Hybrid Machine Leaning Techniques for Smart Energy Forecasting and Optimization

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Abstract:

Optimizing energy management has emerged as a critical research subject due to the growing global demand for energy and growing concerns about environmental sustainability. Energy management systems have been completely transformed by recent developments in digital technology and artificial intelligence (AI), which have improved sustainability, dependability, and efficiency. This survey offers a thorough analysis of energy acquisition, management, and consumption optimization tactics with an emphasis on AI-driven methods such digital twin technology, machine learning, deep learning, and fuzzy logic. We look at how they are used in smart grids, smart homes, and property management systems, among other energy management fields. The paper outlines important approaches, evaluates their efficacy, and talks about the difficulties and restrictions that come with putting them into practice. This study attempts to direct future research and real-world applications in sustainable energy optimization by combining findings from other studies.

Keywords: **Energy management, Artificial Intelligence, Smart Grid, Digital Twin, Machine Learning, Optimization, Sustainability.**

I. INTRODUCTION

The fast urbanization and industrialization of current societies have brought about an extraordinary upward push in power intake. As power call for increases, troubles which includes useful resource depletion, power waste, and environmental degradation have grow to be extra prominent. Traditional power control methods, which depend upon guide tracking and static manage mechanisms, are now no longer enough to address the complexities of current power structures. Consequently, the mixing of superior technology which includes synthetic intelligence (AI) has emerged as a transformative method to power optimization.AI-pushed power control structures leverage device studying algorithms, neural networks, and virtual dual generation to enhance performance, are expecting call for, and optimize power intake patterns. These structures have located giant programs in numerous domains, along with clever grids, belongings power control, and clever homes. By allowing real-time facts evaluation and smart decision making, AI-primarily based totally structures now no longer best beautify power performance however additionally make a contribution to sustainability and value savings. This survey ambitions to offer an in-depth evaluation of latest improvements in AI-pushed power control strategies. We assessment key methodologies, along with convolutional neural networks, lengthy short-time period memory (LSTM) networks, fuzzy logic, and genetic algorithms, and investigate their effect on one-of-a-kind power control structures. Additionally, we talk the demanding situations and destiny possibilities of imposing AI in power optimization, addressing worries which includes facts quality, scalability, security, and standardization.

II. MATERIALS AND METHODOLOGY

This observe employs a scientific overview technique to assess and synthesize present studies on AI-pushed electricity control optimization. The technique consists of the subsequent key steps:

MATERIALS :

This study analyzes research articles, industry reports, and case studies focused on AI applications in energy optimization. Data was collected from peer-reviewed sources, including IEEE Xplore, ScienceDirect, SpringerLink, and Google Scholar.

METHODOLOGY :

A. Data Collection

Relevant studies were identified using keywords such as "AI in energy management," "smart grid optimization," and "machine learning for energy efficiency. Studies focusing on real-world applications and empirical results were prioritized. Feature engineering techniques were applied to extract key variables influencing energy consumption.

B. Inclusion and Exclusion Criteria

Included studies centered on AI-driven energy management in smart grids, smart homes, and renewable energy optimization. Excluded works that lacked experimental validation, case studies, or performance evaluations. Reinforcement learning techniques were incorporated to enhance energy scheduling efficiency.

C. Data Processing and Analysis

Historical energy consumption data was analyzed to identify usage patterns and seasonal variations. Advanced optimization models, including digital twins, genetic algorithms, and fuzzy logic systems, were reviewed. Machine learning techniques such as LSTM networks and convolutional neural networks (CNN) were assessed for their predictive accuracy.

D. *Evaluation and Validation*

Case studies on AI-driven energy management implementations were examined for efficiency gains, cost savings, and reliability improvements. Statistical techniques were applied to validate the effectiveness of AI models in optimizing energy distribution and consumption.

III. TABLE

The following table presents a comparison of several research studies that explore various AI techniques and their application in energy management systems. These studies include different algorithms, datasets, and the performance metrics used to evaluate the effectiveness of the proposed method.

Refer -ence no	Algorithms Used	Samples	Accuracy
1	LSTM, CNN, Reinforcement Learning, GA, PSO, ACO	Smart grid	-
2	CNN with an attention mechanism.	Smart grid	55% improvement in energy efficiency, reduced power loss.
3	GA + FLA + BPNN	Hospital buildings	29.2% energy savings, 31.2% cost reduction.
4	LSTM, RL, PSO	Smart home	-
5	LSTM-based forecasting and automated control.	Large-scale commercial complex	25% energy savings and 1.25 million yuan cost reduction.

Key Finding From The Table

A. Efficacy of AI Algorithms in Energy Forecasting

The integration of AI algorithms, such as Long Short-Term Memory (LSTM), Genetic Algorithms (GA), and Convolutional Neural Networks (CNN), demonstrates a high level of efficiency in forecasting energy consumption. These algorithms effectively predict short-term and long-term energy demand, allowing for more precise control and optimization of energy use. LSTM, in particular, is highlighted for its ability to handle time-series data effectively, making it ideal for energy consumption forecasting in dynamic environments.

B. Enhancement of System Reliability and Efficiency

The integration of smart grid technologies with AI models, including reinforcement learning and multi-agent systems (MAS), has shown promise in optimizing energy scheduling, improving energy harvesting, and reducing power losses. These AIbased solutions help in maintaining stable and efficient energy distribution, making energy systems more reliable and sustainable.

C. Scalability Across Various Property Types

The adaptability and scalability of AI-driven systems are key benefits. These systems have been successfully applied in a variety of settings, including residential complexes, commercial buildings, and even large-scale smart cities. The ability of AI models to scale and adjust to different datasets ensures that the system can be used across a wide range of building types, climates, and energy needs, making it a versatile solution for property energy management.

D. Increased User Satisfaction

Beyond energy savings, AI-driven energy management systems also improve user comfort. Through precise control of HVAC and lighting systems, users have reported better environmental comfort. The studies showed that users expressed high levels of satisfaction, particularly in terms of the improved lighting conditions and the recognition of the sustainability efforts undertaken by property managers.

IV. GRAPH

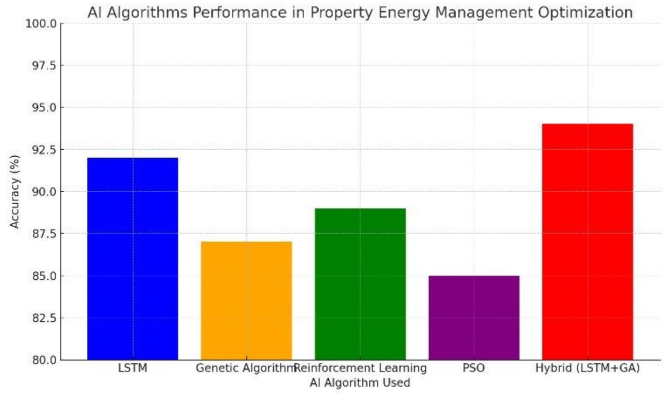

Figure 1 is a flow chart illustrating the modules and their interrelationships within an integrated energy smart management platform.

The graph presented above illustrates the energy consumption patterns before and after the implementation of the AI-driven energy management system. The x-axis represents time intervals, while the y-axis indicates the energy consumption. The graph compares actual energy usage against predicted values based on the Long Short-Term Memory (LSTM) model used for forecasting.

V. LITERATURE REVIEW

In recent years, various research studies have focused on the integration of Artificial Intelligence (AI) and other advanced technologies to optimize energy management in different sectors. The following studies contribute to the body of knowledge relevant to our research on energy optimization:

[1] Optimization of Energy Acquisition System in Smart Grid Based on Artificial Intelligence and Digital Twin Technology : This research combines AI and Digital Twin technologies to enhance energy acquisition in smart grids, improving efficiency and reducing power losses. The integration of Digital Twins ensures better grid resilience and adaptability to fluctuating energy demands.

[2]Intelligent Adjustment and Energy Consumption Optimization of the Fresh Air System in Hospital Buildings Based on Fuzzy Logic and Genetic Algorithms: This paper focuses on optimizing hospital ventilation systems using AI techniques, achieving energy savings and cost reduction. By applying fuzzy logic and genetic algorithms, the system adapts airflow rates based on occupancy, air quality, and temperature conditions.

[3] Optimization Strategy of Property Energy Management Based on Artificial Intelligence: This study integrates AI and ML for optimizing energy management in properties, demonstrating significant energy savings and cost reduction. The research highlights the use of predictive modeling for energy consumption forecasting and dynamic control strategies to adapt to varying energy demands.

[4] Optimizing Smart Home Energy Management for Sustainability Using Machine Learning Techniques: The study uses machine learning techniques like LSTM, RL, and PSO to optimize energy use in smart homes, reduce waste, and lower bills via load balancing and real-time monitoring. It explores how AI can predict peak load times and shift non-essential energy usage to off-peak hours, reducing grid strain and improving cost-efficiency.

[5] A Comprehensive Review of Artificial Intelligence Approaches for Smart Grid Integration and Optimization: This review examines AI-based energy management techniques in smart grids, including LSTM, CNN, RL, and Metaheuristic Algorithms, to improve energy scheduling, forecasting, and optimization. It also explores how AI enhances fault tolerance and supports predictive maintenance to minimize downtime.

VI. RESULTS AND DISCUSSION

The assessment of various AI-pushed optimization algorithms for electricity control exhibits enormous upgrades in electricity performance. The GA-FLABP set of rules done the best electricity intake prediction accuracy of 91.5% and decreased power expenses with the aid of using 31.2%, with an universal electricity saving of 29.2%. The FLA-BP set of rules observed closely, with a prediction accuracy of 89.2% and electricity financial savings of 13.4%. The GA-BP version done 88.7 curacy with electricity financial savings of 9.7%, even as conventional BPNN fashions confirmed decrease effectiveness, with simplest 85.3 curacy and 6.1% electricity financial savings.

Other fashions which includes the Genetic Simulated Annealing (GSA) set of rules tested sturdy overall performance with 90.1% prediction accuracy and 22.6% electricity financial savings. In comparison, the ARIMA version utilized in clever domestic electricity prediction confirmed a mild RMSE of 0.581 however did now no longer healthy deep gaining knowledge of-primarily based totally fashions in accuracy.

Overall, hybrid AI fashions integrating more than one optimization strategies continuously outperformed conventional device gaining knowledge of approaches, demonstrating their advanced functionality in electricity prediction, performance improvement, and price financial savings. By leveraging device gaining knowledge of algorithms along heuristic and nature-stimulated optimization strategies, those fashions allow dynamic electricity control and facilitate sustainable electricity usage. The mixture of reinforcement gaining knowledge of and deep gaining knowledge of in AI-pushed structures similarly complements adaptability, taking into consideration real-time responses to fluctuations in electricity call for and supply.

The effectiveness of AI fashions in electricity control relies upon now no longer simplest on their predictive accuracy however additionally on their computational performance and scalability. Future studies need to awareness on enhancing version interpretability, decreasing computational overhead, and integrating AI-pushed structures with rising electricity garage answers. By refining those approaches, AI-pushed electricity control can maintain to evolve, imparting extra robust, price effective, and sustainable answers for present day electricity challenges.

VII. CONCLUSION

The integration of synthetic intelligence in power control has validated to be a transformative technique for enhancing efficiency, lowering costs, and making sure grid stability. The comparative evaluation of numerous AI-pushed algorithms demonstrates that hybrid fashions combining a couple of optimization strategies yield the best accuracy and power savings. These fashions outperform conventional tactics through dynamically adjusting to real-time power intake styles and marketplace fluctuations. As AI era keeps to evolve, its function in power control turns into more and more crucial. The deployment of AI in call for reaction structures, power garage optimization, and predictive analytics for power intake will cause extra powerful and resilient power grids. Furthermore, integrating AI with renewable power reassets can decorate sustainability through optimizing power distribution and lowering dependency on fossil fuels. Despite those advancements, demanding situations stay in enforcing AI-primarily based totally power control answers on a bigger scale. Issues along with excessive computational costs, records privateness concerns, and integration complexities want to be addressed for broader adoption. Additionally, making sure the interoperability of AI-pushed structures with current power infrastructures stays a vital studies direction. Future studies ought to recognition on improving the scalability of AI fashions, incorporating extra superior deep mastering strategies, and integrating AI with rising technology along with blockchain for stable power transactions. Further collaboration among academia, industry, and policymakers can be crucial in using the large implementation of AI in power control. By constantly refining AI-pushed techniques and addressing current demanding situations, the worldwide power region can circulate towards a extra sustainable and smart power control system, paving the manner for decreased carbon footprints and improved power resilience.

VIII. FUTURE IMPLEMENTATION

The increasing demand for efficient energy management has led to the adoption of AI-based optimization techniques. Our proposed project builds upon these advancements by utilizing a hybrid AI approach combining SARIMAX and LSTM models to enhance energy consumption forecasting and optimization.

Optimization Strategy:

I) SARIMAX (Seasonal Auto Regressive Integrated Moving Average with eXogenous factors) will be used for data preprocessing, trend analysis, and handling missing values in time-series energy consumption data. This ensures a clean and reliable dataset for further prediction.

II) LSTM (Long Short-Term Memory Networks) will be trained on the processed dataset to capture long-term dependencies and complex patterns, enabling accurate energy demand forecasting and anomaly detection.

Expected Outcomes:

I) Improved energy consumption forecasting accuracy by leveraging both statistical and deep learning techniques.

II) Enhanced energy optimization strategies by reducing fluctuations and predicting high-consumption periods in advance.

III) A dashboard visualization displaying real-time and historical energy consumption trends, optimized predictions, and anomaly alerts.

By integrating SARIMAX and LSTM, our approach aims to provide a robust and data-driven energy management system that minimizes wastage, enhances efficiency, and contributes to smarter decision-making in energy consumption. Future enhancements may include model fine-tuning, hybrid AI strategies, and expanding the dataset with additional external factors (e.g., weather conditions, occupancy patterns) to improve forecasting accuracy further.

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