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Smart System Solutions in Wind Power Plants

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Abstract – Wind Power Plants (WPP) have great potential as environmentally friendly renewable energy sources. However, challenges in monitoring, fault detection, and performance optimization remain significant. This study presents a systematic literature review that investigates the implementation of intelligent systems incorporating Internet of Things (IoT), machine learning (ML), and artificial intelligence (AI) in WPP operations. A total of 40 relevant studies published between 2020–2025 were analyzed. The reviewed literature highlights that IoT-based monitoring systems can improve operational efficiency, while machine learning techniques demonstrate high fault prediction accuracy, with reported performance reaching up to 99.24% in prior studies. Optimization strategies such as Maximum Power Point Tracking (MPPT) and Fuzzy Logic Controller (FLC) also show potential in enhancing energy efficiency. Overall, this review confirms that smart systems significantly contribute to improving the reliability and sustainability of wind power generation. Further development and integration are required to address connectivity limitations and system complexity, especially in remote areas.

Keywords: smart system, WPP, machine learning, aritificial intelligence

I. Introduction

Renewable energy became a primary focus in efforts to meet the world's energy needs in a sustainable and environmentally friendly way. One of the renewable energy sources with significant potential was wind energy, which could generate electricity without carbon emissions and reduce dependence on fossil fuels [1]. Wind power plants (WPP) were increasingly built in various countries as part of the green energy transition strategy. However, the operation of wind power plants faced major challenges related to monitoring, detection, and performance optimization, which led to issues with mechanisms, currents, and the generated voltage, as well as wind speed [2][3]. he main cause observed in the field was that fluctuations in wind speed resulted in power predictions being off by 15–30% from the actual value [4].

With the advancement of technologies such as machine learning, the Internet of Things (IoT), and artificial intelligence, effective solutions were provided to address these challenges [5]. These technologies played a role in supporting wind power plants by enhancing monitoring responsiveness and accelerating disturbance handling, allowing the plants to operate optimally [6] [7] [8]. Artificial Intelligence technology played a role in predicting wind potential and the amount of electrical power generated, as well as detecting damage so that repairs could be carried out quickly. The Internet of Things connected various sensors that transmitted data in real-time, enabling effective remote monitoring and quick responses to disruptions in wind power plants. Machine Learning processed the collected data to identify hidden patterns that humans were unaware of, allowing the system to learn independently, improve prediction accuracy, and make automatic adjustments according to changes in wind conditions [5] [9] [10].

In the study conducted by Malar Jasmine et al. [11] the results showed that the cloud-based IoT system had a response time between 100 and 300 ms. This time indicated that the use of IoT in real-time monitoring could reduce response time to issues by up to 50% compared to conventional methods [6]. Meanwhile, in the research by Hasan, A., et al [12] the hybrid control system, which combined conventional control with AI techniques, proved to enhance efficiency, stability, and operational resilience of wind turbines, especially offshore turbines that faced more extreme environmental conditions, reaching over 25 m/s (90 km/h). Although smart system technology offered great potential in improving the efficiency and performance of wind power plants, implementation and integration challenges still needed to be addressed to maximize its benefits.

The purpose of this literature study was to examine the application of intelligent systems in the monitoring, optimization, and performance detection of wind power plants (WPP). This research was unique because it systematically reviewed the implementation of intelligent systems based on the Internet of Things (IoT) and artificial intelligence, which combined various technologies to enable real-time monitoring, early fault detection, and energy production optimization. In this way, it was expected that the study could offer solutions to these issues.

II. METHOD

This study uses a literature review method to collect and analyze research related to monitoring, detection, and optimization in wind power plants (WPP). The purpose of this approach is to identify, evaluate, and integrate research findings published in scientific journals. This study adopts a Systematic Literature Review (SLR) approach, as illustrated in Figure 1.

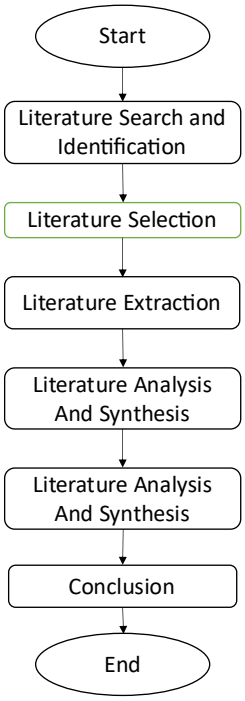

Figure 1. Stages of Systematic Literature Review

A. Literature Collection

The first step involves reviewing the literature to identify relevant articles and scientific journals. This process includes using databases such as ScienceDirect, IEEE Xplore, and Google Scholar. The keywords used in this research include "wind energy smart system", "IoT wind energy", "wind power plant optimization", and "wind power plant detection". The articles must meet the criteria set within the last five years (2020–2025) and be highly relevant to the topic of wind power plants, covering aspects such as maintenance, detection, and optimization. Only articles that meet these criteria are used for further analysis.

B. Literature Selection

The next step is the process of selecting literature based on predetermined criteria, including both inclusion and exclusion criteria. The selected articles must be published in either Indonesian or English and must have accreditation or an equivalent standard. In addition, the relevance of the articles to the topic of wind power generation must be highly significant. After the selection stage is completed, 20 articles that align with the research theme are obtained. The list of selected articles is presented in Table 1 as the main reference for the systematic literature review.

Table 1. The literature search results from scientific databases

No.	Database	Initial Number of Articles
1	Google Scholar	14
2	ScienceDirect	16
3	IEEE Xplore	10
Total		40

C. Literature Extraction

Data extraction in this study follows a structured approach to ensure that all relevant information from the selected articles is identified and thoroughly processed. Data is collected from each article with a focus on several key aspects, such as the type of technology used, the parameters analyzed, the methodology applied, and the results reported. This process begins by reading the full text of each article to ensure its relevance to the research topic. Each article is analyzed using a category-based method. Articles discussing smart systems for wind power plants (WPP) are grouped into three main categories: monitoring, detection, and optimization. The collected data is then organized into tables to facilitate comparative analysis. For example, in the monitoring category, information such as the type of sensors used (e.g., speed sensors, voltage-current sensors), data transmission methods (CoAP, LoRaWan, or Wi-Fi), and data storage platforms (cloud or local) is neatly recorded. Based on the search conducted, 40 articles are obtained. The categorization results are presented in Table 2, which shows the classification by category, and are visually summarized in Figure 2.

Table 2. Number of articles by category

No.	Category	Number of Articles
1	Monitoring	12
2	Detection	14
3	Optimization	14
Total		40

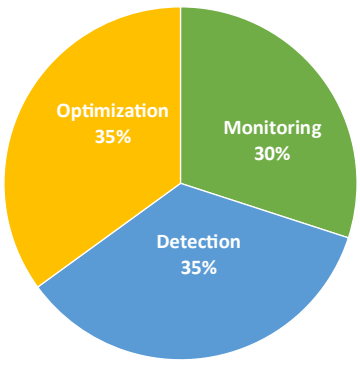

Figure 2. A pie chart that illustrates the distribution of research

D. Literature Synthesis

The next step in this research is to conduct an analysis and synthesis of the literature to identify patterns and trends emerging from various strategies applied in the use of wind power plant (WPP) technology in previous studies. The analysis process is carried out qualitatively by grouping findings based on the types of technologies and methods used. In addition, the effectiveness of each technological strategy is compared to assess its strengths and weaknesses. The main findings related to the implementation of smart systems in WPPs, which are divided into three categories monitoring, detection, and optimization are discussed in more detail in the results and discussion section. This process aims to provide a broader understanding of the technologies applied and to offer recommendations for future technological development. At the end of this study, conclusions and recommendations are presented based on the synthesis of the literature that has been conducted. The conclusions summarize the key findings related to the implementation of smart systems in WPP, which include technologies such as the Internet of Things (IoT), machine learning, and artificial intelligence (AI). In addition, this study also provides practical suggestions for more effective implementation of smart system technologies, particularly in supporting the management and optimization of WPP. This research aims to answer questions regarding the most effective strategies and methods for implementing smart systems in WPP. Therefore, this study is expected to make a significant contribution to the development of smart system technologies applied to WPP and to offer clear directions for future research.

III. Result and Discussion

In this literature review, a total of 40 articles related to the implementation of intelligent systems in Wind Power Plants (WPPs) are identified. These articles are then categorized into three main groups: monitoring, detection, and optimization, as illustrated in Figure 3.

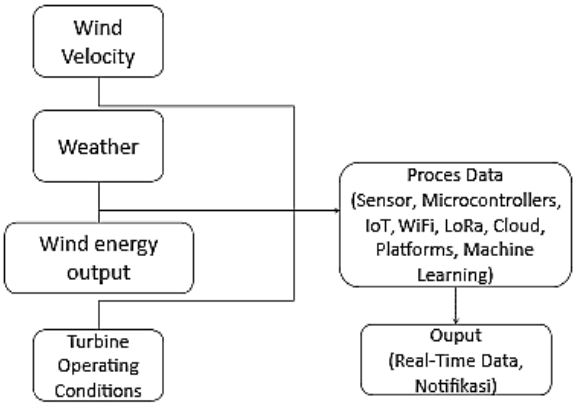

Figure 3. WPP smart system category

A. Monitoring Technology on WPP

Internet of Things (IoT) technology has been implemented in the monitoring system of Wind Power Plants (WPPs) to improve operational efficiency and effectiveness. Using IoT, the data generated by wind turbines can be collected and analyzed in real-time, allowing operators to unify system performance remotely. This process uses a variety of sensors mounted on the wind turbine to measure parameters such as wind speed, voltage, current, and power, weather and turbine conditions as shown in figure 4.

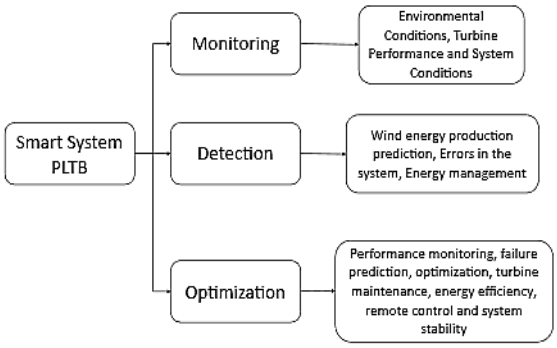

Figure 4. WPP Monitoring System Block Diagram

The importance of IoT in WPP lies in its ability to connect these sensors through Wi-Fi modules, which allows data to be transmitted wirelessly to a web-based or cloud-based platform. One of the microcontrollers that is often used in this system is the ESP32, which has the ability to process sensor data and send it over the internet to a monitoring system that can be accessed anytime and from anywhere. The monitoring technology in WPP will be described in Table 3 presenting a summary of the various applications of Internet of Things (IoT) technology in Wind Power Plants (WPP) based on a number of studies, which include advantages, challenges, and solutions applied in various operational scenarios.

By using this technology, the monitoring of WPP systems not only becomes more efficient, but also allows for faster detection of problems or damage to turbines. For example, a study conducted by Azhari, M., et al [2] if there are anomalies in the resulting data (such as inappropriate voltage or current), operators can immediately take action to prevent further damage. In addition, IoT technology also allows the use of machine learning algorithms to perform predictive maintenance and optimize the distribution of energy produced by wind turbines. Meanwhile, research conducted by Emoxidis, C., et al [15] The integration of machine learning significantly improves the ability to predict energy production with greater accuracy by using a random forest regression model provides the best results for predicting wind energy production, with better statistical performance.

Overall, the advantages of implementing IoT on WPP bring many benefits, from automatic data collection, remote monitoring, to more efficient maintenance, as well as more controlled and optimal performance improvements. This technology also

supports energy development renewable energy that is more sustainable and environmentally friendly by minimizing energy waste and extending the life of wind turbines. A study conducted by son, M, E., real-time monitoring can reduce response time to problems by up to 50% compared to conventional methods [6]. But the application of this technology overcomes some key challenges, especially in areas with limited network infrastructure. While technologies such as LoRa can be used to address these issues, their use is often hampered by limited transmission range and low data rates. On the other hand, the integration of various hardware requires sufficient technical expertise, which can be a barrier in remote locations or for inexperienced operators. In addition, environmental data such as wind speed, wind direction, and air pressure can also help detect degradation patterns in wind turbines, allowing preventive maintenance to be carried out in a timely manner. Overall, IoT-based monitoring technology provides a promising solution to overcome the limitations of conventional methods. However, the success of its implementation depends on these various factors.

Table 3. Application of PLTB Monitoring Technology

Yes	Monitoring	Monitored parameters	Sensor	Data Delivery	Data Storage
1	Environmental Conditions	Temperature, Wind Speed, Wind Direction, Humidity, Air Pressure	Esp 32, Temperature and Humidity Sensor: DHT11, DHT22, SHT31[13][14]. Wind Speed Sensor: Cup Anemometer, Vane Anemometer [15], Ultrasonic Anemometer [16], Hot-wire Anemometer, Wind direction sensor: wind vane, hall effect, Raspberry Pi 3B+ Air pressure sensor: BMP180, BMP280, BME280[17],	WiFi, Blockchain[18]	
2	Turbine Performance	Current, Voltage, Vibration Power, rotational speed,	Current Sensor: INS219, ACS712 [21], Voltage Sensor: ZMPT101B [6], Vibration Sensor: accelerometer, piezoelectric [20], Rotational speed sensor: IR LM393, Optical, Hall effect, optical endcoder [22]	WiFi, BLE	*Cloud* [19], Website open source (Blnyk)[2], *MicroSD* [20],
'3	System Conditions	Angle of movement, power factor, payout value, system condition, Inverter Productivity, Characteristics Current-Voltage Curve	Yaw angle sensor [15], ACS712, ZMPT101B [6] [23],	WiFi, LoraWan	

B. Detection Technology for WPP Systems

The detection technology applied to WPP is a very important aspect to prevent damage. The use of deep learning architecture in detecting and predicting wind turbine damage has an accuracy of more than 95% [10]. In addition, the research conducted by Abdel, A., et al [1] using the ARMA-LSTM model has an accuracy rate of 99.24%, the model shows significant potential in improving the operational efficiency of WPP. The application of detection and prediction technology in the WPP system plays an important role in optimizing use of wind energy. With an intelligent monitoring system, operators can make automatic adjustments to WPP's operating system, which can reduce downtime and improve energy production efficiency. In addition, precise predictions also help in more efficient energy management, especially when combined with energy storage or synchronized with the power grid to maintain a stable energy supply. Table 4 presents a summary of findings from various studies on the application of detection and prediction technology in the WPP system. Based on Table 4, methods have been applied for detection in wind power generation systems, in energy production prediction, faults in WPP systems and energy

management. In predicting electrical energy production by detecting wind speed and direction using the Weater Research and Forecasting (WRF) method, it can provide estimates of short-term weather conditions that can warn of extreme weather. In addition, temperature and humidity detection using the Generative Adversial Network (GANs) method can be used to produce synthetic weather data, improving uncertainty in forecasting or analyzing weather disturbances. In animal detection to reduce bird or animal collisions when crossing turbines using Convolutional Neural Networks (CNN) and R-Shiny-based Interactive, the accuracy obtained reached 80-90%.

In fault detection on WPP systems, algorithms such as Support Vector Machine (SVM), Convolutional Neural Networks (CNN), and Long Short-Term Memory (LSTM) are used to identify damage caused by weather factors and other potential system damages. This method serves to analyze data in real-time, recognize abnormal patterns, and mendeteksi anomali that may happen to wind turbines. SVM and LSTM can be used for damage classification based on sensor data, CNN serves to recognize features related to damage to turbine components, while LSTM, with its ability to process data time sequences, is highly effective in predicting damage that may occur based on weather patterns or previous operational conditions. Overall, the use of this algorithm allows for early detection and preventive maintenance, thereby reducing the risk of greater damage and improving the operational efficiency of wind turbines.

Various algorithms such as WRF, LSTM, GANs, CNN, SVM, ARMA, and Random Forest Regression are used to improve prediction and detection in WPP systems, each of which has advantages in handling weather data, turbine breakdowns, as well as system performance optimization. WRF excels in weather prediction, LSTM and CNN are effective for time data and images, while SVM and ARMA are better suited for structured data analysis and time series. GANs are useful for data synthesis and training augmentation, while random forest regression offers resistance to overfitting and ease of processing big data. Nonetheless, challenges such as high computing requirements, risk of overfitting, and reliance on representative data need to be taken into account to ensure the successful implementation of these algorithms in real-world applications.

Table 4. Applications Related to Detection Technology in WPP

No	Predictions	Detection	Method
1	Wind energy production prediction	Wind speed and direction	Weater Research and Forecasting (WRF) Convolutional Neural Network (CNN) [24] [7]
		Temperature and humidity	Long Short_Term Memory (LSTM) dan Gated Recurrent Unit (GRU) dengan Particle Swarm Optimization (PSO) dan Bayesian Model Averaging (BMA)[25] [1]
		Weather conditions	Generative Adversial Network (GANs), Linear Regression (LR), Back Propagation Neural Networks (BPNN), Support Vector Regression (SVR), dan Reduced-Error Pruning Tree (REPTREE) [26] [7]
		Animal	Convolutional Neural Networks (CNN), R-Shiny-based Interactive[8] [27]
2	Errors in the system	Acceleration error	Support Vector Machine (SVM) dan Long Short-Term Memory (LSTM)[28] [29]
		Turbine operational sound	Convolutional Neural Networks (CNN) dan Long Short-Term Memory (LSTM) [30][31]
3	Energy Management	Power production	Autoregressive Moving Average (ARMA) dan Long Short-Term Memory (LST M) [1][32]
		Wind Energy	Random Forest Regression dan Genetic Algorithm (GA) - Backpropagation Neural Network (BP) [15][33]
		Power prediction	Autoregressive (AR) dan Support Vector Regression (SVR) [7] [34]

C. Optimization Technology for WPP systems

The technology optimization applied includes various technical methods and algorithms developed to improve the performance of wind turbines, so that WPP can generate maximum power, even in changing conditions. This approach aims to ensure that the energy generated by wind turbines can be harnessed efficiently under a variety of operational conditions.

The optimization method that is often used is Maximum Power Point Tracking (MPPT). The technology uses a combination of Fuzzy Logic Controller (FLC) algorithms that are able to produce an efficiency of 87% of the initial operating system of

45.5%, this improvement means that the bsyu turbine system can extract almost twice as much power useful in various wind conditions compared to the initial conditions [35]. This method is designed to optimize the efficiency of the plant in changing wind conditions. In addition, intelligent control approaches such as AI and hybrid techniques such as fuzzy logic-based control and artificial neural networks (ANN) function to overcome uncertainty and non-linear dynamics in wind turbines, other approaches combine conventional control with metaheuristic particle swarm optimization techniques and Genetic Algorithm (GA), useful for optimizing pitch angle contortions in wind turbines [12].

In grid connected WPP systems, optimization not only focuses on improving wind turbine efficiency, but also includes smarter energy management. WPP can operate in synergy with energy storage systems, such as batteries, to store excess energy when energy production peaks, and release it when energy demand increases. This approach not only reduces dependence on conventional energy, but also helps to maintain the stability of the power grid. Table 5 presents a summary of the various optimization technologies that have been applied to the WPP system according to the latest studies and research.

Based on table 5, optimization aspects in wind energy systems include load supply control, wind direction, energy efficiency, distribution energy optimization, optimal location selection, short-term turbine power prediction, wind turbine system size optimization and increased energy system stability with Critical Clearing Time (CCT) [36]. The use of wind vane technology, IoT microcontrollers, and MPPT algorithms combined with the Fuzzy Logic Controller (FLC) algorithm has shown Outstanding performance in optimizing wind turbine turnover. This method allows the turbine to automatically adjust the direction according to the direction of the wind, ensuring the turbine is operating at its maximum capacity. While these systems can significantly improve efficiency, they also have high mechanical complexity and require a large initial investment, especially if applied on a large scale.

The efficiency of the wind power plant can be improved by monitoring parameters such as wind direction, wind speed, and ambient temperature using ESP32. This solution provides a more cost effective alternative to improve wind turbine performance, especially on small to medium scales. for energy distribution, load supply control is optimized using the Pulse Wide Modulation (PWM) method combined with Real Time Clock (RTC), as well as Pitch Control.

Table 5. Research Related to Optimization in WPP

Aspects	Conventional Methods	*Smart system* (*IoT* dan *Machine learning)*	Increased Effectiveness (%)
Performance Monitoring	Manual, not real-time	Real-time *monitoring* via *IoT*	95% (monitoring efficiency level)
Damage Prediction	Manual and offline inspection	Machine learning-based predictions (*CNN* and *LSTM)*	99.24 % (higher prediction accuracy)
Energy Optimization	Static turbine position, limited efficiency	Intelligent pitch control angle, wind direction and wind pressure determination	50% (increased efficiency)
Turbine maintenance	Inefficient manual inspection	Automatic detection and prediction of damage	99% (accuracy of diagnosis)
Energy Efficiency	Depends on the position of the turbine	Optimize output power with *MPPT, IoT* monitoring	87% (increased energy efficiency)
Remote Control	Not Available	Remotely controlled looting via the user's device	100% (remote control effectiveness)
Distribution System Stability	High current and power fluctuations	Stability using Critical Clearing Time (CCT)	Response time 0.28 seconds

This technology offers high efficiency in load management and power distribution, although electromagnetic interference-related challenges that can affect other devices in the network still require appropriate technical solutions.

Energy distribution optimization spreads out aspects of energy use, initial model, and wind energy value by using pitch control. This method allows for more adaptive and efficient energy management, but relies heavily on the stability of the internet connection to support the integration of smart technologies in real-time. In the selection of the optimal location for the installation or installation of wind power plants, CFD (Computional Fluid Dynamics, GIS (Geographic Information Systems), AMDAL (Environmental Impact Analysis) and Multi-Criteria Decision Analysis (MCDA) methods are used. This approach takes into account various factors such as site selection, potential disruption to ecosystems, wind speed, weather conditions, and land costs to ensure the selection of sites with optimal energy production potential. However, its implementation requires high technical skills as well as accurate and thorough data.

Short-term WPP power prediction was conducted using the hybrid ARMA-LSTM model method showing significant potential in improving the operational efficiency of wind turbines. Extensive testing validates the efficacy of the system in providing precise power estimates. However, this

model requires large data sets and significant delivery capacity, which is a challenge in areas with limited technological infrastructure. The optimization of the size of the WPP and Electric Vehicle (EV) systems is carried out through a smart charging scheme that considers energy consumption patterns, self consumption, and self sufficiency to maximize renewable energy efficiency.

Controlling the battery energy storage system (BESS) is an important aspect to maintain the stability of the power grid, especially in grid-connected systems. By analyzing parameters such as feeder current, active and reactive power, and state of charge (SoC), BESS can efficiently manage energy storage and distribution. This technology allows for the storage of excess energy when production is high and its use when demand increases. However, the main challenges of this technology are the high implementation costs, long-term battery degradation, as well as the need for complex management tools. [37][38]

Each method offers specific solutions to address challenges in renewable energy management, but its advantages are offset by technical and economic challenges that need to be addressed. With further development, particularly in lowering implementation costs, improving the quality of technology, and ensuring adaptation to specific conditions, these technologies can make a significant contribution in supporting the transition to sustainable renewable energy.

D. Comparison of the Effectiveness of Using Smart Systems and Conventional Methods

The use of smart systems in energy management, such as WPP, has a number of advantages compared to traditional methods. Intelligent systems utilize technologies such as the Internet of Things (IoT), machine learning-based prediction algorithms, and automated control systems that can improve system performance directly. On the other hand, traditional methods of energy management rely more on manual controls, systems that tend to be more static, and limited monitoring, which can lead to energy wastage or sub optimal performance.

One of the key differences lies in performance monitoring. Conventional methods, which rely on manual inspections and monitoring that are not carried out in real-time, are often late in detecting degradation in performance or damage to solar panels. Instead, IoT-based intelligent systems enable real-time monitoring through cloud platforms, allowing WPP managers to immediately detect issues and take action faster. Monitoring efficiency increases by up to 95% with intelligent systems, thanks to continuous data collection and the ability to analyze data automatically, providing a significant advantage over manual monitoring which takes longer and often relies on limited forecasts or inspections. The comparison can be seen in table 6.

Damage prediction shows advantages by using machine learning algorithms such as the hybrid Convolutional Neural Networks (CNN) and Long Short-Term Memory (LSTM) methods used by smart systems with higher accuracy compared to conventional methods that rely only on physical inspection and estimates based on experience. Smart systems improve accuracy by 99.24% compared to conventional methods that are usually not able to provide the same accuracy in detecting damage.

Wind turbine maintenance is an important aspect to ensure optimal performance and efficiency. Sensor based systems and algorithms detect anomalies automatically, detecting malfunctions faster than conventional methods. The use of smart systems can increase efficiency by 99%, so that maintenance can be carried out on time, reduce downtime and extend the life of wind turbines. This smart technology not only improves WPP's long-term performance, but also helps lower operational costs, extend system life, and reduce dependence on fossil energy.

Table 6. Comparison of conventional methods and smart systems

Aspects	Conventional Methods	*Smart system* (*IoT* dan *Machine learning)*	Increased Effectiveness (%)
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E. Optimization of the use of smart systems in WPP based on operational conditions

The optimization of the use of smart systems in wind power plants can be adjusted to certain operational conditions to optimize system performance. These systems, which combine technologies such as the Internet of Things (IoT), artificial intelligence (AI), and machine learning (ML), allow for more accurate operational adjustments based on changing environmental conditions and specific characteristics. Based on the results of this study, the use of smart systems offers a more efficient solution in managing extreme conditions and Variables affect wind energy production, such as weather, wind speed, temperature fluctuations, turbulent winds and environmental temperature conditions.

In areas with wind speed fluctuations, such as valley, coastal and tropical areas, IoT technology equipped with sensors, such as temperature sensors, wind speed sensors, wind pressure sensors, is essential to monitor and adjust the performance of wind turbines. By utilizing real-time data obtained from sensors, smart systems can dynamically adjust operational conditions to optimize the energy efficiency produced. For example, when high temperatures occur, the system can change the operating parameters of the panel to prevent overheating and decreased efficiency. The system also uses machine learning algorithms to predict potential performance degradations in the future, providing an opportunity to perform preventive maintenance or operational adjustments before problems develop.

In areas with rapid weather changes, such as highlands or tropical regions, the application of Maximum Power Point Tracking (MPPT) technology is very important in Wind Power Plants (WPPs). MPPT allows wind turbines to operate at maximum power points even when wind conditions change rapidly, by adjusting power settings based on changing wind speeds and directions. This system can maximize energy production when winds are strong and store excess energy for use when the wind subsides, thus improving the stability and efficiency of the system. In addition, MPPT helps reduce dependence on fossil energy by harnessing the full potential of wind energy.[39][40]

The application of smart systems in WPPs, which are tailored to specific operational conditions, provides greater benefits in renewable energy management. With its ability to adapt to wind variability and weather conditions, intelligent systems improve operational efficiency over conventional systems. The use of intelligent sensors, machine learning, and integrated communication technologies not only improves energy efficiency, but also reduces operational costs and maximizes the potential of renewable energy in the long run. Therefore, further development to integrate smart systems with conditions is critical to maximise the benefits of WPP and support the global transition to more sustainable energy.

The use of smart systems in WPP systems that are directly connected to the power grid is very important to maintain the sustainability and effectiveness of the system. The integration of BESS aims to maintain the stability of energy supply in the event of low wind speeds or rainy weather. In addition, the application of the Critical Clearing Time (CCT) algorithm serves to overcome disturbances in the system and maintain stability, even if there is a short relationship. In remote areas with limited internet access, such as in mountains or small islands, the deployment of smart systems is still possible by utilizing solutions such as local data storage via microSD or using communication networks to transmit data such as LoRaWAN. Although connectivity limitations are a challenge, local storage allows for the collection and processing of data for further analysis without the need for a stable internet connection. In this way, the system can remain operating optimally even in locations with limited access, while optimizing energy production without relying on a constantly available internet connection.

The application of smart systems in WPP based on specific operational conditions provides more flexibility in managing this renewable energy source. With high adaptability to wind variability, such as wind speed, wind direction, and air pressure, the intelligent system allows for greater operational efficiency compared to conventional systems. The use of intelligent sensors, machine learning, and integrated communication technology not only improves energy efficiency, but also reduces operational costs and maximizes the potential of renewable energy in the long run. Therefore, further development in integrating smart systems with local conditions is essential to maximise the benefits of WPP and support the global transition towards more sustainable energy.

V. Conclusion

The application of intelligent systems in Wind Power Plants (WPPs), which combines Internet of Things (IoT) technology and machine learning, can improve operational efficiency and detect faults faster than conventional systems. This intelligent system enables real-time monitoring, early detection of faults, and better optimization of energy production, even in changing environmental conditions. In this systematic literature review, the use of IoT technology with intelligent sensors such as wind speed, temperature, and air pressure sensors allows for more efficient monitoring and rapid response to disturbances, thereby improving the performance and lifespan of wind turbines. Machine learning-based detection technologies, such as Convolutional Neural Networks (CNN) and Long Short-Term Memory (LSTM), It has high accuracy in detecting errors and preventing further damage. In addition, the optimization system

applied through the Maximum Power Point Tracking (MPPT) method and intelligent controls such as the Fuzzy Logic Controller (FLC) improves the energy efficiency generated by wind turbines. The use of intelligent systems also facilitates remote control and integration with energy storage systems (BESS), which ensures the stability of energy supply despite fluctuations in wind speed. However, challenges in the implementation of this technology, such as the limitations of network infrastructure in remote areas, need to be overcome to maximize its benefits. Further development in these technologies can help improve the sustainability and efficiency of renewable energy, supporting the global transition to cleaner and greener energy.

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