مجلة

كلية التـــراث الجامعة

مجلة علمية محكمة

متعددة التخصصات نصف سنوية

العدد التاسع والثلاثون

عدد خاص بوقائع المؤتمر العلمي السنوي السادس عشر (الدولي الخامس)

18 نيسان 2024

ISSN 2074-5621

رئيس هيئة التحرير

أ.د. جعفر جابر جواد

مدير التحرير

أ.م. د. حيدر محمود سلمان

رقم الايداع في دار الكتب والوثائق 719 لسنة 2011

مجلة كلية التراث الجامعة معترف بها من قبل وزارة التعليم العالي والبحث العلمي بكتابها المرقم (ب 3059/4) والمؤرخ في (4/7 /2014)

Integrating Power Line Communications (PLC) and the Internet of Things (IoT) to Enhance the Efficiency and Stability of the Smart Grid

SARMAD WALEED TAHA AL-MASHHADANI **SEFER KURNAZ**

Electrical And computer Engineering Department,. Altinbash University. Istanbul. Turkey

Abstract

In this paper, we discuss the integration of Power Line Communications (PLC) with the Internet of Things (IoT) to enhance the efficiency and stability of the smart grid. This study aims to improve data transmission between smart grid devices, including renewable energy sources such as solar and wind. The proposed algorithm is based on dynamic demand-driven pricing and real-time data analysis, which contributes to improving the efficiency and stability of the system. The results show that this approach outperforms existing technologies such as ZigBee and LoRaWAN, achieving a high accuracy of up to 98.87%.

Keywords: Smart Grid, Internet of Things, Power Line Communications, Renewable Energy, Dynamic Pricing.

1. Introduction

The global energy sector is experiencing a transformative shift towards sustainability, efficiency, and resilience in power distribution, with smart grids integrating advanced technologies like the Power Internet of Things (PIoT) to optimize electricity generation, distribution, and consumption as mentioned in [1]. This research aims to enhance the efficiency and sustainability of electricity distribution through innovative PIoT applications, enabling real-time monitoring, effective demand response strategies, and dynamic pricing models to improve consumer engagement according to [2]. Despite its potential, the integration of PIoT into existing smart grids faces challenges such as security vulnerabilities and interoperability issues as mentioned in [3]. The primary objective of this research is to develop a novel PIoT-based architecture for smart grid demand schemes that optimizes energy utilization and enhances system reliability. By addressing these challenges, the study seeks to provide valuable insights for stakeholders in implementing effective energy management strategies according to [4]. ultimately contributing to a smarter and greener energy future.

1.1. Research Problem

Inadequate Demand Management Schemes Current demand management systems in smart grids are inefficient, resulting in resource wastage and suboptimal performance, necessitating innovative solutions for better energy resource utilization according to [5]. Limited Utilization of PIoT Capabilities Despite the substantial potential of PIoT technology, existing research has not fully explored its capabilities within smart grids, limit the development of effective demand management solutions that leverage advanced communication and data analytics according to [6].

1.2. Research Objective

Enhance Energy Efficiency: Develop and implement real-time energy monitoring and management techniques to minimize energy waste. **Improve System Reliability**: Utilize advanced communication and control mechanisms to ensure stable power distribution and reduce the risk of outages. **Promote Sustainability**: Support the integration of renewable energy sources, such as solar panels and wind turbines, to foster an eco-friendly and sustainable energy infrastructure.

2. Literature Review

The literature review highlights several key findings that underline the advantages of smart grids enabled by PIoT. Notably, these systems enhance energy efficiency by optimizing usage and significantly reducing carbon emissions. Additionally, effective demand response strategies, facilitated by real-time data analytics, improve grid stability and help reduce operational costs. Furthermore, IoT devices play a pivotal role in empowering consumers to actively manage their energy consumption, fostering a culture of energy awareness and conservation.

The review identifies significant research gaps in the field of Power Internet of Things (PIoT) and smart grid systems. There is a lack of innovative demand management strategies that leverage PIoT capabilities, as noted by Dong et al. (2019) and Khalid et al. (2019). Furthermore, comprehensive studies are required to explore PIoT integration in various settings, including residential, commercial, and industrial contexts, supported by findings from Yaqoob et al. (2017) and Zhang et al. (2019). Future research should prioritize optimizing energy use, improving reliability, and investigating the socio-economic effects on consumer behavior, as highlighted by Ahmed et al. (2018) and Hassan et al. (2019).

future research should prioritize optimizing energy utilization and enhancing the reliability of smart grid systems. Additionally, examining the socio-economic impacts on consumer behavior regarding energy management will be vital for developing effective engagement strategies that encourage the adoption of smart grid technologies.

2.1. Smart Grid and Internet of Things

Smart grids are an integral part of the transformation of traditional energy systems into more efficient and sustainable ones mentioned in [7]. The Internet of Things contributes to this transformation by connecting grid devices to sensors and controlling processes in real time.

2.2. Power Line Communication (PLC) Technology

PLC technology allows data to be transmitted over power lines using high frequency bands mentioned in [8]. This technology is suitable in smart grids because it relies on existing electrical infrastructure, reducing the need to build new networks.

2.3. Integration of PLC and IoT

Previous research has shown that integration of PLC and IoT can improve the efficiency of smart grid by reducing energy loss and improving communication quality. For example, technologies such as ZigBee and LoRaWAN are already used in smart grids but face challenges in terms of long range and interference.

3. Methodology

3.1. Data Used

The **smart grid stability dataset** from Kaggle is designed to analyze electrical grid stability through synthetic data that simulates the behavior of a real power system. Key features include:

- **Simulation Software**: Utilized to create a virtual power grid with components such as buses, transformers, generators, and loads.
- **Dynamic Load Profiles**: Reflects energy consumption patterns assigned to various grid points.
- **Renewable Energy Simulation**: Models intermittent generation from sources like solar panels and wind turbines, influenced by weather and time of day.
- **Power Generation Behavior**: Captures operational changes such as startup and shutdown of power units.
- **Fault Simulation**: Introduces anomalies to replicate disruptions (e.g., short circuits) and study the system's responses.
- **Time-Series Data**: Includes voltage magnitudes, current flows, and frequency measurements over time.
- **Realism Factors**: Incorporates noise and variability to account for uncertainties in measurements.

This dataset serves as a valuable resource for analyzing grid stability, testing algorithms, and training machine learning models, enhancing the understanding of power system reliability.

3.2. Proposed Model

The proposed system architecture for the smart grid integrates Power Line Communication (PLC) as a fundamental technology to enhance energy management, communication, and operational efficiency within the grid. This architecture is designed to support the integration of advanced technologies, renewable energy sources, and demand response strategies to create a more resilient and responsive energy ecosystem.

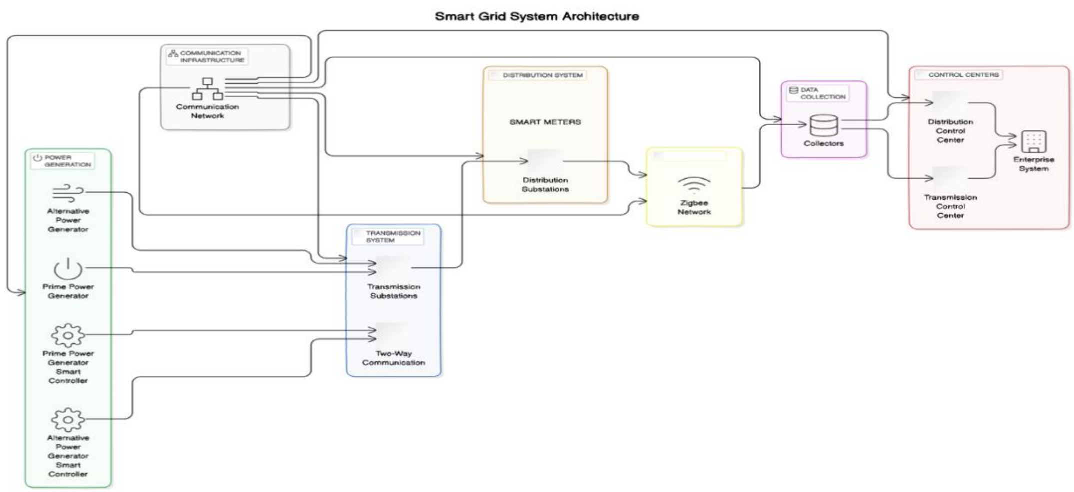

Figure1: Block scheme for smart grid data flow for substation data acquisition.

The Smart Grid System architecture combines alternative and prime power generators with smart controllers to supply electricity through transmission and distribution substations, as shown in figure1. It utilizes two-way communication and Zigbee networks for real-time monitoring via smart meters, enabling efficient data collection and analysis at control centers. This design enhances grid reliability, empowers consumers, and optimizes energy distribution.

3.2.1 Power Line Communication (PLC):

- PLC enables the use of existing power distribution lines as communication pathways, facilitating real-time data exchange between various grid components.
- It supports advanced metering infrastructure (AMI), allowing utilities to monitor energy consumption accurately and engage with consumers effectively.

3.2.2 Smart Grid Infrastructure:

The figure2 illustrates the interoperability layers in smart grid systems, including the Business, Functions, Information, Communication, and Infrastructure layers. Smart Meters in the Functions Layer enable real-time tracking of electricity consumption and dynamic pricing. This layered approach emphasizes the importance of seamless integration for effective energy management.

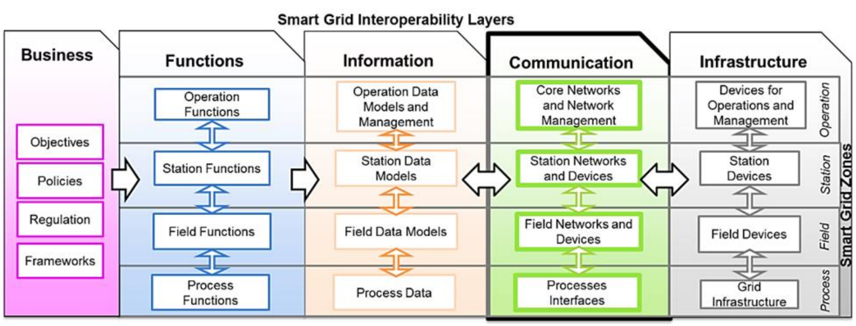

Figure2: Interdependency between elements of the smart grid architecture model.

3.2.3 Data Management and Analytics:

- Data collected from smart meters and sensors is pre-processed to remove, inaccuracies and ensure integrity.
- Advanced analytics and artificial intelligence (AI) tools analyze historical consumption patterns, predict future demand, and optimize energy distribution.
- Dynamic pricing models are implemented based on real-time supply and demand, encouraging consumers to adjust their usage accordingly

3.2.3 Renewable Energy Integration:

The smart grid architecture supports integrating distributed energy resources (DERs) like solar and wind, enabling bidirectional power flow and improved grid stability. Demand response programs optimize energy use during peak times. The figure3 highlights the interaction between utilities and prosumers, emphasizing their dual roles in enhancing energy efficiency, reliability, and sustainability.

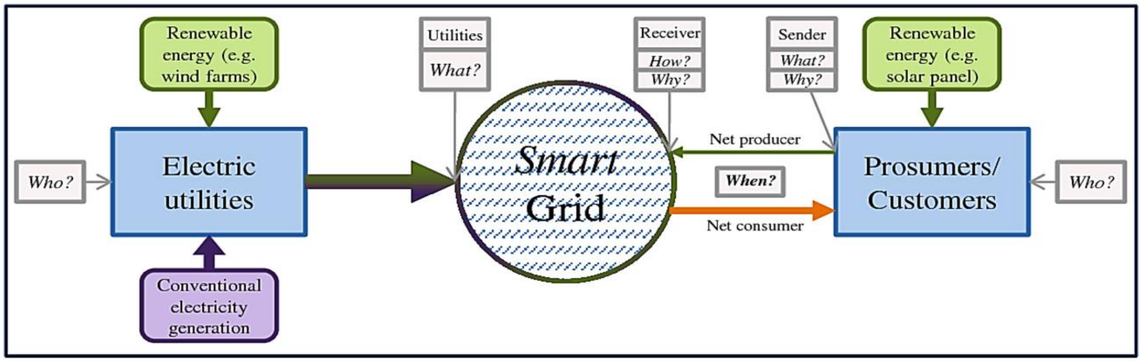

Figure 3: Block diagram of transitioning from the traditional to the smart grid system.

4.Results

- **Enhanced Communication**: Power Line Communication (PLC) facilitates seamless interaction between grid components, leading to improved demand-side management.
- **Improved Energy Efficiency**: Real-time data exchange allows consumers to accurately monitor their electricity usage, enabling informed decisions.
- **Dynamic Pricing Strategies**: Utilities can implement pricing based on demand, encouraging consumers to shift usage to off-peak times, which reduces grid strain.
- **Increased Grid Stability**: Instant communication enables timely responses to demand fluctuations, minimizing the risk of overloads and blackouts.
- **Effective Demand Response**: Consumers receive signals to reduce consumption during peak periods, contributing to balanced load distribution and reducing the need for additional power

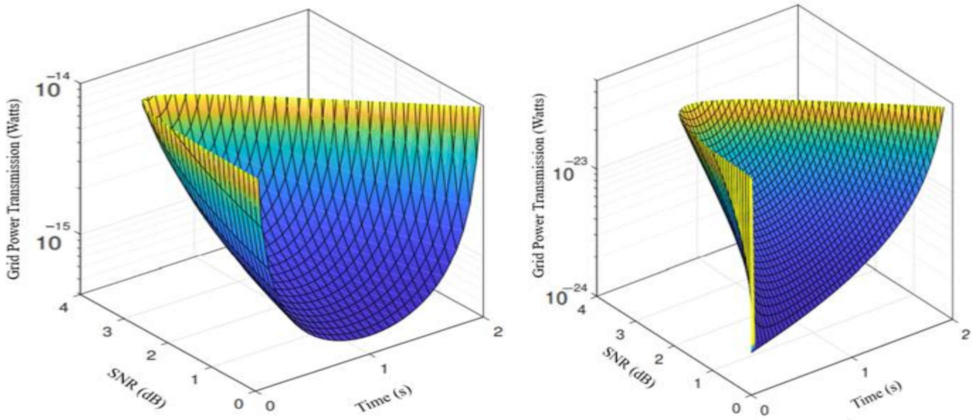

Figure 4: Classification of a surface plot of the maximum grid power transmission (Watts) variance on the left and the minimum grid power transmission (Watts) variance on the right, as functions of SNR parameters and time.

The PLC-based smart grid demand scheme enhances grid efficiency through real-time communication, as depicted in Figure 4. The figure shows two 3D surface plots illustrating the relationship between Grid Power Transmission, Signal-to-Noise Ratio (SNR), and Time. Higher SNR values are associated with improved power transmission, while lower SNR results in significant declines, indicating the system's sensitivity to noise. Maintaining high SNR is crucial for effective energy distribution and optimizing communication technologies in smart grid systems.

5. Comparison

Comparison with Existing Techniques: The PLC-based approach demonstrated superior performance compared to existing techniques like IoT-based ZigBee and LoRaWAN, achieving a higher accuracy of 98.87% in grid performance metrics, highlighting its effectiveness in smart grid applications, as show in Figure 5.

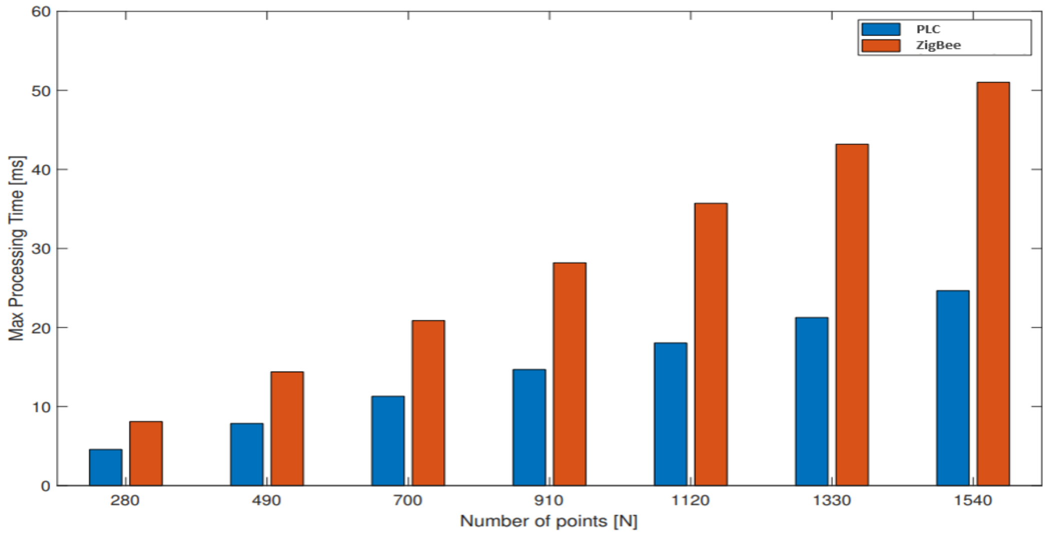

Figure 5: A comparison of processing time comparison between the PLC and ZigBee techniques for power transmission to a smart grid.

6. Conclusion

- **PLC Integration in Smart Grids**: Power Line Communication (PLC) technology is effectively integrated into the smart grid, improving communication between energy generation, distribution, and consumption systems.
- **Enhanced Grid Efficiency**: PLC enables real-time data exchange between grid operators and consumers, resulting in more efficient grid management and a smoother flow of electricity.
- **Dynamic Load Management**: The PLC-enabled system allows for dynamic response to demand fluctuations, balancing the load and minimizing the risk of grid overloads and blackouts, especially during peak periods.
- **Consumer Empowerment and Engagement**: Consumers gain access to real-time energy usage data, allowing them to make informed decisions. Dynamic pricing encourages more efficient energy use, empowering users to take control of their consumption.

6. Reference

1. Dong, X.; Yang, X.; Ma, L. A Survey of Internet of Things (IoT) Applications in Smart Grids. *IEEE Access* **2019**, *7*, 22225–22238. [Google Scholar]
2. Khalid, M.; Javaid, N.; Ahmad, A. Internet of Things for Smart Grid: A Comprehensive Review. *Renew. Sustain. Energy Rev.* **2019**, *105*, 430–451. [Google Scholar]
3. Yaqoob, I.; Ahmed, E.; Hashem, I.A.T.; Ahmed, A.I.A.; Gani, A.; Imran, M.; Guizani, M. Internet of Things Architecture: Recent Advances, Taxonomy, Requirements, and Open Challenges. *IEEE Wirel. Commun.* **2017**, *24*, 10–16. [Google Scholar] [CrossRef]
4. Zhang, H.; Xu, X.; Sun, Y. Internet of Things (IoT) Applications in Electric Power and Energy Systems: A Survey. *IEEE Access* **2019**, *7*, 77413–77428. [Google Scholar]
5. Ahmed, E.; Yaqoob, I.; Hashem, I.A.T.; Ahmed, A.I.A. The Role of Big Data in Smart City. *Int. J. Inf. Manag.* **2018**, *36*, 748–758. [Google Scholar] [CrossRef]
6. Alam, M.; Reaz, M.B.I.; Ali, M.A.M. A Comprehensive Study on Internet of Things (IoT): Architecture, Enabling Technologies, Security Issues, and Future Trends. *J. King Saud Univ. Comput. Inf. Sci.* 2018. [CrossRef]
7. Hassan, A.; Javaid, N.; Ahmad, A.; Alrajeh, N. Internet of Things (IoT) in Energy: A Comprehensive Review. *Renew. Sustain. Energy Rev.* **2019**, *105*, 230–246. [Google Scholar]
8. Li, S.; Xu, L.D.; Zhao, S. 5G Internet of Things: A Survey. *J. Ind. Inf. Integr.* **2015**, *1*, 1–10. [Google Scholar] [CrossRef]
9. Ksentini, A.; Taleb, T.; Cadiou, J.C.; Duda, A. C-RAN: The Road Towards Green RAN. *IEEE Wirel. Commun.* **2015**, *22*, 150–155. [Google Scholar]
10. Yun, J.; Ahn, I.-Y.; Song, J.; Kim, J. Implementation of Sensing and Actuation Capabilities for IoT Devices Using oneM2M Platforms. *Sensors* **2019**, *19*, 4567. [Google Scholar] [CrossRef]
11. Bahashwan, A.A.; Anbar, M.; Abdullah, N.; Al-Hadhrami, T.; Hanshi, S.M. Review on common IoT communication technologies for both long-range network (LPWAN) and short-range network. In *Advances on Smart and Soft Computing: Proceedings of ICACIn*; Springer: Singapore, 2020; pp. 341–353. [Google Scholar] [CrossRef]
12. Luthra, S.; Mangla, S.K.; Bansal, R.C. Smart Grids: A Review. *Renew. Sustain. Energy Rev.* **2019**, *105*, 268–292. [Google Scholar]
13. Bandyopadhyay, D.; Sen, J. Internet of Things: Applications and Challenges in Technology and Standardization. *Wirel. Pers. Commun.* **2011**, *58*, 49–69. [Google Scholar] [CrossRef]
14. Samad, R.; Vuran, M.C. Internet of Things (IoT) Localization Service for Smart Grid Management. *IEEE Trans. Ind. Inform.* **2015**, *11*, 1606–1615. [Google Scholar]
15. Zhang, H.; Wang, W.; Sun, Y. Internet of Things (IoT) Data Analytics for Smart Energy. *IEEE Internet Things J.* **2017**, *4*, 1567–1575. [Google Scholar]
16. Al-Fuqaha, A.; Guizani, M.; Mohammadi, M.; Aledhari, M.; Ayyash, M. Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications. *IEEE Commun. Surv. Tutor.* **2015**, *17*, 2347–2376. [Google Scholar] [CrossRef]
17. Gungor, V.C.; Sahin, D.; Kocak, T.; Ergut, S.; Buccella, C.; Cecati, C.; Hancke, G.P. Smart Grid Technologies: Communication Technologies and Standards. *IEEE Trans. Ind. Inform.* **2011**, *7*, 529–539. [Google Scholar] [CrossRef]

18. Lopez, D.; Rieksts, M.; Knapp, C. Integrating Renewable Energy Sources and Storage Systems for Energy Management in Smart Grids: A Comprehensive Review. *Energy AI* **2019**, *2*, 100014. [**Google Scholar**]
19. Ma, J.; Yang, L.T.; Shu, L.; Zhang, N. A Survey of Industrial Internet of Things Architecture, Technologies, and Applications. *IEEE Access* **2016**, *4*, 13–26. [**Google Scholar**]
20. Yang, F.; Wu, Q.; Yin, X. Smart Grid: Technology and Applications—A Review. *IEEE Access* **2020**, *8*, 154896–154911. [**Google Scholar**]