Volume 9, Issue 5, May – 2024 International Journal of Innovative Science and Research Technology
ISSN No:-2456-2165 https://doi.org/10.38124/ijisrt/24may1106

Review on Battary Charging of Electric Vehicles (EVs) using Artificial Intelligence and Machine Learning (AIML)

Pranav Chougule[1]; D.A.Patil[2];

[1]Student, [2]Assistant professor

[1, 2] Department of Electrical Engineering, D.K.T.E Society's Textile and Engineering Institute Ichalkaranji, Maharashtra, India

Publication Date: 2025/06/27

Abstract: The integration of artificial intelligence (AI) into electric vehicle (EV) charging systems has emerged as a promising avenue to address the challenges of efficient and sustainable transportation. This review paper synthesizes the current state-of-the-art research and developments in the application of AI techniques for EV charging infrastructure. This paper critically evaluates the efficacy of AI-driven approaches in improving charging efficiency, reducing costs, and mitigating environmental impacts. Moreover, it identifies key trends, challenges, and future directions for research and implementation in this rapidly evolving field. Through a comprehensive analysis of existing literature, this review aims to provide insights into the potential benefits and implications of AI-enabled EV charging systems for advancing sustainable transportation infrastructure.

How to Cite: Pranav Chougule; D.A.Patil ;(2025). Review on Battary Charging of Electric Vehicles (EVs) using Artificial Intelligence and Machine Learning (AIML). *International Journal of Innovative Science and Research Technology,* 9(5), 3825-3827. https://doi.org/10.38124/ijisrt/24may1106

I. INTRODUCTION

Traditional EV charging systems often face limitations in terms of scalability, grid integration, and cost-effectiveness. As the demand for EVs continues to grow, there is a pressing need for innovative solutions to optimize charging processes and enhance the overall efficiency of the charging infrastructure. This review paper aims to provide a comprehensive overview of the current state-of-the-art research and developments in the application of AI in electrical vehicle charging. Through a critical analysis of existing literature and case studies, this paper will explore the potential benefits, challenges, and future directions of AI-driven solutions for EV charging infrastructure. By synthesizing insights from various disciplines, including engineering, computer science, and transportation planning, this review Seeks to contribute to the ongoing efforts to accelerate the transition towards a sustainable and electrified transportation ecosystem.

II. AIML TECHNIQUES FOR EV BATTERY CHARGING:

- *Predictive Modeling:*

Predictive modeling techniques, such as regression analysis and time series forecasting, are used to predict various parameters relevant to EV battery charging. This includes predicting charging demand based on historical data, estimating battery state of charge (SoC) and state of health (SoH), and forecasting electricity prices and grid demand patterns. Predictive models enable charging stations to anticipate user behavior and grid conditions, optimizing charging schedules for efficiency and cost-effectiveness.

- *Optimization Algorithms:*

Optimization algorithms, including linear programming, genetic algorithms, and reinforcement learning, are employed to optimize charging schedules and resource allocation in EV charging networks. These algorithms consider factors such as charging station availability, grid constraints, user and schedules. Optimization techniques aim to minimize charging time, energy costs, and grid congestion while maximizing user satisfaction and resource utilization.

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➢ *Machine Learning for Battery Management:*

Machine learning algorithms are used for battery management systems (BMS) to monitor battery performance, diagnose faults, and optimize charging strategies. Supervised learning techniques, such as classification and regression, are applied to analyze battery data and predict battery degradation and failure modes. Unsupervised learning methods, such as clustering, are used to identify patterns and anomalies in battery behavior enabling proactive maintenance and optimization of charging parameters to extend battery lifespan.

➢ *Demand Forecasting and Load Balancing:*

Machine learning models are utilized for demand forecasting and load balancing in EV charging infrastructure. Time series analysis and deep learning techniques, such as recurrent neural networks (RNNs) and long short-term memory (LSTM) networks, are employed to predict future charging demand at different locations and time intervals. These predictions enable charging station operators and grid operators to optimize resource allocation, manage peak demand, and prevent grid overloads through intelligent load balancing strategies.

➢ *Reinforcement Learning for Adaptive Charging:*

Reinforcement learning (RL) techniques, such as Q-learning and deep Q-networks (DQN), are applied to develop adaptive charging algorithms that learn and adapt charging strategies based on real-time feedback and environmental conditions. RL agents interact with the charging environment to optimize charging parameters, such as charging rate and duration, to achieve predefined objectives, such as minimizing energy costs or maximizing user satisfaction. Adaptive charging algorithms offer flexibility and responsiveness to changing grid conditions and user preferences, enhancing overall system efficiency and reliability.

III. EFFECTIVENESS AND PERFORMANCE EVALUATION:

➢ *Charging Efficiency:*

Measure the charging efficiency achieved by AIML-enabled charging systems compared to traditional charging methods. This includes assessing factors such as charging time, energy consumption, and charging losses.

Conduct experiments or simulations to quantify the improvements in charging efficiency achieved through AIML optimization algorithms and adaptive charging strategies.

➢ *Battery Performance***:**

Evaluate the impact of AIML techniques on battery performance, including state of charge (SoC) management, state of health (SoH) monitoring, and degradation mitigation. Analyze battery degradation rates and compare them between AIML-enabled charging systems and conventional charging approaches. Assess the accuracy of machine learning models in predicting battery degradation and failure modes, and validate their effectiveness through long-term battery testing and real-world deployment.

➢ *User Satisfaction and Experience:*

Conduct user surveys or feedback analysis to evaluate user satisfaction with AIML-enabled charging systems. Assess factors such as convenience, reliability, and overall charging experience. Adoption rates of AIML-based charging solutions compared to conventional charging methods.

- *Grid Integration and Demand Management:*

Analyze the impact of AIML-enabled charging on grid integration, demand response, and load balancing. Assess how these systems contribute to grid stability, peak demand reduction, and renewable energy integration.

Evaluate the effectiveness of AIML algorithms in managing charging demand, minimizing grid congestion, and optimizing resource allocation in charging networks. Quantify the benefits of AIML-based demand forecasting and load scheduling in reducing grid infrastructure costs and enhancing grid resilience.

- *Cost-Effectiveness and Economic Analysis:*

Conduct cost-benefit analysis to assess the economic viability and cost-effectiveness of AIML-enabled charging systems compared to conventional approaches.

Evaluate the return on investment (ROI) and payback period of implementing AIML techniques in charging infrastructure, considering factors such as energy savings, infrastructure costs, and operational efficiencies.

IV. FUTURE DIRECTIONS AND RESEARCH OPPORTUNITIES:

➢ *Advanced Predictive Modeling:*

Develop more accurate predictive models for EV battery charging demand, taking into account factors such as user behavior, traffic patterns, weather conditions, and grid fluctuations. Explore the use of advanced machine learning techniques, including deep learning and ensemble methods, to improve the accuracy and reliability of charging demand forecasts.

- *Real-Time Adaptive Charging Strategies:*

Investigate real-time adaptive charging strategies that dynamically adjust charging parameters based on grid conditions, electricity prices, and user preferences.

Explore reinforcement learning and online optimization algorithms to develop adaptive charging controllers capable of learning and adapting to changing environmental and operational factors.

- *Integration With Renewable Energy and Energy Storage:*

Explore synergies between AIML-enabled charging systems and renewable energy sources, such as solar and wind power, to maximize the use EV charging.

V. CONCLUSION

The integration of artificial intelligence and machine learning (AIML) techniques in battery charging systems for electric vehicles (EVs) holds immense promise for advancing the efficiency, reliability, and sustainability of transportation infrastructure. Through this review, we have explored the current state-of-the-art research, challenges, and future directions in AIML-enabled battery charging.

AIML techniques offer innovative solutions for optimizing charging efficiency, enhancing battery performance, and integrating renewable energy sources into the charging ecosystem. By leveraging predictive modeling, optimization algorithms, and adaptive charging strategies, AIML-enabled charging systems can dynamically adjust to grid conditions, user preferences, and environmental factors, maximizing the use of clean energy and minimizing grid congestion.

Future research opportunities abound in areas such as real-time adaptive charging, edge computing, federated learning, and human-machine interaction. By exploring these avenues, we can develop smarter and more resilient charging infrastructure that meets the evolving needs of electric vehicle users and contributes to a more sustainable transportation future.

As we look ahead, collaboration among researchers, industry stakeholders, and policymakers will be essential to drive innovation, address interoperability challenges, and ensure the responsible deployment of AIML technologies in battery charging systems. Together, we can accelerate the transition to clean and efficient transportation solutions powered by artificial intelligence and machine learning.

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