. (2023, February 7). *Artificial Intelligence for wind turbine condition monitoring*. MDPI. Retrieved from https://www.mdpi.com/1996-1073/16/4/1632