Pakistan Journal of Engineering and Technology
ISSN (Print): 2664-2042; ISSN (Online): 2664-2050
Received: 2023-06-16
Accepted: 2023-09-01
https://doi.org/10.51846/vol6iss3pp8-15

PAKJET
Pakistan Journal of Engineering & Technology

Review

A Review of Real-Time Monitoring of Hybrid Energy Systems by Using Artificial Intelligence and IoT

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Abstract: This research focuses on the invention of real-time monitoring of hybrid energy systems using artificial intelligence (AI) and the Internet of Things (IoT). The study aims to develop a monitoring system that provides real-time insights, anomaly detection, fault diagnosis, and energy optimization. The research methodology involves the integration of AI algorithms and IoT devices to collect, analyze, and visualize system data. The results demonstrate the effectiveness of the developed monitoring system in improving system performance, sustainability, and cost savings. The practical implementation and scalability of the system are also addressed, along with future research opportunities. This research contributes to the advancement of monitoring systems for hybrid energy applications, promoting efficiency and sustainability in energy management. This research provides significant contributions to the field of real-time monitoring of hybrid energy systems. The article focuses on addressing key problems related to the real-time monitoring of hybrid energy systems using AI and IoT technologies. The lack of real-time insights provided by conventional methods also limits timely decision-making and responsiveness to dynamic changes in the system.

Keywords: Real-Time Monitoring, Hybrid Energy System, Artificial Intelligence, Internet of Things

1. Introduction

Hybrid energy systems integrate multiple energy sources and storage technologies and its efficient monitoring is crucial for optimal performance [1]. The integration of AI and IoT offers real-time data analysis, anomaly detection, and control capabilities [2]. AI algorithms analyze data for insights, while IoT devices enable seamless data collection and communication [3]. This integration enhances monitoring, improves efficiency, and enables adaptive control strategies in hybrid energy systems. Addressing these research problems will contribute to the advancement of real-time monitoring techniques, enhancing the efficiency, reliability, and overall performance of hybrid energy systems. It focuses on enhancing anomaly detection, optimizing energy generation and storage, enabling adaptive control and predictive maintenance [4]. The existing research on real-time monitoring of hybrid energy systems using AI and IoT technologies explores real-time monitoring techniques, the application of AI in energy systems, the role of IoT in energy monitoring, and the integration of AI and IoT for monitoring [5]. This framework provides the theoretical lens for analyzing and interpreting the research findings in the context of real-time monitoring of hybrid energy systems [6].

The demand for electricity generation is rising quickly in emerging nations such as Pakistan, involving the economic sector has experienced phenomenal expansion throughout the past decades [7]. In the Islamic Republic of Pakistan, electricity production is currently inadequate, and the circumstance keeps getting worse. The traditional Renewable energy techniques like thermal power plants, hydroelectric power plants, and nuclear power plants cannot provide the enormous requirement for energy [8]. Pakistan experienced significant energy difficulties throughout the course of the year [9]. Despite the fact that the crisis root caused in the year 2006, At present, the discrepancy that exists between production and consumption is realized in a massive range, between 4800 and 7000 MW, and Up to 20 hours a day were lost due to electricity shortages. Notwithstanding the price of petroleum swings and its all-time high of $104 per barrel in 2008, which sent the energy industry towards an extensive recession, around 38.5% of the world's electrical power remains generated from oil. It indicates that electricity production is costly and largely reliant on crude oil prices. Additionally, it raises oil tariffs, which somewhat already account for 40% of all imports into the nation [10]. Momentary hydroelectric [11] and thermal energy production account for around 30.7% and 64.2% of the total production of electricity, compared to 54% and 46%, to be exact, in 1990. Additionally, Pakistan's consumption of energy is unexpectedly much higher than the newly industrialized nations of its neighbors. The solution might be found in alternatives of renewable power including wind and solar power. These power-producing techniques are long-term cost-effective and environmentally. Almost ninety percent of Pakistan's entire surface area has global horizontal irradiance (GHI) values that are par or above, making the southwest region of the nation ranked among the finest regions in the entire globe for sun illumination. Over the past ten years, renewable energy from the wind has grown significantly [12]. For the purpose of the production of electrical power, it is currently the second-most significant renewable energy source in the world. The integration of AI and IoT offers real-time data analysis, anomaly detection, and control capabilities. AI algorithms analyze data for insights, while IoT devices enable seamless data collection and communication. This integration enhances monitoring, improves efficiency, and enables adaptive control strategies in hybrid energy systems.

This research adds to the body of knowledge by providing the first comprehensive review of the application and impact of AI and IoT-based real-time monitoring in hybrid energy systems. The study investigates the potential of artificial intelligence algorithms to analyze and make decisions based on information gathered from a wide range of energy sources, including solar panels, wind turbines, batteries, and grid connections. We highlight real-world applications of AI-driven, continuous monitoring to improve productivity, reduce downtime, and maximize resource utilization through anomaly detection, predictive maintenance, and energy management. The review also discusses the scalability and grid integration of this technology, as well as its potential to hasten the transition to a more sustainable and ecologically friendly energy landscape. This paper synthesizes existing research and case studies to demonstrate how the integration of AI and IoT paves the way for the creation of resilient and environmentally conscious energy systems for a greener tomorrow

2. Literature Review

2.1. The Role of IoT in Real-Time Monitoring:

The collection and use of data for real-time monitoring has been drastically altered by the incorporation of IoT devices in hybrid energy systems. Throughout the hybrid energy architecture, IoT devices with sensors and communication capabilities are strategically placed to collect data from various sources, such as solar panels, wind turbines, batteries, and grid connections. These gadgets serve as information hubs, constantly gathering and relaying data such as energy production, storage capacity, grid voltage, and weather conditions. In order to better understand the dynamics of the system and make educated decisions and proactive responses to fluctuations in energy supply and demand, IoT-enabled data gathering is essential.

Several studies have shown that IoT devices are superior to traditional methods of data collection for gathering specifics about various energy sources. [13] study provided an example of the effective use of Internet of Things-enabled sensors in a hybrid microgrid, demonstrating how such gadgets successfully tracked parameters like solar irradiance, wind speed, battery life, and power usage. Similarly, [14] study investigated the use of IoT-based smart metres to measure residential energy consumption in a hybrid energy configuration, empowering individuals to monitor their energy consumption in real time and make educated decisions about how to reduce their carbon footprint.

Monitoring via the Internet of Things has various benefits that boost the effectiveness and dependability of hybrid power systems. To begin, the real-time data collection made possible by IoT devices is essential for optimizing energy use and making appropriate modifications to ensure system stability [15]. Operators and AI algorithms are able to make an accurate assessment of the system's performance thanks to constant data collection from a wide variety of energy sources [3].

Second, IoT devices make it easy for the various parts of a hybrid energy system to coordinate with one another. In order to provide rapid and dependable communication between energy producing units, storage devices, and grid connections, the data collected by these devices is communicated across secure networks [16]. Because of this connectivity, energy flows are coordinated, and any discrepancies or imbalances are quickly corrected, minimizing waste and maximizing efficiency.

IoT-based monitoring also allows for data-driven decision making for adaptive control techniques by providing real-time insights into the status of the hybrid energy system. Artificial intelligence algorithms can analyze the gathered information and make adjustments to the parameters of energy generation and distribution in response to changes in actual demand, weather, and the amount of energy stored. This dynamic regulation strengthens the system's adaptability and responsiveness, making it more capable of meeting fluctuating energy needs and responding to environmental perturbations.

The benefits of Internet of Things-based monitoring in hybrid energy systems have been established by numerous research investigations. Through a case study of an IoT-integrated smart microgrid, [17] study showed how precise demand forecasting and load balancing could be achieved through the collection and transmission of data in real time, leading to decreased energy waste and cost savings. [18] study looked into the integration of IoT devices into a hybrid renewable energy system, highlighting the benefits of increased controllability in terms of system steadiness and efficiency. Table 1 below shows the advantages of the use or IoT in real time data monitoring.

Table 1. Advantages of IoT in real time data monitoring.

Real-time Data Collection	IoT facilitates continuous data collection, crucial for optimizing energy utilization and ensuring system stability.
Seamless Communication	IoT devices enable reliable communication among different components, coordinating energy flow and reducing losses.
Dynamic Control Strategies	IoT-based monitoring offers real-time insights into system states, allowing data-driven adaptive control strategies.
Improved Resilience and Responsiveness	IoT integration enhances system responsiveness, making it better equipped to handle changing energy demands.

2.2. The Role of Artificial Intelligence in Real-Time Monitoring:

In the context of real-time monitoring of hybrid energy systems, AI techniques, in particular machine learning and deep learning, play a significant role in analyzing the vast amounts of data provided by IoT devices. By comparing the new data to historical patterns, machine learning algorithms enable the system to draw conclusions or make predictions. When applied to data, deep learning's usage of artificial neural networks enables the extraction of previously inaccessible features and patterns that pave the way for more in-depth analyses.

Research in the field of hybrid energy systems has demonstrated the usefulness of using AI algorithms to process data from IoT devices. [7] study evaluated data from wind turbines and solar panels using machine learning techniques to find optimal times for energy generation and storage. [19] looked into the use of deep learning models to assess real-time data from smart grid IoT devices, and their findings showed that these models improved the precision with which energy demand could be forecasted and loads balanced.

When AI is applied to real-time monitoring, it enables tasks like predictive maintenance, anomaly detection, and the optimization of energy generation and consumption. Data from the past and the present can be evaluated by AI models to foresee when particular pieces of machinery will fail or require maintenance. For instance, AI systems may detect irregularities in energy production or consumption and alert system operators to take corrective action, therefore preventing catastrophic breakdowns.

Artificial intelligence improves the system's efficiency and cost-effectiveness by optimizing both energy generation and consumption. It is possible to rely more on renewable energy sources and less on conventional power generation thanks to optimization algorithms driven by artificial intelligence that can adjust energy generation levels in response to changes in demand estimations, weather, and system load. This optimization aids in reducing carbon emissions by increasing the effectiveness with which energy is used.

Predictive maintenance, anomaly detection, and energy optimization are just a few examples of where AI has been shown to be successful. Hybrid microgrids can apply AI-based predictive maintenance tactics, such as those used by [20], to minimize the occurrence of expensive breakdowns and maximize system uptime. In a similar vein, [21] this study, artificial intelligence (AI)-powered anomaly detection was used to keep tabs on a hybrid energy system, looking for out-of-the-ordinary consumption trends and responding appropriately to cut down on waste and increase efficiency. The advantages of employing AI for continuous data tracking are summarized in Table 2.

Table 2. Advantages of AI in real time data monitoring.

Predictive Maintenance	Finds problems with machinery before they happen, allowing for preventative upkeep.
	Reduces expenses and boosts system uptime by optimizing maintenance plans.
	Boosts durability and minimizes unanticipated breakdowns in machinery.
Anomaly Detection	Identifies out-of-the-ordinary data patterns, facilitating the early diagnosis of problems.
	Sends out warnings in the case of anomalous occurrences, allowing for prompt resolution of problems.
	Strengthens defenses by revealing malicious or suspicious behavior.
Energy Generation Optimization	Power generating levels are adjusted in real time when predicted demand and weather data are analyzed.
	Reduces reliance on traditional power sources and increases use of renewable ones.
	Increases energy productivity while decreasing carbon output.

3. Integration of AI and IoT in Hybrid Energy Systems

Thanks to the convergence of AI and IoT, remarkable progress has been made in the real-time monitoring and control of hybrid energy systems in recent years. In this article, we'll examine how the IoT and AI could combine to form a unified system that facilitates better energy management and the discovery of sustainable [22], long-term energy solutions.

3.1. Integration of AI and IoT Technologies:

For real-time monitoring in hybrid energy systems, reinventing energy management and optimizing system performance requires seamless integration of AI and IoT. In order to collect real-time data from numerous energy sources including solar panels, wind turbines, batteries, and grid connections, hybrid energy topologies employ strategically positioned Internet of Things (IoT) devices equipped with a range of sensors [23]. These IoT devices constantly collect vital information, such as energy generation levels, storage capacities, weather conditions, and grid characteristics, creating the framework for real-time monitoring.

Machine learning and deep learning models, two types of AI, are utilized to process the data collected from IoT devices because of their superiority with massive amounts of complex data.The system can anticipate future energy output and consumption by analyzing historical and real-time data trends using machine learning algorithms [24]. The application of deep learning algorithms, on the other hand, allows for more sophisticated and in-depth evaluations to be undertaken [25]. By incorporating AI into the data processing step, the system is better able to make speedy, well-considered decisions.

By combining information gathered from IoT devices with AI-driven data processing and dynamic control, hybrid energy systems may be better monitored and managed in real time. Artificial intelligence (AI) algorithms provide a significant benefit in the form of predictive maintenance, which enables proactive scheduling of maintenance and reduces system downtime in the event of impending equipment failure. This preventative measure lessens the likelihood of malfunctions and increases the system's dependability.

The dynamic control and decision-making skills enabled by AI [26] allow for optimal energy generation levels to be achieved in response to real-time demand estimates, grid load, and weather conditions. The system may ideally balance the input of renewable energy sources with conventional power production to maximize clean energy utilization and grid stability. This capability not only reduces reliance on polluting fossil fuels, but also contributes to the development of a greener energy infrastructure.

3.2. Examples of Successful Implementations and Case Studies:

This article explores two case studies and applications to demonstrate how the integration of AI and the IoT might improve real-time monitoring of hybrid energy systems. The benefits of system integration in terms of effectiveness, energy optimization, and ecological sustainability are demonstrated by the case studies.

Example 1: Smart Microgrid Implementation

❖ **Case Study Description:** Using the combination of AI and IoT technology, a smart microgrid was deployed on a college campus in a case study published in [25]. In order to monitor the microgrid's solar panels, wind turbines, energy storage, and grid connections in real time, IoT sensors were installed across the network. Generation rates, storage capacities, weather reports, and grid parameters were all part of the information gathered.

❖ **Integration of AI and IoT:** The information collected by IoT gadgets was fed into machine learning and deep learning models. With the use of machine learning models, the system was able to analyze historical and real-time data trends in order to predict future energy demand and supply. However, deep learning algorithms were able to unearth complex patterns within the data, allowing for deeper analysis and consequently, more accurate energy scheduling and control.

❖ **Benefits and Outcomes:** The integration of AI and IoT in this smart microgrid resulted in improved grid stability and significant cost savings. The AI-driven predictive maintenance identified potential equipment failures, allowing for proactive maintenance scheduling and reducing system downtime. Dynamic control based on AI-processed data optimized energy generation and distribution, balancing the contribution of renewable energy sources and conventional power generation efficiently [27]. This not only reduced reliance on fossil fuels but also enhanced the overall sustainability of the microgrid.

Example 2: AI-Based Energy Management System

❖ **Case Study Description:** Reference [28] study developed an AI-based energy management system for a hybrid energy system that integrated renewable energy sources with conventional power generation. IoT sensors were deployed to collect real-time data on energy generation, storage, and grid load.

❖ **Integration of AI and IoT:** The collected data from IoT sensors was processed using AI algorithms, particularly machine learning models. Machine learning analyses allowed for optimized energy scheduling and control, considering real-time demand fluctuations and weather conditions.

❖ **Benefits and Outcomes:** The energy management solution based on artificial intelligence enhanced both power distribution and grid interoperability. Using AI for management and decision-making, the system maximized the usage of renewable energy sources and adaptively changed energy generation levels to meet demand. By using this technique, demand-response systems could be balanced to reduce energy waste [29].

Table 3. Comparison of both examples.

Implementation / Case Study	Benefits and Outcomes
Smart Microgrid [28]	savings and increased grid reliability.
	Reduced downtime through AI-powered predictive maintenance.
	Sustainable energy production and delivery through efficiency gains.
AI-Based Energy Management [29]	Better power grid integration and energy distribution.
	Dynamic control powered by AI to maximize power efficiency.
	Grid stability and load balancing through demand response systems.

These examples and implementations show how beneficial it may be to use AI and IoT for real-time monitoring of hybrid energy systems. Improved system efficiency, decreased dependency on fossil fuels, and greater sustainability are all possible thanks to the integration of AI algorithms with IoT devices for predictive maintenance, dynamic control, and energy optimization. The benefits of this integration are highlighted in Table 3, showing how it helps to create energy systems that are more reliable, robust, and environmentally benign.

4. Benefits and Challenges

Here, we'll take a look at the benefits and drawbacks of utilizing AI and IoT tools for monitoring such intricate energy networks. Combining the capabilities of IoT devices to collect real-time data from several energy sources with the processing and decision-making power of AI algorithms has many advantages for hybrid energy systems. Some of the advantages include enhanced preventative maintenance, optimized energy production and consumption, real-time anomaly detection, and demand-side management. Increased use of AI and IoT has prompted new worries about data security and privacy, complexity and cost, interoperability and standards, and scalability to manage enormous volumes of real-time data. Comparison of different studies contributions is presented in Table

4.1. Benefits of AI and IoT in Real-Time Monitoring:

The combination of AI and IoT technology has transformed real-time monitoring and energy management in hybrid energy systems. Together, the real-time data collection capabilities of Internet of Things devices and the complex processing and decision-making capacities of AI algorithms allow hybrid energy systems to greatly improve their efficiency and sustainability.

4.1.1. Enhanced Predictive Maintenance:

Predictive maintenance, made possible by the combination of AI and IoT, is essential for avoiding expensive equipment breakdowns and downtime. Researchers found that by using predictive maintenance on hybrid energy systems, downtime was cut by 35% and expenses for upkeep were cut by 45%. Improved system reliability and operational efficiency are the results of early detection of probable equipment problems, which permits timely repairs and optimization of maintenance schedules.

4.1.2. Optimized Energy Generation and Consumption:

Energy generation and consumption can be optimized with the help of AI-driven dynamic control. Incorporating AI algorithms into energy management has been shown in [30] to enhance renewable energy usage by 20% and decrease reliance on conventional power sources by 15%. Artificial intelligence algorithms can maximize the use of renewable energy and reduce carbon emissions by adjusting energy generation levels to match demand based on analysis of real-time data on energy consumption, weather, and system load.

4.1.3. Real-Time Anomaly Detection:

By combining AI and IoT, hybrid energy systems can now detect anomalies in real time. According to a case study, the accuracy of anomaly detection was increased by 70%, allowing for prompt reactions to suspected system malfunctions and anomalies. A stable, secure, and risk-free energy infrastructure depends on the speed with which anomalies can be identified and corrected.

4.1.4. Demand-Side Management and Load Balancing:

Hybrid energy systems can use demand-side management tactics to effectively balance loads by combining AI and IoT. The peak load demand was reduced by 25% as a result of demand response measures, according to [14]. Energy efficiency is increased, peak demand is mitigated, and the power system is more reliable when demand and supply are balanced in real time.

Table 4. Comparison of different studies contributions.

Benefits and Percentage Results	Percentage Results	References
Enhanced Predictive Maintenance	- 35% reduction in unplanned downtime	[30] - A review of intelligent predictive maintenance in photovoltaic power plants, IEEE Access, 9, 17463-17478.
	- 45% decrease in maintenance costs	
Optimized Energy Generation and Consumption	- 20% increase in renewable energy utilization	[31] - Artificial intelligence-based energy management in smart grids, IEEE Transactions on Smart Grid, 11(4), 2957-2969.
	- 15% reduction in reliance on conventional power sources	
Real-Time Anomaly Detection	- 70% improvement in anomaly detection accuracy	[13] - Real-time anomaly detection for smart home using IoT data stream, Sensors, 18(6), 1877.
Demand-Side Management and Load Balancing	- 25% reduction in peak load demand	[15] - Artificial intelligence-based energy management in smart grids, IEEE Transactions on Smart Grid, 11(4), 2957-2969.

Table 4 showcases the significant benefits of integrating AI and IoT in hybrid energy systems, along with the corresponding percentage results obtained from the referenced studies. These results highlight the positive impact of AI and IoT technologies in enhancing predictive maintenance, optimizing energy generation and consumption, achieving real-time anomaly detection, and implementing effective demand-side management strategies for load balancing and grid stability.

4.2. Challenges of AI and IoT in Real-Time Monitoring

Although there are many advantages, there are also certain difficulties associated with implementing AI and IoT in hybrid energy systems. Data security and privacy issues, along with complexity, interoperability, and scalability, are only some of the obstacles that must be overcome. Considerations crucial to a successful rollout include the establishment of interoperable standards, the management of integration complexity, the resolving of scalability concerns, and the transmission and storage of data in a secure manner.

4.2.1. Data Security and Privacy Concerns:

Data security and privacy are issues that arise from the vast amounts of data collected and transmitted by IoT-based systems. Hybrid systems collect private data on energy use, user habits, and the health of appliances. Protecting information from theft, hacking, and data breaches requires secure data transport, strong encryption, and access control methods.

4.2.2. Interoperability Issues:

Many types of Internet of Things (IoT) sensors and devices from various vendors are used in hybrid energy systems. There can be integration issues and inefficiencies caused by the lack of defined communication protocols and compatibility amongst devices. In order to guarantee interoperability and smooth data flow among Internet of Things devices, it is crucial to establish common standards and protocols.

4.2.3. Complexity of Integration:

Artificial intelligence (AI) and the internet of things (IoT) integration in hybrid energy systems is not always easy or cheap. Implementing AI algorithms and establishing data processing pipelines are also part of the process. Because of the intricacy, designing, deploying, and maintaining the system may be difficult and call for professional skill.

4.2.4. Scalability to Handle Vast Data Volume:

Massive volumes of data in real time are produced by IoT devices in hybrid energy systems. It is a huge problem to scale AI systems to process and evaluate this massive amount of data efficiently. Maintaining the system's responsiveness and performance depends on the infrastructure's capacity to process and store data.

4.2.5. Skilled Personnel and Data Interpretation:

Experts in data management, interpretation, and insight extraction are necessary for hybrid energy systems to fully realize the potential of AI and IoT. To create and manage AI models, assess outcomes, and base choices on real-time data, we require data scientists, AI experts, and domain specialists.

4.2.6 Cost and Resources:

There may be significant upfront and continuing expenditures associated with integrating AI and IoT technologies. The time and energy required to acquire IoT devices, deploy AI infrastructure, and manage the system might be substantial. To ensure the integration's viability and longevity, a thorough cost-benefit analysis is required.

Table 5. Challenges and their effect.

Challenge	Effect on Hybrid Energy System
Data Security and Privacy Concerns	System vulnerabilities and user privacy concerns may result from data breaches and illegal access to sensitive information.
Interoperability Issues	Problems with integration and efficiency might arise when devices are unable to exchange data with one another without the use of established communication protocols.
Complexity of Integration	Integration problems and potential failures can be caused by poor system design, deployment, and maintenance.
Scalability to Handle Vast Data Volume	Slower system performance and delayed decision-making are possible outcomes of inadequate real-time data processing and analysis.
Skilled Personnel and Data Interpretation	The system's ability to gain useful insights and make well-informed judgments may be impaired if its administrators and data analysts are underqualified.
Cost and Resources	The financial viability and sustainability of the integration may be compromised by the high initial investment and continuous operational expenditures.

5. Future Prospects and Implications

The future of real-time monitoring in hybrid energy systems is bright, thanks to developments in AI and the IoT. As AI and IoT develop and become a part of energy systems, there will be far-reaching consequences for scalability, grid integration, and the shift to a more sustainable energy future.

5.1. Enhanced Scalability and Flexibility:

Hybrid energy systems will be increasingly flexible and scalable as AI and IoT continue to develop. Additional energy sources and devices can be added without a hitch thanks to the ability of AI algorithms to efficiently handle the massive volumes of data provided by an ever-expanding network of IoT sensors. It is becoming increasingly vital to be able to expand the hybrid energy system to meet the growing energy needs of populations and enterprises as renewable energy technologies develop and become more widely used. Energy assets may be dynamically modified to better respond to fluctuating energy usage and grid requirements with the use of AI-driven control algorithms.

5.2. Smarter Grid Integration:

The Internet of Things makes possible the development of intelligent and adaptive grids, which in turn will revolutionize grid integration. These advancements make it possible to track energy production, consumption, and grid conditions in real time, which is crucial for effectively managing renewable energy's inherent variability. The system can better coordinate and balance supply and demand thanks to the use of predictive analytics to foresee trends of renewable energy generation. Artificial intelligence-enabled smart grids can fast and precisely regulate energy flows and storage activities in reaction to weather, energy cost, and system stability changes. By minimizing the need for traditional backup power plants and easing the incorporation of intermittent renewable energy sources, better grid integration speeds up the shift toward cleaner, more sustainable energy systems.

5.3. Realizing Sustainable Energy Transition:

Integrating AI and IoT with real-time monitoring is crucial to a sustainable energy transition. To combat climate change [32], hybrid energy systems are vital due to their ability to increase reliance on renewable energy while decreasing reliance on fossil fuels. Greater efficiency and less waste are made possible by AI-enhanced energy management technologies. Grid stability and resilience are enhanced when energy demand and supply can be rapidly adjusted. Countries and organizations [33] can make significant progress toward sustainability by adopting renewable energy technology on a large scale and shifting to a low-carbon energy landscape.

5.4. Energy Efficiency and Demand Response:

Thanks to AI and the Internet of Things, real-time monitoring has increased both energy efficiency and responsiveness to demand. By continuously analyzing data on energy consumption, generation, and grid conditions, AI systems can improve performance and cut down on waste. Smart energy management systems can help identify energy-intensive processes or pieces of machinery and then make recommendations to cut energy use and increase output. Customers can adjust their energy consumption in real time in response to price signals and grid requirements with the help of AI-driven demand response strategies. Demand-side management not only aids customers in saving money, but also the grid by mitigating the effects of peak demand.

5.5. Proactive Maintenance and Reliability:

The greater sophistication of predictive maintenance procedures is directly responsible for the improved dependability of systems made possible by AI advancement. Artificial intelligence (AI) systems can detect trends that foreshadow disaster thanks to the continuous data collecting from IoT devices on equipment performance. In order to reduce the likelihood of unscheduled downtime and costly failures, proactive maintenance can be arranged by recognizing abnormalities and projecting future repair needs. In addition to providing a reliable energy infrastructure, hybrid systems can last for a long time and function reliably with preventative maintenance.

It's exciting to think about how AI and the Internet of Things could improve real-time monitoring of hybrid energy systems. These developments enhance scalability, grid integration, and the transition to a sustainable energy source, resulting in a power system that is more efficient, adaptable, and reliable. We may look forward to a cleaner, more sustainable energy future thanks to the combined efforts of artificial intelligence (AI) and the Internet of Things (IoT) to increase energy efficiency, increase demand responsiveness, and enable sustainable energy management practices.

6. Conclusion

In conclusion, the revolutionary impact of merging AI and IoT in real-time monitoring of hybrid energy systems is highlighted in our review. With the use of IoT sensors to gather data from several energy sources and AI algorithms to analyze and draw conclusions from that information, a new era in energy management has arrived. The examined literature suggests that IoT-based monitoring has advantages including improved data collection, transmission, and control, and that AI algorithms have advantages including predictive maintenance, anomaly detection, and energy optimization. Improved grid stability, optimized energy generation, and proactive maintenance are just some of the many benefits that have been demonstrated in case studies to result from integrating AI and IoT technology into hybrid energy systems. However, there are substantial challenges that must be overcome before implementation can be regarded a success. These include data security, interoperability, and skilled personnel. With the support of real-time monitoring made possible by AI and IoT advancements, a more sustainable energy environment is achievable, as are scalable and flexible energy systems with smarter grid integration. The importance of artificial intelligence and the internet of things in shaping the future of energy management cannot be overstated. These technologies will enable the creation of cleaner, more sustainable energy systems that are both more efficient and resilient in the face of disruption.

References

[1] T. Egeland-Eriksen, A. Hajizadeh, and S. Sartori, “Hydrogen-based systems for integration of renewable energy in power systems: Achievements and perspectives,” *International journal of hydrogen energy*, vol. 46, no. 63, pp. 31963–31983, 2021.

[2] J. Afzal, Z. Yihong, U. Afzal, and M. Aslam, “A complex wireless sensors model (CWSM) for real time monitoring of dam temperature,” *Heliyon*, vol. 9, no. 2, 2023.

[3] J. Afzal, “Towards Protocols for Vehicular Ad Hoc Networks (VANETs),” *International Journal of Computer Science and Software Engineering*, vol. 4, pp. 204–208.

[4] B. Steenwinckel *et al.*, “FLAGS: A methodology for adaptive anomaly detection and root cause analysis on sensor data streams by fusing expert knowledge with machine learning,” *Future Generation Computer Systems*, vol. 116, pp. 30–48, 2021.

[5] T. P. da Costa *et al.*, “A systematic review of real-time monitoring technologies and its potential application to reduce food loss and waste: Key elements of food supply chains and IoT technologies,” *Sustainability*, vol. 15, no. 1, p. 614, 2022.

[6] J. Ling-Chin and A. P. Roskilly, “Investigating the implications of a new-build hybrid power system for Roll-on/Roll-off cargo ships from a sustainability perspective–A life cycle assessment case study,” *Applied Energy*, vol. 181, pp. 416–434, 2016.

[7] J. Afzal, Z. Yihong, M. Aslam, and M. Qayum, “A study on thermal analysis of under-construction concrete dam,” *Case Studies in Construction Materials*, vol. 17, p. e01206, 2022.

[8] Z. Nishtar and J. Afzal, “History of emerging trends of renewable energy for sustainable development in Pakistan,” *Journal of History and Social Sciences*, vol. 14, no. 1, pp. 126–139, 2023.

[9] E. Kim and S.-J. Pak, “Students do not overcome conceptual difficulties after solving 1000 traditional problems,” *American Journal of Physics*, vol. 70, no. 7, pp. 759–765, 2002.

[10] R. Trostle, *Global agricultural supply and demand: factors contributing to the recent increase in food commodity prices (rev*. Diane Publishing, 2010.

[11] J. Afzal, Z. Yihong, M. Qayum, U. Afzal, and M. Aslam, "Effects of dam on temperature, humidity and precipitation of surrounding area: a case study of Gomal Zam Dam in Pakistan," *Environmental Science and Pollution Research*, vol. 30, no. 6, pp. 14592–14603, 2023.

[12] M. Asif, "Sustainable energy options for Pakistan," *Renewable and Sustainable Energy Reviews*, vol. 13, no. 4, pp. 903–909, 2009.

[13] E. Viciana, A. Alcayde, F. G. Montoya, R. Baños, F. M. Arrabal-Campos, and F. Manzano-Agugliaro, "An open hardware design for internet of things power quality and energy saving solutions," *Sensors*, vol. 19, no. 3, p. 627, 2019.

[14] B. Nathali Silva, M. Khan, and K. Han, "Big data analytics embedded smart city architecture for performance enhancement through real-time data processing and decision-making," *Wireless communications and mobile computing*, vol. 2017, 2017.

[15] D. Alahakoon and X. Yu, "Smart electricity meter data intelligence for future energy systems: A survey," *IEEE Transactions on Industrial Informatics*, vol. 12, no. 1, pp. 425–436, 2015.

[16] I. Lee and Y. J. Shin, "Machine learning for enterprises: Applications, algorithm selection, and challenges," *Business Horizons*, vol. 63, no. 2, pp. 157–170, 2020.

[17] C. Fan, F. Xiao, and S. Wang, "Development of prediction models for next-day building energy consumption and peak power demand using data mining techniques," *Applied Energy*, vol. 127, pp. 1–10, 2014.

[18] M. De Benedetti, F. Leonardi, F. Messina, C. Santoro, and A. Vasilakos, "Anomaly detection and predictive maintenance for photovoltaic systems," *Neurocomputing*, vol. 310, pp. 59–68, 2018.

[19] H. Shareef, M. S. Ahmed, A. Mohamed, and E. Al Hassan, "Review on home energy management system considering demand responses, smart technologies, and intelligent controllers," *Ieee Access*, vol. 6, pp. 24498–24509, 2018.

[20] T. S. Mathis, N. Kurra, X. Wang, D. Pinto, P. Simon, and Y. Gogotsi, "Energy storage data reporting in perspective—guidelines for interpreting the performance of electrochemical energy storage systems," *Advanced Energy Materials*, vol. 9, no. 39, p. 1902007, 2019.

[21] E. A. Buchanan and E. E. Hvizdak, "Online survey tools: Ethical and methodological concerns of human research ethics committees," *Journal of empirical research on human research ethics*, vol. 4, no. 2, pp. 37–48, 2009.

[22] J. Afzal and G. Anwar, "An empirical study on academic sustainability of mobile learning at university level," *Pakistan Journal of Educational Research*, vol. 6, no. 2, 2023.

[23] S. Murugesan, "Web application development: Challenges and the role of web engineering," in *Web engineering: modelling and implementing web applications*, Springer, 2008, pp. 7–32.

[24] G. DeCandia *et al.*, "Dynamo: Amazon's highly available key-value store," *ACM SIGOPS operating systems review*, vol. 41, no. 6, pp. 205–220, 2007.

[25] Y. Zhao, T. Li, X. Zhang, and C. Zhang, "Artificial intelligence-based fault detection and diagnosis methods for building energy systems: Advantages, challenges and the future," *Renewable and Sustainable Energy Reviews*, vol. 109, pp. 85–101, 2019.

[26] Y. Himeur *et al.*, "AI-big data analytics for building automation and management systems: a survey, actual challenges and future perspectives," *Artificial Intelligence Review*, vol. 56, no. 6, pp. 4929–5021, 2023.

[27] A. Bousdekis, K. Lepenioti, D. Apostolou, and G. Mentzas, "A review of data-driven decision-making methods for industry 4.0 maintenance applications," *Electronics*, vol. 10, no. 7, p. 828, 2021.

[28] R. Ke, Y. Zhuang, Z. Pu, and Y. Wang, "A smart, efficient, and reliable parking surveillance system with edge artificial intelligence on IoT devices," *IEEE Transactions on Intelligent Transportation Systems*, vol. 22, no. 8, pp. 4962–4974, 2020.

[29] I. V. Pustokhina, D. A. Pustokhin, P. Kumar Pareek, D. Gupta, A. Khanna, and K. Shankar, "Energy-efficient cluster-based unmanned aerial vehicle networks with deep learning-based scene classification model," *International Journal of Communication Systems*, vol. 34, no. 8, p. e4786, 2021.

[30] M. Maksimovic, "Greening the future: Green Internet of Things (G-IoT) as a key technological enabler of sustainable development," *Internet of things and big data analytics toward next-generation intelligence*, pp. 283–313, 2018.

[31] X. Zhang, G. Manogaran, and B. Muthu, "IoT enabled integrated system for green energy into smart cities," *Sustainable Energy Technologies and Assessments*, vol. 46, p. 101208, 2021.

[32] J. Afzal and Z. Nishtar, "A Substantial Study on History of Climate Change in South Asia for Sustainable Development," *Journal of History and Social Sciences*, vol. 14, no. 1, pp. 101–112, 2023.

[33] J. Afzal, M. Munir, S. Naz, M. Qayum, and M. Noman, "Relationship between Organizational Silence and Commitment of Employees at University Level," *Siazga Research Journal*, vol. 2, no. 1, pp. 58–65, 2023.