

Integrating Renewable Energy Sources with Micro Grid Using IOT and Machine Learning

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Abstract. The power system landscape has undergone significant changes over the past few decades, marked by increasing electricity demand, power losses, grid failures, and the absence of smart technology. Simultaneously, security threats have escalated, and conventional power grids are struggling to cope with these challenges. In response to these evolving demands, the Internet of Things (IoT) has rapidly gained prominence due to its transformative potential. By incorporating IoT technology into power grids, we have the ability to improve the efficiency, sustainability, scalability, capacity, reliability, and stability of traditional grid systems. 1. This document provides an in-depth analysis of IoT-enabled intelligent power grids, emphasizing the importance of tackling security concerns, examining diverse use cases, and deliberating on alternative frameworks. Furthermore, we explore IoT and non-IoT technologies utilized in smart grid systems, such as sensing, computing technologies, communication, and applicable standards.

Keywords: Energy Management, Artificial Neural Network, Microgrid, Renewable Energy, IoT, Energy Demand Prediction.

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1. Introduction

The world's dependence on fossil fuels for power generation, coupled with dwindling reserves, necessitates a sustainable and efficient electrical energy supply. The smart grid emerges as a pivotal solution to address the shortcomings of traditional grids, providing not only power transmission but also comprehensive energy monitoring and management capabilities. While the fundamental structure of electrical grids has remained largely unchanged over the years, advancements in information and communication technologies (ICTs) offer opportunities to enhance grid stability, reliability, and energy efficiency, all while catering to diverse consumer needs. This article explores the fusion of contemporary ICTs with power grids, considering the growing influence of renewable energy sources like wind and solar. These decentralized energy sources significantly impact grid performance, requiring advanced ICT solutions for effective monitoring and control. The influence of ICT was demonstrated by various researchers, some notable mentions- a novel energy management framework for a vehicle-to-building (V2B) system with renewable energy sources (RES) and energy storage systems (ESS) [1]. The framework was based on a mixed-integer linear programming (MILP) model that minimized the peak load of the grid. The model took into account the stochastic nature of RES generation and the charging and discharging profiles of the ESS and V2B units. The proposed framework was evaluated using a case study of a residential community in Portugal.

The results showed that the proposed framework could significantly reduce the peak load of the grid, while also ensuring the satisfaction of the energy demands of the V2B units.

The smart grid is a contemporary electrical power grid system that incorporates cutting-edge information and communications technologies (ICT), sensing, automation, and metering technologies, as well as energy management techniques. The ICT layer within the smart grid has the crucial role of gathering and transmitting data from the diverse devices within the grid. Additionally, it is responsible for offering real-time monitoring and control capabilities. The smart grid's communication networks are categorized into three sub-layers: AMI networks, AMR networks, and AMI+ networks. The primary communication technologies utilized for smart grid applications consist of Bluetooth, Z-Wave, SAEJ2847, Wi-Fi, Home Plug, Zigbee, Xbee, 6-lowPAN, and BACnet. The integration of renewable energy sources into the smart grid is a major challenge, but it is essential to achieve a sustainable energy future. The transition from smart grid to micro grid is a crucial factor for utilities to take into account. This transition enables them to enhance efficiency and reliability, while simultaneously cutting down on costs[2][8].

Table 1. Advent of ICT demonstrated- Vehicle-to-building (V2B) system with renewable energy sources (RES) and energy storage systems (ESS) [1].

<i>Data</i>	<i>Description</i>
Number of V2B units	100
Capacity of each V2B unit	2 kWh
Capacity of the ESS	100 kWh
Maximum charging power of the ESS	10 kW
Maximum discharging power of the ESS	10 kW

Maximum generation power of the RES	100 kW
Stochasticity of the RES generation	20%
Case study duration	24 hours
Peak load of the grid without V2B and ESS	150 kW
Peak load of the grid with V2B and ESS	100 kW

Table 2. Modern electrical power grid infrastructure [2].

<i>Communication Network</i>	<i>Devices Served</i>	<i>Communication Technologies</i>
Consumer Premises Networks (CPNs)	Smart home appliances, in-home displays, renewable energy integration, load control devices, demand side management, home computing devices, power measurements, electrical vehicles outlets.	Zigbee, Xbee, 6-lowPAN, BACnet, SAEJ2847, Bluetooth, Z-Wave, Wi-Fi, and Home Plug.
Neighborhood Area Network (NAN)	Advanced smart meters, concentrators	RF Mesh, Wi-Fi, WiMax, LTE, GPRS/EDGE, PLC/BPLC, RF Radio point-to-multiple point, and FTTP/FTTH/Ethernet.
Access Area Network	Voltage regulators, re-closers, remotely operable switches	RF Mesh, Wi-Fi, WiMax, LTE, GPRS/EDGE, PLC/BPLC, RF Radio point-to-multiple point, and FTTP/FTTH/Ethernet.

Table 2. Communication network, latency and data occurrence [2].

Communication Network	Latency	Bandwidth	Payload Size	Frequency	Quality of Service	Reliability	Data Occurrence Interval
Consumer Premises Networks (CPNs)	Highly variable	50 kHz to 40 MHz	10 bytes to 1500 bytes	50 000 packets per second to 1 packet per minute	Some type of quality of service/differentiated services mechanism	Non-essential, important, or essential	Could be periodic or aperiodic
Neighborhood Area Network (NAN)	Highly variable	1 Kbps to 30 Mbps	10 bytes to 1500 bytes	50 000 packets per second to 1 packet per minute	Some type of quality of service/differentiated services mechanism	Non-essential, important, or essential	Could be periodic or aperiodic
Access Area Network	Highly variable	50 kHz to 40 MHz	10 bytes to 1500 bytes	50 000 packets per second to 1 packet per minute	Some type of quality of service/differentiated services mechanism	Non-essential, important, or essential	Could be periodic or aperiodic
Backhaul Network	Highly variable	50 kHz to 40 MHz	10 bytes to 1500 bytes	50 000 packets per second to 1 packet per minute	Some type of quality of service/differentiated services mechanism	Non-essential, important, or essential	Could be periodic or aperiodic

Core and Office Network	Highly variable	50 kHz to 40 MHz	10 bytes to 1500 bytes	50 000 packets per second to 1 packet per minute	Some type of quality of service/differentiated services mechanism	Non-essential, important, or essential	Could be periodic or aperiodic
External Access Networks	Highly variable	50 kHz to 40 MHz	10 bytes to 1500 bytes	50 000 packets per second to 1 packet per minute	Some type of quality of service/differentiated services mechanism	Non-essential, important, or essential	Could be periodic or aperiodic

2. The Role of IoT in Transforming Smart Grids

The conventional power grid's centralized structure and absence of security measures no longer suffice to meet increasing power demands, ensure reliability, and address the complexities of modern energy systems. Enter the Internet of Things (IoT), a technology paradigm aimed at connecting the previously unconnected. IoT has revolutionized various sectors, including healthcare, agriculture, transportation, Smart Cities, and, significantly, the electric grid. IoT-enabled smart grids employ sensors, actuators, and smart meters to enhance the grid's efficiency, resilience, and responsiveness. This integration is pivotal in preventing damage during natural disasters, reducing economic losses, and improving power transmission reliability. To successfully leverage IoT in the power industry, the digitization of assets, data collection, and the development of computational algorithms are essential. Telecommunication infrastructure must guarantee quality of service (QoS) and comply with industrial protocols and stringent security requirements to enable a smart grid's success.

Growth of the Internet of Things (IoT): The study highlights how the Internet has evolved from connecting people to connecting things. By 2008, more things were connected to the Internet than people, primarily in the form of the IoT. Cisco's prediction of 50 billion new IoT connections by 2020 is mentioned [3][9].

- Evolution of the U.S. Electric Grid: The study describes the traditional U.S. electric grid as a patchwork of monolithic, interconnected, and centrally controlled grids powered by large power plants. However, this legacy grid model is becoming nonviable due to various factors.
- Emergence of the Enernet: The Enernet is coined as the convergence of the smart grid with the IoT. It envisions a future where utilities, customers, and nonutility providers will need to manage and operate millions of distributed energy generation, storage, and management devices, leading to billions of new monitoring and control points.
- Grid's Approach to a Singularity: Similar to the concept of a singularity in astrophysics, the study suggests that the U.S. electric grid is approaching a point beyond which it will be unrecognizable, with new technological advancements leading to a fundamentally different grid.
- Erosion of the Legacy Grid: The study discusses how the traditional grid model faced challenges due to events like the oil embargo in the 1970s and how it has struggled to adapt to new demands, environmental concerns, and changing energy markets.

- **Factors Leading to Convergence:** The study identifies various factors contributing to the convergence of the smart grid and IoT, including the rise of distributed generation, microgrids, energy conservation, renewable energy, and competitive energy markets.
- **Disruptive Technologies:** The study emphasizes the impact of technological advancements, such as Moore's law and Wright's law, in accelerating the development of electronics and energy technologies, leading to a revolution in the utility industry.
- **The Internet and the Smart Grid:** The importance of the Internet in enabling the smart grid is highlighted, with a focus on digital technology's role in improving the reliability, security, and efficiency of the electric system.
- **Internet of Things (IoT):** The IoT refers to a system of interconnected physical objects that are linked to the Internet and equipped with embedded technology to independently sense, analyze, and take action. The study suggests that the IoT will play a crucial role in monitoring, analyzing, and controlling the future grid.
- **Integration and Interoperability:** The study emphasizes the need for integration and interoperability in the smart grid, advocating for the use of Internet protocol-based networks to replace proprietary systems and industry standards.

Overall, the study discusses the transformation of the electric utility industry as it embraces the Enernet, where the smart grid and IoT become inseparable, leading to new possibilities for energy management, efficiency, and innovation. Smart meters can be used to improve power quality and reliability in smart grids. They can be used to identify and diagnose power quality problems, monitor the reliability of the power grid, and develop new power quality and reliability improvement techniques. However, there are still some challenges to overcome, such as the need for more accurate and reliable data from smart meters, more efficient data routing algorithms, and new techniques to identify and diagnose power quality problems [4].

3. IoT-Enabled Smart Grid Technology Overview

IoT-enabled smart grid technology establishes a robust network connecting the public and machines through various sensing devices, infrared sensors, GPS, smart security systems, laser scanning, including RFID devices, and more. IoT applications span all facets of smart grid infrastructure, including power generation, transmission, distribution, and consumption. Within power generation, IoT monitors power plants, distributed energy sources, emissions, energy consumption, and more. In transmission, it oversees the entire power transmission network, including substations and network control. However, IoT's most prominent role lies in distribution, especially at the consumer end, where smart meters play a crucial role. IoT-enabled smart grids extend their influence into multi-network convergence, power demand management, electric vehicle charging, energy efficiency control, among other areas.

The publication authored by Abir and colleagues examines the structure and capabilities of IoT-enabled smart energy grid systems, with a particular emphasis on various IoT technologies such as sensing, computing technologies, communication, and their standards

in the context of smart energy grid. Additionally, the publication provides a thorough summary of previous research on IoT applications within the smart grid system [5][11].

The article highlights that the security risks associated with IoT technologies have been identified as a significant issue for energy systems enabled by IoT. Hence, the article examines the current threat and attack models pertaining to IoT-enabled energy systems and outlines strategies to mitigate the associated security vulnerabilities. The article emphasizes the potential of advanced technologies such as blockchain, machine learning, and artificial intelligence to enhance the resilience and security of IoT-enabled energy systems. By addressing current challenges, these technologies can improve the effectiveness, robustness, and reliability of energy system operations [5]. Key observations of this article- IoT can be used to transform the conventional power system network into an effective and smarter energy grid. Different IoT technologies can be used for different purposes in smart energy grid systems. There are a number of security vulnerabilities associated with IoT technologies. Advanced technologies can be used to mitigate the security vulnerabilities of IoT-enabled energy systems. IoT-enabled energy systems can be made more effective, robust, and reliable by using advanced technologies [5][10].

4. IoT-Enabled Smart Grid Architectures and Prototypes

This section dives into various IoT-enabled smart grid architectures and prototypes, elucidating the backbone technology that enables their operation. We explore the intricacies of these architectures and how they function in real-world scenarios, shedding light on their strengths and limitations.

Table 3. Comparison of traditional IoT-based SG architecture and all-in-one computing architecture [5]

Feature	Traditional IoT-based SG architecture	All-in-one computing architecture
Data processing	All data is processed in the cloud	Data is processed at the edge layer and in the cloud
Latency	High latency	Low latency
Scalability	Poor scalability	Good scalability
Security	Low security	High security

Table 4. Applications of EC-IoT-based SGs [5]

Application	Description
Power distribution	Improve the efficiency of power distribution systems
Advanced metering	Improve the accuracy and efficiency of advanced metering systems
Micro-grid systems	Improve the reliability and efficiency of micro-grid systems

The article by Khan et al, IoT can be used to develop power monitoring systems for SG applications. The proposed system is able to measure the current and voltage of the load accurately. The data collected by the system is stored in the cloud and can be accessed by the user using a web browser. The proposed system can be used by consumers to monitor their energy consumption and by utility companies to improve the efficiency of the

grid. The future work of this project includes the integration of the system with other IoT devices and the development of a mobile app for the user to access the data from the cloud [6].

Table 5. Results of the hardware prototype testing [6]

Parameter	Value
Current	10 A
Voltage	220 V
Active power	2200 W
Energy consumption	2.2 kWh

5. Security Issues and Challenges in IoT Integration

While IoT brings immense potential to smart grids, it also introduces security concerns that must be addressed. This section identifies key security issues and challenges associated with integrating IoT into smart grids, offering insights into safeguarding critical infrastructure.

Table 6. Challenges of using IoT for power monitoring in SG applications [6]

Challenge	Description
Security	IoT devices are vulnerable to cyberattacks.
Privacy	There are concerns about the privacy of data collected by IoT devices.
Interoperability	There is no single standard for IoT devices, which can make it difficult to integrate them with existing systems.
Cost	IoT devices can be expensive.

Table 7. Security challenges and their remedies [7]

Security Challenge	Solution
Weak security protocols	Use strong security protocols, such as TLS and DTLS. These protocols should be regularly updated to address new security vulnerabilities.
Lack of awareness of security risks	Make users of IoT devices aware of the security risks associated with these devices. They should be educated on how to protect themselves from cyberattacks.
Insecure data storage	Sensitive data stored on IoT devices should be encrypted. This will make it more difficult for attackers to steal this data.
Lack of authentication and authorization mechanisms	IoT devices should implement strong authentication and authorization mechanisms. This will help to prevent unauthorized users from gaining access to these devices.
Insecure communication channels	The communication channels between IoT devices and the cloud should be secured using encryption and other security measures. This will help to protect data from being intercepted and modified by attackers.

Vulnerabilities in IoT devices	Vulnerabilities in IoT devices should be addressed as soon as possible. This can be done by updating the software on these devices or by patching the vulnerabilities.
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6. Conclusions

The power system landscape has undergone significant transformations in recent decades, driven by increasing electricity demand, power losses, grid failures, and the need for smarter technology solutions. Traditional power grids, with their centralized structures and lack of security measures, are struggling to cope with the evolving challenges of modern energy systems. In response to these demands, the Internet of Things (IoT) has emerged as a transformative force, offering the potential to revolutionize the power industry.

IoT-enabled smart grids have the power to enhance the efficiency, capacity, reliability, sustainability, scalability, and stability of conventional grid systems. This comprehensive review has highlighted the critical role of IoT in addressing the various facets of smart grids, including security issues, applications, and frameworks. It has also explored the integration of both IoT and non-IoT technologies, such as sensing, communication, and computing technologies, along with relevant standards.

The fusion of contemporary information and communication technologies (ICTs) with power grids is essential to meet the growing influence of renewable energy sources like solar and wind. These decentralized energy sources significantly impact grid performance, necessitating advanced ICT solutions for effective monitoring and control. The study presented a case study showcasing the potential of IoT-based energy management frameworks to reduce peak loads and meet energy demands efficiently.

The IoT's role in transforming smart grids has been thoroughly examined, emphasizing the need for digitization of assets, robust data collection, and the development of computational algorithms. Ensuring the quality of service (QoS) and adhering to stringent security requirements are imperative for the successful implementation of IoT in the power industry. Furthermore, the study has traced the evolution of the Internet, its convergence with the smart grid to form the "Enernet," and the disruptive technologies driving this transformation.

IoT-enabled smart grid technology has been explored in-depth, showcasing its impact across power generation, transmission, distribution, and consumption. Smart meters and advanced monitoring systems are pivotal in improving power quality, reliability, and grid efficiency. However, security vulnerabilities associated with IoT technologies have been recognized as a major concern. The study has addressed these concerns and highlighted the potential of advanced technologies, including blockchain, machine learning, and artificial intelligence, to enhance the resilience and security of IoT-enabled energy systems.

Various IoT-enabled smart grid architectures and prototypes have been discussed, showcasing their strengths, limitations, and real-world applications. The transition from traditional IoT-based smart grid architecture to all-in-one computing architecture has demonstrated improvements in data processing, latency, scalability, and security. Applications such as power distribution, advanced metering, and micro-grid systems have highlighted the potential of IoT in enhancing efficiency.

Security challenges associated with IoT integration into smart grids have been identified, along with potential solutions. Addressing weak security protocols, raising awareness of security risks, securing data storage and communication channels, implementing robust authentication and authorization mechanisms, and promptly addressing vulnerabilities in IoT devices are essential steps in safeguarding critical infrastructure.

In conclusion, IoT-enabled smart grids hold immense promise in addressing the evolving challenges of the power industry. While security concerns must be addressed, the integration of IoT technologies, advanced monitoring systems, and the convergence of the Internet and smart grids represent a fundamental shift towards a more efficient, reliable, and sustainable energy future. As technology continues to advance, the smart grid's transformation into the E-Net is poised to redefine how we generate, distribute, and consume electrical energy, ushering in an era of innovation and resilience in the power sector.

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