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Review Article

Exploring the Convergence of IoT Technology and Hybrid Renewable Energy Systems: A review

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Abstract: The Internet of Things (IoT) has revolutionized how we interact with our environment by connecting physical items through software and sensors. This interconnection allows for seamless communication between people, processes, and things, enabled by technologies such as low-cost sensors, network protocols, cloud computing, machine learning, and AI. The affordability and popularity of IoT devices for personal use have increased, with applications such as smart cities, connected logistics, and smart manufacturing improving operational efficiency and business value in industrial settings. Oracle's intelligent apps utilize IoT technologies to enhance customer experiences, productivity, and operational effectiveness while seizing new business opportunities. By leveraging IoT technology, hybrid renewable energy systems can optimize energy generation and distribution, promote intelligent energy management, and enable applications like demand response management and predictive maintenance. Despite challenges like security issues and interoperability, the integration of IoT technology with hybrid renewable energy systems holds the promise of sustainable energy management and a greener future.

Keywords: IoT; smart grid; industrial IoT; renewable energy

1. Introduction

The Internet of Things, or IoT, is one of the most significant technological advancements of the twenty-first century. It refers to the network of actual physical goods, or "things," that are implanted with sensors, software, and other technologies in order to communicate and share data with other devices and systems over the internet. The complexity of these products varies, ranging from simple household items to intricate industrial machinery. Over 29 billion IoT devices are expected to exist globally by 2030, almost doubling from 15.1 billion in 2020 (Vailshery, 2023).

The spread of Internet of Things technology has completely changed how we interact and converse with our environment. Thanks to low-cost computers, cloud platforms, big data analytics, and mobile technologies, physical devices may now communicate and collect data with little assistance from humans. The way we interact with the physical world is changed by this interconnection, which makes it possible for people, processes, and objects to communicate with ease. IoT has been made possible by a number of technological developments, such as the availability of inexpensive, low-power sensor technology, connectivity via a variety of network protocols, cloud computing platforms that provide easy access to infrastructure, machine learning and analytics for quicker insights, and conversational artificial intelligence that incorporates natural language processing. These developments have increased the affordability, attractiveness, and viability of IoT devices for use at home (Oracle, 2024), (Magara, 2024).

Industrial Internet of Things (IIoT) is the term used to describe the application of IoT technologies in industrial settings, particularly in connection to the instrumentation and administration of sensors and devices through cloud services. IIoT, or Industry 4.0, finds use in linked logistics, smart cities, smart power grids, smart manufacturing, and connected assets and preventive maintenance. These apps optimize energy distribution, boost operational effectiveness, improve maintenance procedures, and simplify logistics processes. (Chalapathi, 2021), (Isah, 2023).

IoT technology has revolutionized business operations by generating data-driven insights, boosting productivity and efficiency, generating new business models and revenue streams, and bridging the physical and digital worlds. The market's broad adoption of IoT has enabled companies to unlock significant business value (Noor, 2023), (Liyakat, 2023).

One of the key applications of IoT in renewable energy systems is in the monitoring and optimization of energy production. By using sensors and connected devices, renewable energy assets such as solar panels, wind turbines, and hydroelectric plants can be monitored in real-time to ensure optimal performance. This can lead to increased energy production and reduced downtime, ultimately improving the overall efficiency of the renewable energy system. IoT can also be used to improve the overall energy management of a renewable energy system. By integrating IoT devices such as smart meters and energy storage systems, energy consumption can be optimized based on real-time data. This can help to reduce energy waste and improve the overall sustainability of the system. In order to improve performance, security, and dependability, a rising number of information technologies (ITs) provide scalable, integrated software and hardware solutions that are designed to satisfy a range of market expectations and effectively interface with existing energy networks (Ahmad, 2021), (Martin-Lopo, 2020).

Additionally, the integration of renewable energy sources into the grid can be greatly aided by IoT. By using IoT devices to communicate with grid operators, renewable energy systems can be better integrated into the existing infrastructure, leading to a more stable and reliable energy supply. Overall, the application of IoT in renewable energy systems has the potential to revolutionize the way we produce and consume energy. By leveraging IoT technology, renewable energy systems can be more efficient, reliable, and sustainable, ultimately leading to a greener and more sustainable future. The effects of IoT on active distribution networks, smart buildings, microgrids, smart cities, and the industrial sector are examined at the distribution level. IoT adoption handles power system congestion management and guarantees system security at the transmission level (Shahinzadeh, 2019), (Muleta, 2021).

Several technological advancements have made IoT possible in energy technology (Krishnamurthi, 2019):

- Access to low-power sensor and low-cost technology: The availability of affordable and reliable sensors has played a crucial role in enabling IoT technology in energy industries.

- Connectivity: In order to provide effective data transfer in the power grid system, energy generator, and end user communication, a variety of internet network protocols have made it simpler to link sensors to the cloud and other devices.

- Cloud computing platforms: The emergence of cloud platforms has made it convenient for businesses and consumers to access the necessary infrastructure without the need for comprehensive management. Every stakeholder can access the data from everywhere without limit.

- Machine learning and analytics: With advancements in machine learning and analytics, necessary data quickly gather insights from vast amounts of IoT data stored in the cloud, enabling faster and easier decision-making.

- Conversational artificial intelligence (AI): Advances in neural networks have made it possible to integrate natural-language processing (NLP) capabilities into IoT devices. This integration has made IoT devices more affordable, appealing, and viable in energy source and load pattern forecasting.

2. Smart Grid technology through IoT integration

The combination of smart grid technologies and the Internet of Things (IoT) has the potential to fundamentally alter how we use and manage energy. By connecting appliances, sensors, and gadgets to the grid, we can create a more dependable and efficient energy system that can quickly adjust to changing supply and demand conditions (Ahmad, 2021).

Among the key benefits of combining IoT and smart grid technology is better energy usage monitoring and control. By obtaining information from sensors, smart meters, and other devices, utilities can gain valuable insights into patterns and trends in energy consumption. With the aid of this data, energy distribution may be maximized, trouble spots may be identified, and outages can even be predicted and prevented. Another advantage of the Internet of Things is increased automation and coordination among the many components of the grid. For example, smart appliances are able to communicate with the grid to adjust their operating schedules in response to variations in energy prices or grid load. This can save costs, minimize peak demand, and restrict the need for additional infrastructure investments.

The integration of energy storage systems and renewable energy sources can be enhanced by combining IoT with smart grid technology. Utilities can enhance their ability to control the variability of renewable energy generation and maximize the use of energy storage to balance supply and demand by facilitating improved communication and coordination across distributed energy resources (Kataray, 2023).

3. Applications and Benefits of IoT in Energy Sector

Utilization of IOT in Energy sector has different benefits as discussed in (Mahale, 2024), (Swathika, 2023).

Smart metering: The deployment of smart meters that offer real-time data on energy consumption is made possible by IoT technology. Customers can monitor and control their energy use more skilfully as a result, which lowers costs and boosts productivity.

Predictive maintenance: Predictive maintenance can be performed before equipment problems occur by using IoT sensors to monitor assets and equipment in the energy sector. This increases overall efficiency by lowering maintenance costs and downtime.

Demand response: By interacting with smart appliances and gadgets to lower energy use during moments of high demand, Internet of Things technology helps energy providers better manage peak demand periods. This aids in grid stabilization and blackout prevention.

Energy management systems: Energy management systems can be integrated and optimized with the use of IoT solutions, providing more effective control over energy generation, distribution, and consumption. Cost reductions and improved sustainability may result from this.

Energy grid optimization: The performance of energy networks may be monitored and enhanced with the use of IoT sensors, which can also be used to spot inefficiencies and possible improvement areas. This can promote the integration of renewable energy sources, lower energy losses, and improve grid resilience.

Remote monitoring and control: Energy infrastructure may be remotely monitored and controlled thanks to Internet of Things technology, which gives operators global access to oversee operations. This can raise safety, lower operating expenses, and increase operational efficiency.

Asset tracking: Energy assets, like solar panels or wind turbines, can have their location and state monitored by IoT sensors. Improved inventory control, scheduling of maintenance, and asset management are made possible by this.

Renewable Energy Integration: IoT devices can aid in more effectively integrating renewable energy sources, such wind and solar power, into the grid. This can lessen dependency on fossil fuels and increase the usage of renewable energy.

Energy Efficiency: IoT technology can be used to optimize energy usage in buildings and industrial facilities. Smart thermostats, lighting controls, and HVAC systems can adjust automatically based on occupancy and environmental conditions, saving energy and reducing costs.

Environmental Monitoring: It is possible to measure emissions from energy generating facilities and check air and water quality with IoT sensors. This data can help identify and address environmental concerns and improve overall sustainability in the energy sector.

4. Challenges of IoT in smart grid

As it has more benefits, there is some challenges for the integration of IoT to smart grids as discussed as follows (Rekeraho, 2024).

Interoperability: One of the biggest challenges in implementing IoT is making sure that devices made by different manufacturers can connect and function as a unit in the smart grid network.

Security: IoT devices are vulnerable to cyber-attacks, and the large number of connected devices in a smart grid network increases the potential attack surface. Protecting sensitive data and ensuring the security of the grid infrastructure are critical challenges.

Scalability: As the number of IoT devices in the smart grid network grows, managing and scaling the network to accommodate the increasing data traffic and communication requirements becomes a significant challenge.

Reliability: Ensuring the reliability and uptime of IoT devices in the smart grid network is crucial for the smooth operation of the grid. Any downtime or malfunctions can have serious implications on the grid's performance and efficiency.

Data management: Managing the vast amounts of data generated by IoT devices in the smart grid network poses a challenge in terms of storage, processing, and analysis. Extracting meaningful insights from this data is essential for optimizing grid operations and energy efficiency.

Regulatory compliance: Meeting regulatory requirements and standards for IoT implementation in the smart grid is a complex challenge, as regulations are continuously evolving to address emerging risks and challenges in the energy sector.

Cost: Implementing IoT technology in the smart grid can be costly, and the upfront investment required for deploying and maintaining IoT devices can be a barrier for some utilities and grid operators.

Skill gap: Building and maintaining the technical expertise and skills required to implement and manage IoT technology in the smart grid network is a challenge, as the field of IoT is constantly evolving, and professionals with specific expertise in this area may be limited.

5. Overcoming Challenges in IoT-Powered Smart Grids

To reduce the challenges explained, there is different tasks taken to reduce them as discussed in (Gowri, 2024) (Rao, 2024), and (Abbas, 2023). The challenges of IoT in smart grid will be eliminated by implementing the following tasks:

Communication: Implement robust and secure communication protocols between devices, such as MQTT or CoAP, to ensure reliable data transmission between sensors, actuators, and the central control system.

Scalability: Design the Smart Grid system to be easily scalable to accommodate a growing number of devices and sensors as the grid expands. Use cloud-based solutions to handle increased data processing and storage requirements.

Interoperability: Ensure that all devices and systems within the Smart Grid ecosystem are interoperable, allowing them to communicate and work together seamlessly. Implement industry standard protocols and open APIs to facilitate interoperability.

Security: Implement strong encryption protocols, authentication mechanisms, and access controls to protect sensitive data and prevent unauthorized access to the Smart Grid system. Regularly update and patch software to address vulnerabilities.

Data Management: Develop a robust data management strategy to collect, store, analyse, and visualize data generated by sensors and devices within the Smart Grid. Use big data analytics and machine learning algorithms to extract valuable insights from the data.

Grid Resilience: Implement fail-safe mechanisms, such as redundant communication channels and backup power sources, to ensure the Smart Grid remains operational in case of failures or disruptions. Implement remote monitoring and control capabilities to quickly respond to and resolve issues.

Regulatory Compliance: Ensure that the Smart Grid system complies with relevant regulatory requirements and standards, such as data privacy regulations and grid reliability standards. Regularly audit and assess the system to ensure compliance.

Stakeholder Engagement: Involve all relevant stakeholders, including utilities, regulatory bodies, and end-users, in the design and implementation of the Smart Grid system. Conduct regular outreach and engagement activities to address concerns and gather feedback for continuous improvement.

6. Conclusions

A network of physical items with sensors and other electronics implanted in them that can communicate over the internet is known as the Internet of Things (IoT). It has completely changed networking and communication by enabling object-to-object data sharing with very little human intervention. IoT is made possible in large part by low-cost sensors, cloud computing, machine learning, networking protocols, and conversational AI. Applications of the Industrial Internet of Things (IIoT) include connected assets, smart power grids, smart cities, smart manufacturing, and connected logistics. Businesses can benefit from IoT by using it to generate new business models, boost efficiency, gain data-driven insights, and successfully connect the digital and physical worlds. IoT apps that are suitable for business use provide real-time dashboards and alerts that improve financial, customer service, and supply chain processes. Numerous industries, including manufacturing, automotive, energy, retail, public sector, and healthcare, can benefit from the Internet of Things. Intelligent energy management, effective monitoring, and optimum energy distribution are made possible by the convergence of IoT technologies with hybrid renewable energy systems. Data management, security, interoperability, and scalability are issues with IoT integration. IoT has enormous potential for energy management, sustainable energy supply, and a greener future despite these obstacles.

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References

Ahmad, T., & Zhang, D. (2021). Using the internet of things in smart energy systems and networks. Sustainable Cities and Society, 68, 102783.

Chalapathi, G. S. S., Chamola, V., Vaish, A., & Buyya, R. (2021). Industrial internet of things (iiot) applications of edge and fog computing: A review and future directions. Fog/edge computing for security, privacy, and applications, 83, 293-325.

Gowri, N. V., Krishna, T. M., & Krishnaveni, K. (2024). Enhancing Sustainability: Exploring IoT Integration in Renewable Energy Infrastructure. International Research Journal on Advanced Engineering Hub (IRJAEH), 2(04), 793-800.

Isah, A., Shin, H., Aliyu, I., Oh, S., Lee, S., Park, J., ... & Kim, J. (2023). A Data-Driven Digital Twin Network Architecture in the Industrial Internet of Things (IIoT) Applications. arXiv preprint arXiv:2312.14930.

Kataray, T., Nitesh, B., Yarram, B., Sinha, S., Cuce, E., Shaik, S., ... & Roy, A. (2023). Integration of smart grid with renewable energy sources: Opportunities and challenges–A comprehensive review. Sustainable Energy Technologies and Assessments, 58, 103363.

Krishnamurthi, R., & Goyal, M. (2019). Enabling technologies for IoT: issues, challenges, and opportunities. Handbook of research on cloud computing and big data applications in IoT, 243-270. Liyakat, K. S. (2023). IoT in the Electric Power Industry. Journal of Controller and Converters, 1--7.

Magara, Tinashe, and Yousheng Zhou. "Internet of Things (IoT) of Smart Homes: Privacy and Security." Journal of Electrical and Computer Engineering 2024, no. 1 (2024): 7716956.

Mahale, M. D., Patra, B. B., & Mahale, S. M. Applications of IoT in renewable energy sector: Smart energy management, opportunities, challenges and applications. Highly Efficient Thermal Renewable Energy Systems, 62-82.

Martín-Lopo, M. M., Boal, J., & Sánchez-Miralles, Á. (2020). A literature review of IoT energy platforms aimed at end users. Computer Networks, 171, 107101.

Muleta, N., & Badar, A. Q. (2021, January). Study of energy management system and IOT integration in Smart Grid. In 2021 1st International Conference on Power Electronics and Energy (ICPEE) (pp. 1-5). IEEE.

Noor, F. (2023). Internet of Things and Big Data: Transforming Business and Society Through Advanced Analytics. Journal Environmental Sciences and Technology, 2(2), 48-60.

Oracle. (2024). What technologies have made IoT possible? Oracle Intelligent Applications.

Rao, K. S., Lean, C. P., Yuan, K. F., Kiat, N. P., Li, C., Khan, M. R. B., & Ismail, D. (2024). Transformative Applications of IoT in Diverse Industries: A Mini Review. Malaysian Journal of Science and Advanced Technology, 4(2) 130-140.

Rekeraho, A., Cotfas, D. T., Cotfas, P. A., Bălan, T. C., Tuyishime, E., & Acheampong, R. (2024). Cybersecurity challenges in IoT-based smart renewable energy. International Journal of Information Security, 23(1), 101-117.

Shahinzadeh, H., Moradi, J., Gharehpetian, G. B., Nafisi, H., & Abedi, M. (2019, January). IoT architecture for smart grids. In 2019 International Conference on Protection and Automation of Power System (IPAPS) (pp. 22-30). IEEE.

Swathika, O. G., Karthikeyan, K., & Padmanaban, S. (Eds.). (2023). IoT and Analytics in Renewable Energy Systems (Volume 2): AI, ML and IoT Deployment in Sustainable Smart Cities. CRC Press.

Vailshery, L. S. (2023). Number of Internet of Things (IoT) connected devices worldwide from 2019 to 2023, with forecasts from 2022 to 2030. Statista.