A systematic literature review of AI-enabled predictive analytics in smart grids

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Abstract
Smart grids (SG) transform a traditional electricity energy grid by incorporating many emerging disruptive technologies to produce clean, efficient, and dependable energy. This review focuses exclusively on one instance of AI application in SG - predictive analytics. We conducted a systematic literature review on AI applications in SG, which resulted in a review of 18 articles published after 2015. In the first part of the review, it is concluded that integrating AI into SG could address many challenges in SGs and transform traditional grids. The second part focuses on the predictive analytic capability enabled through AI in SG. Predictive analytics can be applied in many contexts to optimize decision-making, diagnose faults, and enhance grid stability. The last part presents two use cases for AI-enabled predictive analytics: energy outage prediction and security enhancement. AI, especially the predictive analytic technique, is a future avenue for SG enhancement. The main conclusion from the review is that more research describing empirical examples of the adoption and deployment of AI predictive analytics in SG is needed.

Keywords
Smart Grids, Artificial Intelligence, Predictive Analytics

1. Introduction

Emerging disruptive technologies such as artificial intelligence (AI) and the Internet of Things (IoT) have gained appeal globally in recent years. They are widely recognized for their innovative and transformative nature, which explains their practical applications across diverse industries [1, 2]. These developments have revolutionized the production and distribution of power[3]. This paper reports a structured literature review focusing on presented research on AI applications in the electronic power grid industry. In recent years, the electric power grid has seen significant transformation due to the adoption and applications of AI in combination with many disruptive technologies [4-8]. Smart grid (SG), which is the transformation from a conventional electric power grid, initially controlled by electromechanical means, to a grid network controlled by information and communication technologies (ICTs) [4, 5, 9], has emerged as a solution to growing energy needs. As

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described in the US Department of Energy's Smart Grid System Report, the SG encompasses information management, control technologies, digitally based sensors, ICTs, and field devices [1]. Under the SG concept, these components coordinate various electric operations. SG has evolved over the years due to advanced technologies such as AI. This is facilitated by the availability of data generated in SG and is used to train AI models, allowing SG to monitor, measure, and report electronic transmission processes. AI processes analyze generated data and produce patterns that assist human operators in accessing and utilizing data across the grid [1, 10]. For this reason, AI applications, in the form of predictive analytics, in SG are evolving and transforming SG to be more efficient, intuitive, and cooperative for all actors involved. Enabling a fully collaborative operating mode where each participant relinquishes their decision-making autonomy to a centralized system, works towards achieving global optimization, and allocates the resulting expenses to each participant. Global optimization, cost-sharing among actors, cost-effectiveness, environmental friendliness, stability analysis, and the generation of a reliable power grid are some benefits of AI applications in the SG [1, 11]. However, despite these benefits of AI application in SG, there is limited literature on how AI interpretability is addressed in SG to enhance trust and transparency. The lack of technical knowledge and the lack of ability to interpret AI decisions have not been addressed, raising trust concerns in the application of AI in SG.

This study, a structured literature review, aims to clarify the existing literature on AI applications in SG, analyze use cases, and determine how AI's interpretability can be defined in SG. It takes a different approach than existing studies on AI in SG, which only focuses on AI's technical ability without considering human understanding and interpretation of AI decisions.

Previous studies have predominantly tackled separate challenges, such as efficient stability analysis and control [11], power consumption, and peak hours prediction using Deep Learning (DL) [12-15]. The literature review will explore the literature from the perspective that there has been limited research on how AI's predictive models in SG can be transparent and easily understandable by humans. AI applications in SG can be enhanced when users step in when AI fails or becomes biased in addressing stability control, reliability, security, and transmission cost. Hence, our study seeks to leverage the recent developments in AI and its applications, big data, SG-generated data, and the capabilities of AI to explore how AI can be transparently applied to SG. To enhance human understanding of AI decisions and increase their engagement and autonomy to improve energy distribution and management in SG. The following research questions are explored in this paper:

RQ1: What is the current stage of reported research regarding AI in SG?

RQ2: How are predictive analytics for AI applications in SG portrayed in the literature?

RQ3: What can be learned from reported use cases on AI and predictive analytics applied in SG?

The paper is structured as follows. After the introduction, the next section provides information regarding the literature review method and process used in this paper. Section 3 provides an overview of the current stage of AI research in SG. Section 4 specifically discusses the predictive analytic technique enabled by AI in the context of SG. Section 5 provides two examples of use cases for predictive analytics in SG. The paper closes with a summary.

2. Systematic literature reviews

Our literature review follows the recommended systematic literature review approach by Webster and Watson [16]. This approach suits the research questions proposed in the introduction. It allows us to explore and explain the current stage of AI research in SG (RQ1). For this research question, our literature review covers all aspects of AI applications in SG, regardless of methodology, field, publication types, or places of publication Webster and Watson [13]. Regarding the research questions on predictive analytics (RQ2), we explore the effect of predictive analytics more deeply [17].

To achieve these goals, a study needed a broader viewpoint than a single primary study focused on a specific place. The study used an inductive technique to perform a systematic literature review, which was in line with our research purpose and followed specific protocols, including defining the scope, searching relevant literature, selecting representative methodologies, and analyzing acquired materials [16, 17]. To get a feel for the breadth of the literature covered around the topic, the study ran several searches on Scopus, IEEE Xplore, ACM, and Science Direct. The above databases were queried for pertinent publications about the subject of interest using the following keywords: artificial intelligence, smart grid, and predictive analytics. Also, Google Scholar was queried using the above keywords; from initial interesting articles, the "cited by" operator was used to filter search results. The initial search across these five databases yielded 748 articles, as shown in Table 1.

These papers underwent a second screening process. These initial screening criteria include: (1) articles must be presented in the English language, (2) full articles must be retrievable from our contracted repositories, and (3) articles should be peer-reviewed. The second screening process resulted in 81 articles, as shown in Table 1.

After the second screening of articles, we applied inclusion and exclusion criteria [1] to determine which articles should be included in this review. The inclusion criteria included (1) articles highlighting diverse technical AI application techniques, such as machine learning, reinforcement learning, and deep learning within the context of SG, and (2) articles published in and after 2015 since these AI application techniques evolved quickly. The exclusion criteria applied included (1) articles that do not contain empirical data, (2) articles that are unrelated to AI and larger-scale computing and/or networking infrastructure, and (3) articles on assistive devices. For the articles we were uncertain about, we checked their bibliographies to see if any could be useful for our evaluation and how relevant they were to the topic at hand [16]. This final screening process resulted in 18 articles being selected for review, as shown in Table 1. Table 2 provides a full list of all 18 articles selected for this literature review. In Table 2 a summary of key findings, research gaps identified, and the area of predictive analytics addressed in each of the research articles is presented.

Table 1
Summary of selected papers from the five databases used

Databases	1st search: String results	2nd screen: Relevant articles after	3rd screen: Selected articles	Percentage (%)
Google scholar	376	20	4	22.2
ACM	47	10	1	5.6
Scopus	112	12	2	12.1
Science Direct	174	26	7	38.9
IEEE Xplore	39	13	4	22.2
Total	748	81	18	100

Table 2 points out that research gaps within the reviewed SG literature can be divided into three areas:

1. Practical application: The study lacks practical case studies [3] and does not address the real-world challenges in implementing AI in smart grids (SG) [1, 18], including the interpretability of AI techniques, security concerns [12], efficiency, viability [19] , and environmental factors [20]. It also falls short of addressing real-time predictions[21].
2. Reliability and generalizability: It focuses on a single type of disaster, limits the generalizability of the findings [22, 23], does not consider the consequences of AI failures or false predictions [6, 24] , and relies mostly on the same type of dataset which is contrary to diverse and multidimensional data generated in SG [25].
3. Methodological limitations: The study relies solely on simulated experiences and systems control variables [11, 14], overlooking environmental factors [26] and the need for real-world testing [27] to validate the reliability and adaptability of reinforcement learning (RL) and the proposed framework. Also, Shi et al.[15] identify load aggregation to offset uncertainties, customer classification to cluster uncertainties, and spectral analysis using the same data set. Chae et al. [13] study falls short of addressing real-time electricity forecasting.

Table 2
Reviewed and Synthesized Articles

Article	Key findings/Results	Research Gaps identified	Address Predictive Analytics in SG
Olufemi A. and Haoran [1]	Applications of AI techniques can enhance and improve the reliability and resilience of SG systems.	It does not address the practical challenges in the implementation of AI in SG and how the interpretability of the different AI techniques can be solved.	Present different AI techniques used for predictive analytics in SG.
Bose [6]	AI applications are a powerful tool for SG and renewable energy.	The study is limited on simulated experiences, hence the need for practical case study. The study does not investigate what happens when AI fails or make false prediction.	Investigate the application of AI-driven predictive analytics in SG, for prediction, estimation, control, fault diagnostics, and fault tolerant.
Zhongtuo, Wei [11]	AI applications have achieved impressive results in stability and analysis control in SG. It also identifies some challenges, such as interpretability and large data requirements.	There is a need to explore new approach to train AI algorithms and make them human understandable. Also, there is a need to investigate how humans can help improve AI algorithms in SG.	Present a comprehensive review of AI techniques used for predictive analytics in SG for security and stability assessment, fault diagnosis and stability control.
Kehkashan et al. [22]	The effectiveness of ML algorithms and highlights some of the key issues and challenges of integrating ML algorithms in SG.	It focuses on a single type of disaster and the findings are not generalizable for other cases of natural disaster	Present AI-based predictive analytics for power outage prediction.
Abdullah et al. [18]	It shows how SG technologies and power distribution automation have improved sequentially over the past decade.	It only highlights the implementation challenges that arises, hence there is need to find methods and approaches to overcome these challenges.	Present how AI application together with other technologies enhances security and automation in SG

Article	Key findings/Results	Research Gaps identified	Address Predictive Analytics in SG
Barth et al. [24]	It proposes a distributed and autonomous AI model based on game theory using learning techniques from reinforcement learning.	It fails to recognize the possibility of failures within SGs and error or bias predictions by AI models.	Proposed using distributed machine learning algorithms to facilitate numerous actors in SG's decision-making process.
Feng, Zhou [26]	Presents the first complex-valued encoding artificial hummingbird algorithm, to reduce the algorithm's likelihood of local peak, and improved Complex Artificial Hummingbird Algorithm's problem-solving capacity.	There is a need to explore the proposed solution in other sources.	Present an artificial hummingbird method using complex-valued encoding. Predictive analysis for short term wind forecasting.
José R. and Zoltán [27]	Only few RL control algorithms are deployed in physical systems. There is limited evidence of RL algorithms' reliability and adaptability.	There is need for real-world study to ascertain the reliability and adaptability of RL.	Present a comprehensive review on the application of RL for demand response and explore different algorithms and models techniques.
Boopathy et al. [12]	This study covers deep learning (DL) applications for intelligent SGs and demand response.	Security concerns with enormous data accumulations, security issues with vulnerable centralized controllers, incomplete energy acquisition and inaccuracies in electric load forecast have not been addressed.	Comprehensive survey on the application of DL in smart grids and how predictive analytics can be leveraged for demand response predictions.
Cao et al. [19]	Provides a safe foundation for renewable hybrid AC-DC microgrids (MG) scheduling. The proposed framework considers renewable energy resources, microturbines (MTs), plug-in hybrid electric vehicles, and energy storage.	The suggested framework needs to be evaluated to determine it efficiency and viability before real-life implementation.	Present a framework of scheduling of renewable energy sources using real-time ML

Article	Key findings/Results	Research Gaps identified	Address Predictive Analytics in SG
Ahmad et al. [20]	It shows that tree-based ensemble methods improved prediction results of solar thermal energy with better accuracy.	The work only relies on systems control variable for training and testing of ML models, however there are also environment factor that need to be considered.	Compare different ML algorithms and identified the best performing algorithms for predictive modelling in solar thermal energy systems.
Ma et al. [14]	Competition among numerous stakeholders makes SG energy optimization scheduling difficult.	Findings are based on simulations, an implementation in a real-world scenario is necessary.	Proposed an optimized demand response strategy based on federated learning and Twin Delayed Deep Deterministic policy gradient algorithm, using RL.
Rahman et al. [23]	A fault tree (FT) analysis method for estimating distribution power system customer dependability has been developed.	The method Is not generalizable and does guarantee autonomous decision-making.	Developed a new predictive analytics method for predicting customer's reliability using FT.
Chae et al.[13]	A strong predictive model of energy consumption in buildings is useful not only for properly projecting future energy consumption, but also for establishing a good model predictive control (MPC) system that can reduce building energy expenses.	The study used stored dataset from a relational database, this limit the predictiveness of real-time electricity due the constant changing weather conditions making their predictive model less adaptive.	Present a data-driven forecasting model for sub-hourly electricity usage in building. Investigate predictive analytics for monitoring, analyzing and predicting electricity consumption.
Ahmad et al.[21]	It finds that ensemble-based methods have not sufficiently been addressed in energy prediction despite their growing popularity and advancement. It finds that ensembled-based methods offer better performance.	The study uses historical dataset for training and evaluation of machine learning algorithms; hence, real-time predictions is not possible with their models.	Compares random forest and artificial neural networks and identified which is best for energy prediction models in building. Explore the Predictive power of the different models in energy consumption prediction.

Article	Key findings/Results	Research Gaps identified	Address Predictive Analytics in SG
Khalid Muhammad[3]	Results shows that integration of AI into smart grid has some challenges, it also finds that despite a significant progress in AI, adoption of AI a smart grid still requires incorporating the right methodology and advanced technologies.	The study is a comprehensive literature review which highlights existing challenges of AI integration into power systems, however, the study does propose solutions to overcome existing challenges in AI incorporation into power systems	Investigate the application of predictive analytics for load and demand site forecasting. It also investigates the integration of AI and ML for predictive maintenance in SG.
You et al.[25]	AI-based stability evaluation tool can accurately and quickly measure frequency, transient, and tiny signal stability analysis in power grid.	The study focuses mainly on AI-based stability assessment, the method of model evaluation and testing is not clearly defined, which makes practical implementation and evaluation difficult.	Explore AI-based predictive analytics for grid stability assessment.
Shi et al.[15]	Their proposed strategy can significantly enhance household load forecasting. Compared to the state-of-the-art, the suggested technique outperforms ARIMA by 19.5%, SVR by 13.1%, and classical deep RNN by 6.5% in terms of RMSE with similar performance under other metrics.	Their proposed deep learning method works well with a specific dataset with a define set of features as well as rely on historical data. It does investigate the possibility of real-time analysis and diverse datasets and features.	Uses historic data from user's profiles to forecast household energy load. Uses big data and predictive analytics for household load forecasting.

3. AI application in SG

SG is a comprehensive electric energy system incorporating different technologies to offer many benefits over the traditional grid, such as stability, reliability, resilience, sustainability, and efficiency [6-9, 11]. Their operation spans throughout the process of electricity generation, transmission, substations, distribution, and consumption. They also integrate unpredictable and irregular renewable energy sources into the electronic grid to reduce pollution [12]. However, one of SG's most important functions is facilitating bidirectional energy flows, which enable individuals to consume and sell energy simultaneously [2]. Ensuring a well-functioning SG is a challenging task. Challenges such as security, stability, and reliability are present. Hence, the reliability assessment of SG has also gained interest through an analytic approach, which involves methods like fault-tree analysis and Markov modelling [23]. These techniques continue to evolve as AI is integrated into SGs as a solution [11].

SG can gather vast quantities of multi-type, high-dimensional data regarding electric power grid operations by integrating modern metering infrastructure, control technologies, and other advanced communication technologies. For these reasons, SG is seeing more benefits in integrating various AI methods to improve its functionalities. These AI methods can improve many limitations with conventional modeling, optimization, and control analysis used in the traditional grid [1] to transform it into a more efficient, stable, and reliable SG.

AI has exhibited much human-like thinking and behaviors [11, 28]. Its application into SG means fewer human interventions will be required to manage the grid. With advancements in computational power, data volume, and data modeling techniques, AI has reemerged in the 2020s as a crucial component of various industries, economies, and aspects of daily life after its ups and downs in prior decades. AI improvement and application in SG have enabled SG to meet stringent dependability, security, and stability standards [11]. AI provides automated control and timely stability analysis necessary to achieve these standards.

Many AI techniques, such as machine learning, deep learning, and reinforcement learning, are continuously integrated into the SG [6, 12, 19, 22, 27]. These AI techniques enhance the performance benefits of SG, such as improved stability control, fault diagnosis, security evaluation, and stability assessment, reduced transmission cost, and enabled seamless demand and supply of power with others [7, 18, 22, 23]. The research on AI applications in SG has accomplished some remarkable milestones due to the advancement of technology in accuracy, security, speed, and effectiveness, combined with a decrease in the human workload field [11].

Finally, AI applications in SG have largely ignored one of the prevalent topics in social science research on algorithms: AI interpretability [29]. This raises concerns about trust and transparency in SG as AI algorithms' models and decisions are not understood by users and can also make false or biased predictions.

4. Predictive analytics - an instance of AI application in SG

Due to a technique called predictive analytics, modern AI models are becoming indispensable tools for risk prediction and decision-making process optimization [10]. Predictive analytics leverage technologies like data mining, predictive modeling, and machine learning to examine historical and real-time data and make predictions. The technique has become the "modern oracles of our networked digital age" [4]. AI in SG is largely adopted to enhance predictive analytics within SG for fault diagnosis, prediction of future happenings, decision-making, and optimization.

The AI-enabled predictive analysis in SG helps address some of the most pressing issues around energy consumption, climate change, energy transmission costs, and managing and predicting the spread of energy demand and grid stability. Addressing energy consumption issues in an environment where energy prices are dynamically decided based on the peak energy consumption and short-term load forecasting of building electricity usage[13], requires the adoption of predictive analytics. Hence, energy producers and consumers are beginning to accept predictive analytics as fact and exploring ways to enhance the prediction [26]. Ahmad, Reynolds [20] laid the groundwork for predicting solar thermal energy's hourly usefulness using machine learning algorithms. In their work, they trained and tested several machine-learning models using experimental data collected. Similarly, Bose [6] states that AI approaches are incredibly potent tools in SG power systems. Bose provides a concise but thorough overview of three significant areas of artificial intelligence: expert systems (ES), fuzzy logic, and artificial neural networks.

Furthermore, Bhuiyan, Hossain [5] provides a detailed and understandable overview of the current adoption of predictive analytics in SG to enable grid stability analysis and control. Similarly, AI in SG provides a thorough analysis to evaluate SG security, stability, fault diagnosis, and stability control [18].

However, as Latour [30] put it, the scientific and technical effort behind an invention often goes unnoticed due to its achievements. When a machine operates efficiently and a matter is definitively resolved, one concentrates solely on its inputs and outputs. One often disregards the underlying complexities and mechanisms of how the machine operates to resolve the matter [30]. Hence, ironically, as AI applications in SG evolve, they become increasingly perplexing and difficult to comprehend [30]. The complexities of AI algorithms raise trust concerns and diminish its benefits. Therefore, to enjoy the full benefit of AI in SG, there is a need for transparency in the design of AI models. This will address transfer learning challenges, make AI resilient to communication quality and security, and attack adversarial instances [18, 27, 31]. To understand how AI models in SG can be made transparent and human-understandable, the next section explores two use cases from past literature where predictive analytics have been used. These two cases have been identified due to their overwhelming integration of renewable energy sources and offer an opportunity to identify how AI interpretability can be addressed to make AI models and AI decisions humanly understandable through integrating domain expertise in the training of AI models.

5. Use cases of AI predictive analytics in SG

AI-enabled predictive analytics can enhance SG's many functions, as described in the following two use cases reported regarding AI applications in SG.

5.1. AI for power outage prediction in SG

The growing demand for clean energy, integration of renewable energy sources, and the risk of power outages in several global marketplaces are just a few new challenges facing the traditional grid [2]. These result from underinvestment in renewable energy sources and grid infrastructure, a lack of maintenance, a poorly optimized structure, and severe weather events like snowfall, tornadoes, and cyclones. The digital disruption offered in SG, including capacities like real-time communication, data storage, and predictive future happenings, could overcome these challenges in the traditional grid [32]. Analysis-based decision-making is made possible by various sensors distributed across transmission and distribution networks and monitoring and control equipment.

A strong use case of AI in SG is power outage prediction. AI could enable SG to deliver dependable yet cost-effective electricity to consumers across the network. The predictive analysis feature offered through AI could become more beneficial if producers and consumers can understand and interpret AI decisions and step in when AI fails or makes false predictions. Understanding the predictive information across the grid is crucial to take necessary actions to avoid a power outage. For example, electricity producers can incorporate future happenings forecasted by AI into their planning and strategy formulation to address the growing demand for energy while tackling a social commitment to climate change. Consumers could use this information to reduce unnecessary energy consumption during peak periods. AI power outage predictions in SG bring about effective stability analysis and control, which are necessary to guarantee reliable operation

5.2. AI-enhanced security in SG

To guarantee the SG's economic efficiency and secure operation, AI-enabled security approaches have been used in dynamic pricing strategy by performing distributed optimization on the multi-agent system to obtain the optimal network weights for different stakeholders [14]. Also, AI algorithms have been trained to detect any abnormality and predict potential attacks to protect stakeholders' privacy by forbidding the exchange of personally identifiable information. Successfully tackling the issues of privacy and competitiveness in economic scheduling. Where numerous stakeholders are dominant by using AI-based distributed optimization systems to improve trustworthiness. Similarly, AI and blockchain-enabled solutions for scheduling, managing, organizing, and optimizing SG power distribution have been proposed for security in SG [18]. It protects the integrity and secrecy of transaction executions to immutable storage in encrypted blocks.

Furthermore, AI capabilities provide a unique advantage to using AI-enabled smart contracts to respond quickly to emerging cyber threats, such as a cyber-physical fusion event or a climate calamity that occurs organically. This would lead to the automated and robust management of some power grid functions. Integrating AI and blockchain technology may create a defense against unauthorized attempts to alter formations or web and sensor scenes instantly and simultaneously [18]. However, the proposed AI algorithms remain largely opaque to many actors within the SG. Addressing the aspect of AI interpretability offers the opportunity to improve the efficiency and effectiveness of the AI. Enhance human understanding of AI models and interpretation of AI decisions and allow humans to come in when AI fails or makes biased predictions. Using algorithmic refraction, the study of the changes that occur when computational software, individuals, and institutions interact [29]. This will improve the security and performance of AI applications in SG, demonstrating the primary advantages of SG innovation and how AI can advance SG security [33, 34].

6. Conclusions and future research

Smart grids (SG) are a technology that offers a framework for producing, distributing, and using environmentally friendly, efficient, and dependable energy. SG functionalities have been improved significantly due to its integration with other emerging disruptive technologies such as AI. Our study's core focus was on the latest academic literature on the development of AI applications in SG, with a specific interest in a particular instance of AI application namely predictive analytics. The structured literature review study viewed 18 articles published after 2015 on AI applications in SG, specifically focusing on predictive analytics.

Based on the first research question regarding the current state of AI research in SG, the literature review concludes that SG offers superior stability, reliability, and efficiency over traditional grids. Integrating AI addresses many challenges in SG and traditional grids, enhances performance, and reduces human intervention in managing energy flow. The second research question concludes that AI-driven predictive analytics in smart grids optimize decision-making, diagnose faults, and enhance grid stability, addressing energy consumption challenges is viewed mostly from the technical perspective. Hence, there is a need to explore AI interpretability in SG to increase efficiency and trustworthiness. The last research question presents two use cases for predictive analytics in SG, which are (1) energy outage prediction and (2) security enhancement. It highlights how AI adds another layer of opacity and discusses how it can be delineated. Our literature review examines what has been done so far in the context of AI applications in SG and highlights the necessity of making AI algorithms in SG transparent. Our findings show that with the recent advancements in AI and the increasing amount of data in SGs, the predictive analytic technique in AI offers robust tools for optimizing SGs and increasing complexity.

The reviewed literature contributes to the discussion on AI-enabled predictive analytic functions in SG. It demonstrates adopting design methods that uncover unforeseen elements of algorithmic systems, such as AI interpretability concerns, has great potential to enhance AI applications in SG. Nevertheless, the literature is limited, and the body of literature could be more extensive. The full benefit of AI applications in SG can be achieved if a study explicitly included algorithms in ethnographic research to uncover unforeseen elements of algorithmic systems, not addressed in the reviewed literature. Hence, future studies can go a step further by exploring methodologies for doing algorithmic ethnography in SG. Many practical issues regarding AI implementation in SG, such as bias predictions, must be addressed based on empirical data. Therefore, future studies could explore these issues. However, a major conclusion from this review is that more research with concrete empirical examples of how to adopt and deploy AI and especially predictive analytics in SG is needed. Doing this kind of research focusing on AI interpretability and predictive analytics models within SG would benefit the development of smart grids.

References

[1] A. Olufemi, O. and N. Haoran, *Artificial Intelligence Techniques in Smart Grid: A Survey* Smart Cities, 2021.

[2] J. Wang, M. K. Lim, C. Wang, M. L. Tseng, *The evolution of the Internet of Things (IoT) over the past 20 years.* Computers & Industrial Engineering, 2021. 155.

[3] M. Khalid, *Energy 4.0: AI-enabled digital transformation for sustainable power networks.* Computers & Industrial Engineering, 2024.

[4] G. W. Arnold, *Challenges and Opportunities in Smart Grid: A Position Article.* Proceedings of the IEEE, 2011.

[5] E. A. Bhuiyan, M. Z. Hossain, S. M. Muyeen, S. R. Fahim, S. K. Sarker, S. K. Das, *Towards next generation virtual power plant: Technology review and frameworks.* Renewable and Sustainable Energy Reviews, 2021.

[6] B.K. Bose, *Artificial Intelligence Techniques in Smart Grid and Renewable Energy Systems—Some Example Applications.* IEEE XPLORE, Proceedings of the IEEE, 2017. 105(11): p. 2262 - 2273.

[7] S. Dhara, A.K. Shrivastav, P.K. Sadhu, *Smart grid modernization: Opportunities and challenges.* Electric Grid Mod, 2022.

[8] Md. M. H. Sifat, S.M. Choudhury, S. K. Das, Md. H. Ahamed, S. M. Muyeen, Md. M. Hasan, P. Das, *Towards electric digital twin grid: Technology and framework review.* Elsevier, Energy and AI, 2023. 11.

[9] M.C. Falvo, L. Martirano, D. Sbordone, E. Bocci, *Technologies for smart grids: A brief review*, in *12th International Conference on Environment and Electrical Engineering*. 2013, IEEE: Wroclaw, Poland.

[10] C. Lazaro, M. Rizzi, *Predictive analytics and governance: a new sociotechnical imaginary for uncertain futures.* International Journal of Law in Context, 2023.

[11] Z.S. Shi, W. Yao, Z. Li, L. Zeng, Y. Zhao, R. Zhang, Y. Tang, J. Wen, *Artificial intelligence techniques for stability analysis and control in smart grids: Methodologies, applications, challenges and future directions.* Applied Energy, Elsevier 2020.

[12] P. Boopathy, M. Liyanage, N. Deepa, M. Velavali, S. Reddy, P. K. R. Maddikunta, N. Khare, T. R. Gadekallu, W. J. Hwang, Q. V. Pham, *Deep learning for intelligent demand response and smart grids: A comprehensive survey.* Elsevier, 2024. 1574-0137.

[13] Y.T. Chae, R. Horesh, Y. Hwang, Y. M. Lee, *Artificial neural network model for forecasting sub-hourly electricity usage in commercial buildings.* Energy and Building, 2016. Vol. 111: p. pp. 184-194.

[14] H. Ma, H. Zhang, D. Tian, D. Yue, G. P. Hancke, *Optimal demand response based dynamic pricing strategy via Multi-Agent Federated Twin Delayed Deep Deterministic policy gradient algorithm.* Engineering Applications of Artificial Intelligence, Elsevier, 2024.
[15] H. Shi, M. Xu, R. Li, *Deep Learning for Household Load Forecasting—A Novel Pooling Deep RNN.* IEEE TRANSACTIONS ON SMART GRID, 2018. Vol. 9(pp 5).
[16] J. Webster, R.T. Watson, *Analyzing the Past to Prepare for the Future: Writing a Literature Review.* MIS Quarterly, 2002. Vol 26.
[17] N. Jahan, S. Naveed, M. Zeshan, M. A. Tahir, *How to Conduct a Systematic Review: A Narrative Literature Review.* Curēus (Palo Alto, CA), 2016. Vol.8 (11): p. 864-872.
[18] A. A. Khan, A. A. Laghari, M. Rashid, H. Li, A. R. Javed, T. R. Gadekallu *Artificial intelligence and blockchain technology for secure smart grid and power distribution Automation: A State-of-the-Art Review.* Sustainable Energy Technologies and Assessments, 2023.
[19] H. Cao, D. Zhang, S. Yi, *Real-Time Machine Learning-based fault Detection, Classification, and locating in large scale solar Energy-Based Systems: Digital twin simulation.* Solar Energy, 2023.
[20] M.W. Ahmad, J. Reynolds, Y. Rezgui, *Predictive modelling for solar thermal energy systems: A comparison of support vector regression, random forest, extra trees and regression trees.* Journal of Cleaner Production, 2018.
[21] M. W. Ahmad, M. Mourshed, Y. Rezgui, *Trees vs Neurons: Comparison between random forest and ANN for high-resolution prediction of building energy consumption.* Ernergy and Buildings, 2017. Vol. 147: p. pp. 77-89.
[22] K. Fatima, H. Shareef, F. B. Costa, A. A. Bajwa, L. A. Wong, *Machine learning for power outage prediction during hurricanes: An extensive review.* The International Journal of Intelligent Real-Time Automation, 2024.
[23] F.A. Rahman, A. Varuttamaseni, M. Kintner-Meyer, J. C. Lee, *Application of fault tree analysis for customer reliability assessment of a distribution power system.* Reliability Engineering & System Safety, 2013. 111: p. 76-85.
[24] D. Barth, B. Cohen-Boulakia, W. Ehounou, *Distributed Reinforcement Learning for the Management of a Smart Grid Interconnecting Independent Prosumers.* Energies, 2022. 15.
[25] S. You, Y. Zhao, M. Mandich, Y. Cui, H. Li, H. Xiao, Y. Zhang, *A Review on Artificial Intelligence for Grid Stability Assessment*, in *2020 IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm)*. 2020, IEEE.
[26] L. Feng, Y. Zhou, Q. Luo, Y. Wei, *Complex-valued artificial hummingbird algorithm for global optimization and short-term wind speed prediction.* Expert Systems with Applications, 2024.
[27] J. R. Vásquez-Cantelli, Z. Nagy, *Reinforcement learning for demand response: A review of algorithms and modeling techniques.* Applied Energy, Elsevier, 2019.
[28] F. Li, Y. Du, *From alphaGo to power system AI : What engineers can learn from solving the most complex board game.* IEEE Power Energy Mag, 2018. 16: p. pp. 76-84.
[29] A. Christin, *The ethnographer and the algorithm: beyond the black box.* Theory and Society: Springer Nature 2020.

[30] B. Latour, *Pandora's hope: Essays on the reality of science studies. Cambridge.* Harvard University Press., 1999a.

[31] M., Faheem, S. B. H. Shah, R. A. Butt, B. Raza, M. Anwar, M. W. Ashraf, Md.A. Ngadi, V. C. Gungor, *Smart grid communication and information technologies in the perspective of Industry 4.0: Opportunities and challenges.* Computer Science Review, 2018.

[32] O. Velsberg, U. H. Westergren, K. Jonsson, *Exploring smartness in public sector innovation - creating smart public services with the Internet of Things.* European Journal of Information Systems, 2020. 29.

[33] R.K. Beniwal, M. K. Saini, A. Nayyar, B. Qureshi, A. Aggarwal, *A critical analysis of methodologies for detection and classification of power quality events in smart grid.* IEEE Access, 2021.

[34] T. Liu, Y, Sun, Y. Liu, Y. Gui, Y. Zhao, D. Wang, C. Shen, *Abnormal traffic-indexed state estimation: A cyber–physical fusion approach for Smart Grid attack detection.* Future Generation Computer Systems, 2015.