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Editorial

IoT-Based Technologies for Wind Energy Microgrids Management and Control

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1. Introduction

As the world continues to shift towards clean and renewable energy sources, wind energy has emerged as a promising alternative to traditional fossil fuels. Wind energy microgrids are an increasingly popular way to harness the power of the wind, but they require advanced control and management technology to operate effectively, and IoT-based technology provides several crucial benefits. One of the most significant benefits of IoT-based technology is its ability to promote sustainability. Wind energy microgrids powered by IoT-based technology provide clean and renewable energy, and thus help to reduce greenhouse gas emissions and mitigate the impact of climate change. In addition to promoting sustainability, IoT-based technology is essential for the continued growth and development of the renewable energy sector. As demand for clean energy sources continues to increase, the development of advanced control and management technology will be necessary to ensure that wind energy microgrids can operate effectively and efficiently. IoT-based technology can also improve the efficiency and reliability of wind energy microgrids. Real-time monitoring and control of the microgrid can help to minimize downtime and optimize the use of available resources, reducing operating costs and maintenance requirements. Furthermore, the data collected by IoT devices can be analyzed in order to identify trends and patterns, predict maintenance needs, and optimize the use of available resources. In conclusion, IoT-based control and management technology is essential for the effective and efficient operation of wind energy microgrids. By promoting sustainability, supporting the growth of the renewable energy sector, and improving the efficiency and reliability of these microgrids, IoT-based technology is helping to pave the way towards a cleaner, more sustainable future.

2. IoT-Based Technologies for Wind Energy Microgrids Management

Syed et al. [1] proposes a comprehensive management system for wind-powered microgrids using IoT-based technologies. The system collects real-time data from various sensors installed in the microgrid, including wind speed, power output, temperature, humidity, and battery status. This data are then transmitted to a cloud-based platform for storage and analysis, which enables the efficient and scalable management of large quantities of data. The collected data are then analyzed using advanced control algorithms and predictive analytics to accurately predict energy demand and supply. These algorithms adjust the microgrid's operation in real-time to maintain a balance between supply and demand, thus optimizing energy management and promoting sustainable energy usage. The use of predictive analytics also enables the system to anticipate changes in energy demand, allowing for the proactive management of the microgrid's operation. Moreover, the system ensures the reliability and safety of the microgrid by detecting and diagnosing faults in real-time. The system employs machine learning and artificial intelligence techniques to

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analyze the data and detect potential faults, allowing for immediate corrective action to be taken. If a fault arises, the system provides alerts and notifications to the operators, which enable the quick and effective management of the microgrid.

Pandiyan et al. [2] proposes a smart energy management system for wind energy microgrids using Internet of Things (IoT) technology. This system employs various sensors to collect real-time data regarding wind speed, power output, temperature, humidity, and battery status, which are then transmitted to a cloud-based platform for storage and analysis. The collected data are analyzed using machine learning and statistical analysis techniques in order to predict the demand and supply of energy, and to optimize the energy management of the microgrid. The system is designed to maintain a balance between energy supply and demand by adjusting the operation of the microgrid in real-time. Pandiyan et al. also discuss the use of a wireless sensor network (WSN) to monitor the performance of wind turbines in the microgrid. The WSN provides real-time data on the health and condition of the turbines, enabling the early detection and diagnosis of faults. The system sends alerts and notifications to the if a fault arises, thus enabling immediate corrective action. Moreover, the proposed system incorporates a user interface that allows operators to monitor the performance of the microgrid and control its operation remotely. The interface provides real-time information regarding energy consumption and production, as well as the status of the wind turbines and their batteries. The proposed system is expected to enhance the performance and lifespan of wind energy microgrids, while minimizing downtime and maximizing energy production.

Indeed, great minds think alike. Duraivel et al. [3] also proposed an energy management system to be applied in the microgrids of wind power systems using IoT technology. However, what sets Duraivel et al. apart is their emphasis on the significance of real-time fault detection and diagnosis, as well as the use of cloud computing in order to efficiently store and process data. The collected data are transmitted to a cloud-based platform, where they is stored and analyzed using advanced analytics and machine learning algorithms. This approach enables the real-time monitoring, analysis, and control of the microgrid, and enables more efficient energy management. Additionally, Duraivel et al. propose a hybrid energy management system that combines battery storage with a wind turbine in order to optimize energy management in microgrids. The battery storage capacity serves as a backup power source for the microgrid during times of low wind speed, and as a means of storing the excess energy generated by the wind turbines during high wind speed periods. The proposed system employs a control strategy that aims to maintain the battery's state of charge within a predetermined range, and simultaneously ensures that the energy demands of the microgrid are satisfied. By utilizing battery storage in conjunction with wind power, the system is able to improve the reliability and stability of the microgrid, and also reduce the overall cost of energy management.

The main innovation of Khan et al. [4] is the development of a smart IoT-based wind energy management system for microgrids. The system is composed of three main components: sensors, cloud computing, and control algorithms. The sensors measure various parameters such as wind speed, power output, temperature, and humidity, and transmit these data to the cloud computing platform. The cloud-based platform provides data storage, real-time analysis, and predictive maintenance capabilities. Compared to other management platforms, one of the primary innovations of the proposed system is application of the control algorithms employed in the system; this uses machine learning techniques to predict the energy demand and supply, and adjust the microgrid's operation accordingly. The algorithms are trained using historical data from the microgrid, which enables them to accurately predict the energy demand and supply for varying weather conditions and other external factors. The second innovative aspect of the proposed system is the use of big data analytics in order to optimize energy management. The system can analyze vast quantities of data generated by the microgrid, including historical energy consumption and production data, weather data, and other relevant data sources. This allows the system to identify patterns and trends in energy consumption and production, and thus make predictions about future energy demand and supply. Another innovative aspect of the proposed system is its ability to perform real-time fault detection and diagnosis. The system continuously monitors the microgrid for faults and anomalies, and provides alerts and notifications to operators if any issues arise. This enables operators to take immediate corrective action, which helps to prevent downtime and ensure the safety and reliability of the microgrid.

Reddy et al.'s [5] "IoT-Based Wind Farm and Microgrid Management Framework" emphasizes the advantageous application of artificial intelligence and machine learning in energy management systems. They propose a framework that consists of four main components: sensor networks, data collection and storage, data analysis, and decision-making. The sensor network is used to collect data from various sources, including wind turbines, solar panels, and energy storage systems, and then transmit them to a cloud-based platform for storage and analysis in order to enable predictive maintenance, fault detection, and energy forecasting. The system uses machine learning algorithms to predict wind speed and direction, which is crucial for optimizing the performance of wind turbines. In addition, a decision-making module is built, which utilizes the information provided by the data analysis component in order to make informed decisions about energy production and consumption, as well as to optimize the use of energy storage systems. On the other hand, Reddy et al. focus to a greater extent upon the integration of battery storage with wind turbines to optimize energy management. The paper proposes a hybrid energy management system that combines wind turbines with battery storage, and uses IoT technology for the real-time monitoring and control of microgrids.

Feng et al. [6] provide a detailed explanation of how the Internet of Things can be used to enhance the performance and control of renewable energy systems such as wind microgrids. The authors propose a hierarchical control structure for the wind microgrid, which consists of three layers: the physical layer, the control layer, and the application layer. The physical layer comprises the wind turbines, energy storage systems, and other components of the microgrid. The control layer consists of the controllers for each component, and the application layer comprises the overall control strategy for the microgrid. Furthermore, the authors implement a fuzzy logic controller to optimize the power output of the wind turbines and ensure the stability of the microgrid. This controller modulates the rotor speed of the turbines based on the prevailing wind speed and the desired power output. Furthermore, the authors incorporate a battery energy storage system in order to balance the power output of the turbines and enhance the microgrid's stability. To enable the real-time monitoring and control of the microgrid, the authors deploy a communication network by applying the MQTT protocol. This protocol facilitates lightweight communication between devices, even over unreliable network connections. Finally, the authors validate the efficacy of their approach through simulations and experiments, comparing their fuzzy logic controller with conventional control techniques. The results reveal that the authors' approach yields a greater power output and superior stability. Moreover, the authors showcase the efficacy of their communication network in facilitating the real-time monitoring and control of the microgrid.

3. IoT-Based Technologies for Wind Energy Microgrids Control

In order to efficiently and reliably manage wind energy microgrids via the detection and diagnosis of faults in real time, Dhar et al. [7] proposed the application of IoT technology in the real-time control and monitoring of wind turbine microgrids. The proposed architecture of the control system integrates wind turbines, power inverters, and sensors in order to collect data regarding various parameters, such as wind speed, power output, temperature, and humidity. These collected data are then analyzed in real-time using statistical analysis, machine learning, and artificial intelligence techniques in order to detect and diagnose any faults that might arise. This enables the efficient and effective management of the microgrid, thus minimizing downtime and optimizing the use of available resources. Dhar et al. emphasize the consequence of the continuous monitoring and control of wind energy microgrids so that their reliable operation is ensured. The application of cloud computing for data storage and processing is also adeptly discussed in the article, which allows for the efficient and scalable management of vast quantities of data. This is of great significance for IoT-based control systems in wind turbine microgrids as they require the ability to collect and analyze large volumes of data in real-time. Furthermore, the article notes that the integration of renewable energy sources and the optimization of energy management are vital components in the IoT-based control systems applied to wind turbine microgrids. To maintain the optimal balance between energy supply and demand, the article recommends utilizing advanced control algorithms that are capable of accurately predicting energy demand and adjusting energy supply accordingly. This process necessitates the employment of predictive analytics and machine learning techniques in order to analyze historical data that reflect energy consumption patterns, as well as real-time data on weather conditions and various other relevant factors. By utilizing this data-driven approach, wind energy microgrids are thus able to optimize energy management systems and ensure that energy supply meets energy demand in real-time, reducing the risk of energy shortages or waste.

Liu et al. [8] propose an optimal energy management strategy for a wind–photovoltaic–battery hybrid microgrid using an IoT-based control system. The microgrid comprises wind turbines, photovoltaic panels, and battery energy storage systems. The authors first develop the mathematical model of the microgrid, which includes wind turbines, photovoltaic panels, and a battery energy storage system, and formulate an optimization problem in order to minimize the operating cost of the microgrid while simultaneously satisfying various operational constraints; these constraints include the power balance, the battery state of charge, and limitations on the maximum and minimum power output of the wind turbines and photovoltaic panels. To solve the optimization problem in real-time, the authors utilize a model predictive control (MPC) approach, which predicts the future state of the microgrid based on its current state, and optimizes the control actions accordingly. The MPC algorithm considers the uncertainties that exist in generation of wind and solar power, and the energy consumption of the loads in the microgrid. To enable the IoT-based control of the microgrid, the authors use a communication network that is based on the MQTT protocol. They develop a software framework that integrates the microgrid model, the MPC algorithm, and the MQTT communication protocol, and implement it on a Raspberry Pi-based control platform. The MQTT protocol enables lightweight communication between devices and is able to operate over unreliable network connections, making it suitable for application in the IoT-based control of the microgrid. Overall, this article elucidates the potential of IoT-based control for optimizing the energy management of hybrid microgrids and provides a framework for integrating the microgrid model, the MPC algorithm, and the MQTT communication protocol for real-time control of the microgrid.

Zhang et al. [9] propose an energy management system (EMS) that utilizes IoT devices and technologies to monitor and control the energy flow in a wind microgrid. The proposed EMS consists of three main components: the sensor and actuator layer, the communication layer, and the control and optimization layer. The sensor and actuator layer of the EMS comprises various sensors and actuators that measure and control the physical parameters of the microgrid, such as the wind speed, temperature, and battery state of charge. The communication layer enables these devices to transmit data to each other and to the control and optimization layer by utilizing IoT technologies such as MQTT and ZigBee. The control and optimization layer is responsible for analyzing the data received from the sensor and actuator layer, and making control decisions that then optimize the energy flow. The authors propose a hierarchical control architecture that consists of three levels: local control, distributed control, and centralized control. Local control is responsible for controlling the individual devices within the microgrid, such as wind turbines and batteries. The distributed control coordinates the operation of multiple devices, controlling, for example, the charging and discharging of multiple batteries. Centralized control optimizes the overall operation of the microgrid, and takes into account factors that include the energy demand, energy supply, and storage capacity. In order to evaluate the performance of their proposed EMS, the authors conducted simulations by utilizing a model of a wind energy microgrid. Their results reveal that the EMS is, indeed, effectual in optimizing the energy flow and ensuring the stable and efficient operation of the microgrid.

Li et al. [10] focuse on the optimization of power management in a wind turbine microgrid using an IoT-based control system. Their objective is to improve the efficiency and stability of the microgrid system, while simultaneously ensuring that the generation and consumption of power are balanced. In order to achieve this objective, the authors present a detailed model of the wind turbine microgrid, which comprises the wind turbine generator, the battery energy storage system, and the loads used. The model considers the various factors that affect the generation and consumption of power, such as the weather conditions, energy demand, and battery state-of-charge. Based on this model, the authors propose an IoT-based control system that uses real-time data obtained from the microgrid components in order to optimize the power management system. The system incorporates a communication module that collects data from the microgrid components and transmits them to the cloud for analysis. The cloud-based analytics system then utilizes the data to optimize the power management capabilities of the microgrid. This involves the scheduling of power generation and storage, and the control of loads. The system uses a combination of machine learning algorithms and optimization techniques in order to determine the optimal power management strategy. Furthermore, the article also provides a detailed description of the implementation of the IoT-based control system and the outcomes of the simulation experiments. The simulation results show that the system can productively manage the generation and consumption of power in the wind turbine microgrid, leading to enhanced efficiency and stability.

Wu et al. [11] address the primary challenges encountered when optimizing the operation of a wind energy microgrid, which involves managing the intermittent and variable nature of wind energy sources. To address this challenge, the authors propose a control system that is based on the IoT technology. The proposed system consists of three main components: a sensor module, a control module, and a data transmission module. It also involves the application of a microcontroller in order to process and analyze the data collected from the sensor module, and the use of wireless communication protocols to transmit data between the different components of the system. Specifically, the authors used an Arduino microcontroller to process and analyze the data collected from the sensor module. The microcontroller was connected to the sensor module using a serial communication interface, and was programmed to collect and process data related to wind speed, temperature, and other relevant parameters. The authors also utilized wireless communication protocols to transmit data between the different components of the system. Specifically, they used ZigBee wireless communication technology to establish a wireless network between the different components of the system, including the wind turbine, battery energy storage system, and loads. This enabled real-time data to be transmitted between the different components of the system, thus facilitating the control system to optimize the operation of the microgrid in real-time.

Liu [12] Huang [13] Shi [14] et al. also propose using IoT technologies to control wind energy microgrid systems in order to enhance their efficiency and reliability. They also applied wireless communication protocols and cloud computing to optimize the power management of the microgrid. However, the specific details of the control systems used vary between the studies. Lu et al. propose a multiagent-based control system for wind turbine microgrids using IoT technologies. Their control system utilized a distributed architecture with multiple agents that could communicate and collaborate to optimize the operation of the microgrid. The agents included a wind turbine agent, a battery agent, a load agent, and a communication agent. The system also employed a centralized decision-making algorithm in order to coordinate the agents and ensure the efficient and reliable operation of the microgrid. Huang et al. present an IoT-based control system that can be applied to wind turbine generators in microgrids with energy storage systems. Their control system utilized a fuzzy logic controller to manage the power flow between the wind turbine generators and the energy storage systems. The system also employed a data-driven approach to predict wind power generation, which was used to optimize the operation of the microgrid and improve its efficiency and reliability. Shi et al. propose an IoT-based framework for the prediction and management of wind power in microgrids. Their control system utilized a deep learning algorithm to predict wind power generation based on historical data and weather conditions. The system also incorporated a control strategy that optimized the operation of the microgrid based on the predicted wind power generation. The control strategy involved adjusting the power output of the wind turbines and the energy storage systems in order to match the predicted wind power generation and maintain the stable and reliable operation of the microgrid.

Liang et al. [15] propound that wind power systems are expected to be a sustainable solution to satisfy the increasing demand for energy and alleviate the impact of greenhouse gas emissions. In order to enhance the durability of wind energy converters, this paper presents a new hybrid fault diagnosis method for wind energy converters based on multivariate empirical mode decomposition (MEMD), fuzzy entropy (FE), and an artificial fish swarm algorithm (AFSA)–support vector machine (SVM). According to the results, the diagnostic accuracy for 22 fault modes is 98.7% under varying wind speeds, and the average accuracy of 30 running generators can be maintained above 84% for varying noise levels. The maximum, minimum, average, and standard deviation are provided in order to prove the robust and stable performance of this study. Compared to various other methods, the proposed hybrid method exhibits excellent performance in terms of high accuracy, strong robustness, and computational efficiency. The method can thus be extended to fault diagnosis based on multi-source signals and can also be applied to other converter systems. This study only considers the impact of wind speed and noise on the wind power system, and it will thus be fascinating to study the applicability of more variable operating conditions.

4. Summary

The IoT plays a crucial role in the management and control of wind energy microgrids. By connecting various sensors and devices through the Internet, the IoT enables the real-time monitoring of energy production, consumption, and storage. This data can be productively analyzed to optimize the microgrid's performance, and to ensure that it operates efficiently and reliably. One crucial application of management and control systems in wind energy microgrids is in the use of intelligent algorithms for forecasting energy production. These algorithms use historical and real-time data to predict the quantity of energy that will be generated by the wind turbines, and can adjust the microgrid's operation accordingly. This is significant as it maximizes the use of renewable energy, and reduces reliance on traditional power sources. Another crucial component is the implementation of demand response strategies in order to manage energy consumption. This involves using IoT-connected devices to adjust energy consumption based on the availability of energy from the wind turbines. For example, during periods of high wind energy production, energy-intensive processes, such as charging electric vehicles or running industrial equipment, can be scheduled to take place. Conversely, during periods of low energy production, non-essential energy-consuming processes can be temporarily halted. The integration of energy storage systems is also crucial for the stable and reliable operation of wind energy microgrids. Energy storage systems, such as batteries or flywheels, can store excess energy generated by the wind turbines, and release it during periods of low energy production. This is beneficial to the balance of energy supply and demand, and to maintaining a stable energy supply. In addition, the use of blockchain technology is able to enhance the security and transparency of microgrid transactions. By creating a distributed ledger of energy transactions, blockchain technology can provide a secure and transparent platform for buying and selling renewable energy. This could incentivize the use of renewable energy, and be advantageous in the transition into a more sustainable energy system. Overall, the management and control of wind energy microgrids based on the IoT is a promising area of research and development, with the potential to transform the renewable energy industry and thus achieve a more sustainable future.

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