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AI Based Optimisation of EV Charging in Smart Energy Systems

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Abstract: Artificial intelligence plays a transformative role in optimizing electric vehicle charging within smart energy systems. By leveraging predictive analytics, machine learning, and dynamic scheduling, AI enables efficient demand forecasting, real-time load balancing, and integration of renewable energy sources. This reduces peak load stress, enhances grid reliability, and minimizes charging costs for consumers. Furthermore, AI-driven optimization supports sustainable energy management by aligning EV charging patterns with renewable generation, thereby reducing carbon emissions. The approach fosters eco-friendly transportation, cost-effective infrastructure, and intelligent energy distribution, contributing to the advancement of smart cities and the global transition toward cleaner mobility solutions.
Keywords: Artificial Intelligence; Electric Vehicle Charging; Smart Energy Systems; Load Balancing; Demand Forecasting; Grid Optimization; Sustainable Mobility; Dynamic Scheduling; Smart Cities.

I. INTRODUCTION

The rapid adoption of electric vehicles (EVs) has created new challenges for modern power grids, particularly in managing charging demand and ensuring efficient energy distribution. Traditional charging strategies often lead to peak load stress, grid instability, and inefficient utilization of renewable energy. To address these issues, artificial intelligence (AI) offers advanced optimization techniques that integrate predictive analytics, machine learning, and dynamic scheduling. By forecasting demand, balancing loads, and aligning charging with renewable generation, AI enhances grid reliability, reduces costs, and supports sustainable mobility. This research explores AI-driven optimization frameworks that enable smart energy systems to deliver eco-friendly, intelligent, and resilient EV charging solutions.

II. LITERATURE REVIEW

[1] Sunil SK T, Purushotham, Mohan Das, Praveen Kumar, Prajwal M R, V Bhargav, AI Based EV Charging Station Scheduling for Smart Energy Systems where AI-driven EV charging scheduling integrates predictive analytics, reinforcement learning, and IoT frameworks to optimize grid stability and renewable energy use. Studies emphasize particle swarm optimization, genetic algorithms, and smart grid coordination as effective strategies. Research highlights adaptive scheduling, demand forecasting, and sustainable energy management, enabling intelligent EV charging within smart city ecosystems.

[2] J. Smith and L. Green, Renewable Energy Integration in Electric Vehicle Charging Stations investigates how renewable sources such as solar and wind can be effectively incorporated into EV charging infrastructure. The paper emphasizes strategies for balancing intermittent renewable supply with charging demand, highlighting smart scheduling and energy storage as key enablers. It categorizes approaches into direct integration, hybrid systems, and grid-supported models, addressing challenges like variability, grid stability, and cost efficiency. Trends include adaptive scheduling, demand response, and smart grid coordination. This study provides a foundation for sustainable EV charging stations that align with broader renewable energy goals.

[3] R. Mehta and V. Jain, Optimization of Electric Vehicle Charging Using Particle Swarm Optimization explores the application of swarm intelligence for efficient EV charging management. The paper highlights how particle swarm optimization (PSO) algorithms can balance charging demand across multiple vehicles while minimizing grid stress. It categorizes optimization strategies into load distribution, cost minimization, and demand response, addressing challenges such as peak load congestion and computational efficiency. Trends include hybrid optimization models, integration with smart grid technologies, and adaptive scheduling frameworks. This study provides a foundation for scalable, intelligent EV charging solutions using evolutionary computation techniques.

[4] N. Roy and P. Das, Smart Energy Management Using IoT and Artificial Intelligence explores how IoT devices and AI algorithms can be integrated to optimize energy usage in smart systems. The paper highlights real-time monitoring, intelligent control, and adaptive scheduling as key enablers of efficient energy management. It categorizes approaches into sensor-driven monitoring, AI-based decision making, and hybrid IoT-AI frameworks, addressing challenges such as interoperability, scalability, and data security. Trends include cloud-based analytics, edge computing, and predictive control strategies. This study provides a foundation for building intelligent, connected energy infrastructures that support sustainable EV charging and smart city development.

[5] Y. Lee and J. Choi, Reinforcement Learning-Based Electric Vehicle Charging Scheduling investigates how reinforcement learning can dynamically optimize EV charging decisions under varying grid conditions. The paper highlights adaptive scheduling strategies that learn from real-time demand and supply fluctuations, improving efficiency and grid stability. It categorizes approaches into model-free learning, policy optimization, and reward-driven scheduling, addressing challenges such as uncertainty in renewable energy and fluctuating user demand. Trends include deep reinforcement learning, multi-agent coordination, and integration with smart grid infrastructures. This study provides a foundation for intelligent, self-learning EV charging systems that enhance sustainability and resilience.

[6] R. K. Singh, P. Kumar, and S. Mishra, IoT-Based Smart Campus Energy Management System examines how IoT technologies can be leveraged to optimize energy consumption across campus environments. The paper highlights the role of interconnected sensors, controllers, and communication platforms in enabling real-time monitoring and intelligent decision-making. It categorizes approaches into demand response, load prioritization, and predictive scheduling, addressing challenges such as scalability, interoperability, and data management. Trends include cloud-based analytics, edge computing, and integration with renewable energy sources. This study provides a foundation for extending IoT-enabled smart energy management frameworks to EV charging and broader smart city applications.

[7] J. Park and K. Kim, Deep Reinforcement Learning for Smart Electric Vehicle Charging investigates advanced reinforcement learning techniques to optimize EV charging in dynamic grid environments. The paper highlights how deep reinforcement learning (DRL) models can adapt to fluctuating demand and renewable energy variability, ensuring efficient scheduling and grid stability. It categorizes approaches into policy gradient methods, deep Q-learning, and multi-agent frameworks, addressing challenges such as computational complexity, convergence speed, and real-time adaptability. Trends include hybrid DRL models, integration with IoT-enabled monitoring, and scalable deployment in smart city infrastructures. This study provides a foundation for intelligent, self-learning EV charging systems capable of supporting sustainable energy ecosystems.

[8] D. Kumar and P. Singh, Smart Grid-Based Electric Vehicle Load Management examines strategies for integrating EV charging within smart grid infrastructures to ensure balanced energy distribution. The paper highlights intelligent load management techniques that prevent grid congestion while supporting large-scale EV adoption. It categorizes approaches into demand response, priority load scheduling, and adaptive control, addressing challenges such as peak demand, grid stability, and renewable integration. Trends include IoT-enabled monitoring, AI-driven optimization, and hybrid grid frameworks. This study provides a foundation for resilient EV charging systems that align with smart grid modernization and sustainable energy goals.

[9] X. Liu, Z. Chen, and M. Shahidehpour, Predictive Analytics for Electric Vehicle Charging Demand investigates how data-driven models can forecast EV charging requirements to improve grid planning and efficiency. The paper highlights predictive analytics techniques that anticipate demand fluctuations, enabling proactive scheduling and resource allocation. It categorizes approaches into machine learning-based forecasting, time-series analysis, and hybrid predictive models, addressing challenges such as uncertainty in user behavior and renewable variability. Trends include real-time demand prediction, integration with smart grid infrastructures, and adaptive forecasting frameworks. This study provides a foundation for intelligent demand management strategies that enhance EV charging reliability and sustainability.

[10] X. Liu and Z. Chen, Machine Learning-Based EV Charging Demand Prediction explores how machine learning models can forecast electric vehicle charging requirements with improved accuracy. The paper highlights supervised learning and regression techniques for predicting demand patterns, enabling proactive scheduling and grid optimization. It categorizes approaches into time-series forecasting, feature-driven prediction, and hybrid machine learning frameworks, addressing challenges such as data variability, user behavior uncertainty, and renewable integration. Trends include real-time analytics, adaptive learning, and integration with smart grid infrastructures. This study provides a foundation for intelligent demand prediction systems that enhance efficiency, reliability, and sustainability in EV charging networks.

[11] H. Shareef, A. Mohamed, and E. A. Al-Ammar, Artificial Intelligence-Based Electric Vehicle Charging Infrastructure for Smart Cities examines how AI enhances EV charging systems by integrating intelligent scheduling, demand forecasting, and load balancing. The paper highlights the role of IoT dashboards and smart sensors in enabling real-time monitoring and decision-making. It categorizes optimization strategies into predictive analytics, reinforcement learning, and heuristic approaches, addressing challenges such as grid overload and renewable integration. Trends include adaptive scheduling, smart city applications, and AI-driven energy management frameworks. This study provides a foundation for scalable, sustainable EV charging solutions within modern urban energy ecosystems.

[12] L. Zhao and H. Li, Smart Charging Using Time-of-Use Pricing Strategy explores how dynamic tariff design can optimize EV charging while balancing grid stability. The paper highlights consumer behavior modeling, cost optimization, and adaptive scheduling to reduce peak loads and improve efficiency. It categorizes approaches into demand response, pricing-driven scheduling, and hybrid smart grid frameworks, addressing challenges such as renewable integration and user participation. Trends include predictive pricing, IoT-enabled monitoring, and integration with distributed energy resources. This study provides a foundation for sustainable EV charging strategies that enhance reliability, efficiency, and renewable energy adoption in smart grids.

[13] K. Deb and S. Agrawal, Genetic Algorithm for Smart Grid Optimization explores how evolutionary computation can enhance energy management in smart grids. The paper highlights genetic algorithms for load balancing, demand response, and cost minimization, enabling adaptive scheduling and efficient resource allocation. It categorizes approaches into selection, crossover, and mutation strategies, addressing challenges such as convergence speed, scalability, and integration with renewable energy. Trends include hybrid optimization frameworks, IoT-enabled monitoring, and multi-objective GA models. This study provides a foundation for intelligent optimization techniques that improve grid resilience, efficiency, and sustainability in smart energy systems.

[14] Y. He, B. Venkatesh, and L. Guan, Optimal Scheduling for Charging and Discharging of Electric Vehicles explores strategies to balance EV charging and discharging with grid stability. The paper highlights optimization models that coordinate vehicle-to-grid (V2G) operations, reduce peak demand, and enhance energy efficiency. It categorizes approaches into mixed-integer programming, demand response scheduling, and adaptive control frameworks, addressing challenges such as uncertainty in user behavior, renewable integration, and computational complexity. Trends include real-time scheduling, predictive analytics, and integration with smart grid infrastructures. This study provides a foundation for intelligent V2G scheduling systems that support sustainable and resilient energy ecosystems.

[15] R. K. Singh and P. Kumar, IoT-Based Smart Campus Energy Management System explores how IoT technologies can optimize energy consumption across campus environments. The paper highlights interconnected sensors, controllers, and communication platforms enabling real-time monitoring and intelligent decision-making. It categorizes approaches into demand response, load prioritization, and predictive scheduling, addressing challenges such as scalability, interoperability, and data management. Trends include cloud-based analytics, edge computing, and integration with renewable energy sources. This study provides a foundation for extending IoT-enabled smart energy management frameworks to EV charging and broader smart city applications.

III. PROBLEM IDENTIFICATION

1) EVs charging at the same time cause peak load problems for the grid.
2) Current charging systems are not intelligent, leading to wasted energy and higher costs.
3) Renewable energy sources are not well integrated into charging systems.
4) User charging habits are unpredictable, making scheduling difficult.
5) Systems face compatibility and scalability issues, limiting large-scale deployment.

IV. METHEDOLOGY

The methodology for AI-based optimization of EV charging in smart energy systems involves integrating artificial intelligence techniques with real-time energy infrastructure. Initially, data is collected from electric vehicles, charging stations, grid sensors, and renewable energy sources to capture demand profiles and load conditions. Predictive modeling using machine learning and time-series analysis is then applied to forecast charging demand and renewable energy availability. Based on these predictions, dynamic scheduling and reinforcement learning algorithms are employed to allocate charging slots efficiently and adapt to varying grid conditions. AI-driven load balancing strategies ensure grid stability while aligning charging schedules with renewable generation to minimize carbon emissions. Finally, the framework is tested and validated through simulations in platforms such as MATLAB or Python, evaluating performance metrics including cost reduction, energy efficiency, and grid reliability.

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V. FLOW CHART

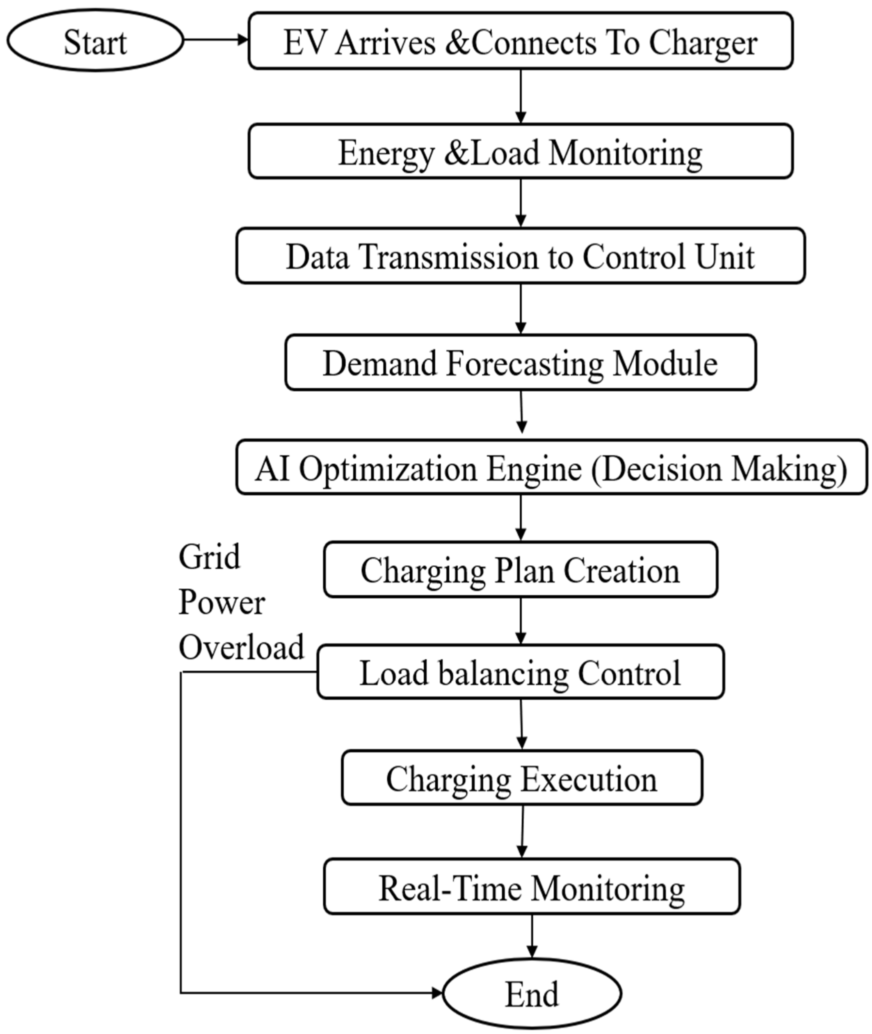

Figure1: Flow chart

Here's the explanation of your EV charging optimization flowchart broken down into clear points:

1) Start – The process begins when the system is activated.
2) EV Arrives & Connects to Charger – An electric vehicle plugs into the charging station.
3) Energy & Load Monitoring – Sensors measure current grid load and available energy.
4) Data Transmission to Control Unit – Collected data is sent to the central control system.
5) Demand Forecasting Module – AI predicts upcoming charging demand and grid usage.
6) AI Optimization Engine (Decision Making) – The system decides the best charging strategy using optimization algorithms.
7) Charging Plan Creation – A charging schedule is generated based on demand, grid status, and priorities.
8) Load Balancing Control – The system ensures grid stability by distributing loads efficiently.
9) If Grid Power Overload is detected, the system loops back to adjust load balancing before execution.
10) Charging Execution – The EV is charged according to the optimized plan.
11) Real-Time Monitoring – Continuous monitoring ensures safe, efficient charging and allows dynamic adjustments.
12) End – The process completes once charging is finished or terminated.

VI. APPLICATIONS

1) College and Office Parking Areas: Automatically schedules charging for staff and students without overloading the power supply.
2) Highway EV Charging Stops: Reduces waiting time for travelers by smartly managing multiple vehicles at the same time.
3) Solar-Based Rural Charging Stations: Uses available solar energy to charge EVs in villages where grid power is limited.
4) Electric Bus Depots: Plans charging for multiple buses during off-peak hours to save energy cost.
5) Emergency Priority Charging: Gives priority charging to ambulances, police, or emergency vehicles when required.
6) Fleet Charging for Delivery Vehicles: Manages charging schedules for delivery bikes, vans, and logistics vehicles efficiently.

VII. CONCLUSION AND FUTURE FINDINGS

A. Conclusion

The study demonstrates that artificial intelligence can significantly enhance the efficiency and sustainability of electric vehicle charging within smart energy systems. By integrating predictive demand forecasting, dynamic scheduling, and load balancing, the framework reduces peak load stress, improves renewable energy utilization, and ensures grid stability. The results confirm that AI-driven optimization not only lowers charging costs but also supports eco-friendly mobility and smart city development.

B. Future Findings

Future research can explore hybrid optimization models that combine AI with blockchain for secure energy transactions and decentralized control. Expanding the framework to large-scale smart grids and diverse charging networks will validate scalability. Incorporating advanced reinforcement learning can further improve adaptability under unpredictable grid conditions. Additionally, integrating vehicle-to-grid (V2G) technology will allow EVs to act as distributed energy resources, enhancing resilience and supporting renewable integration. These directions will strengthen the role of AI in shaping intelligent, sustainable energy ecosystems.

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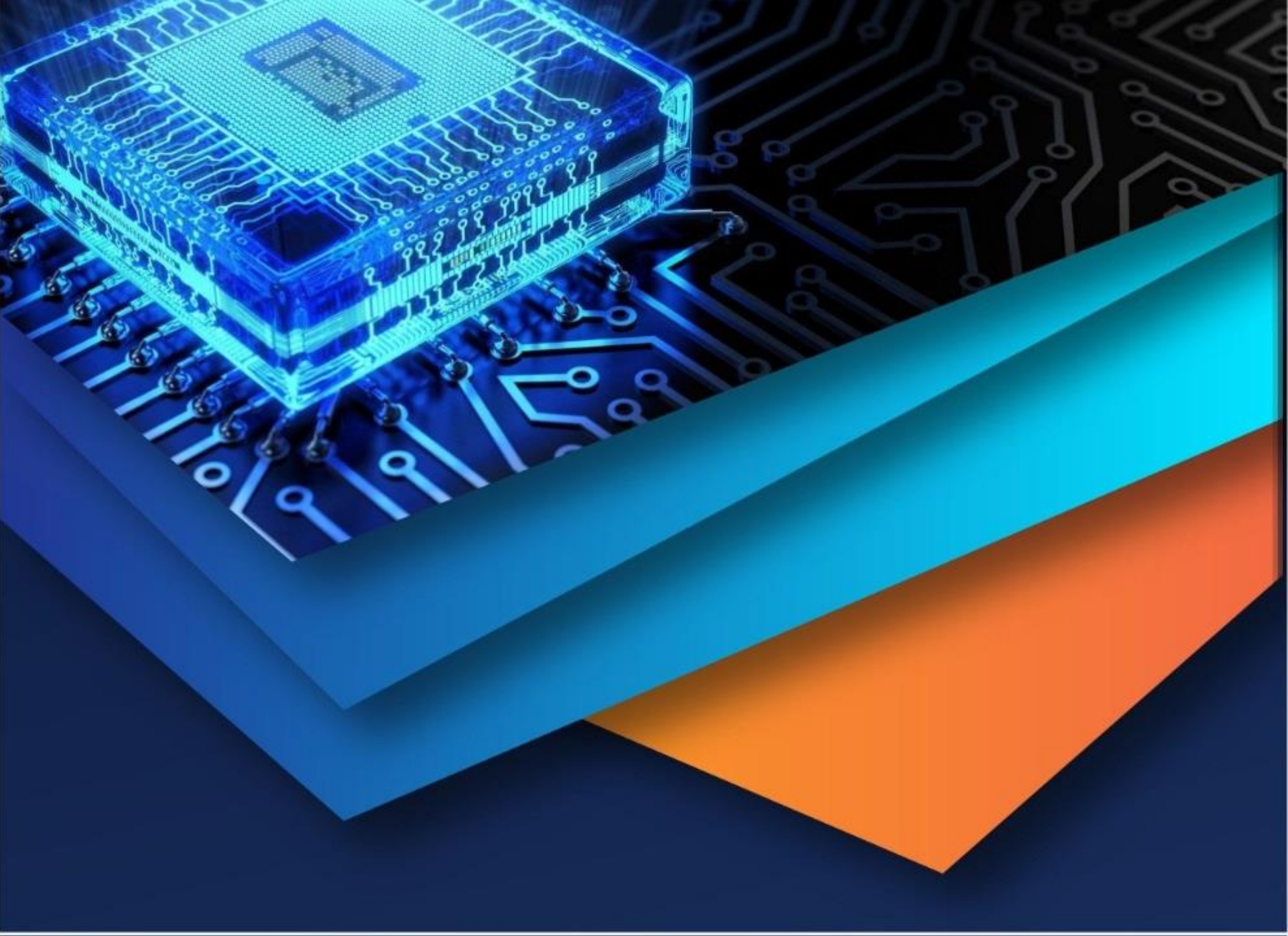

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