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AI BASED OPTIMISATION OF EV CHARGING IN SMART ENERGY SYSTEMS

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Abstract— *The rapid adoption of Electric Vehicles (EVs) has created new challenges for energy management, particularly in campuses where EV charging demand is combined with conventional building loads. This paper presents an AI-based EV Charging Station Scheduling system for Smart Energy Systems that intelligently coordinates EV charging, campus energy consumption, and renewable energy generation. The proposed system collects real-time and historical data from energy meters, EV charging stations, solar and wind sources, and campus loads. Machine learning models, including Multiple Linear Regression, Random Forest Regression, and Long Short-Term Memory (LSTM) networks, are used to forecast campus demand, EV charging requirements, and renewable energy availability. A Genetic Algorithm (GA) is then employed for multi-objective charging scheduling to reduce peak demand and electricity costs while maximizing renewable energy utilization. The system also incorporates battery energy storage and real-time load balancing to maintain grid stability. MATLAB is used for simulation, optimization, and dashboard-based monitoring. The reported simulation results show approximately 25% reduction in peak load, 40% renewable energy utilization, and 18% cost reduction compared with uncontrolled charging and time-of-use strategies. The proposed framework demonstrates the potential for efficient, sustainable, and intelligent EV energy management in campus and microgrid environments.*

Keywords— *Electric Vehicles, EV Charging Scheduling, Artificial Intelligence, Genetic Algorithm, Load Forecasting, Renewable Energy, Smart Grid, Energy Management, Demand Response.*

I. INTRODUCTION

The rapid growth of Electric Vehicles (EVs) is transforming the transportation sector and increasing the demand for efficient and reliable charging infrastructure. The increasing adoption of EVs in university campuses, residential areas, corporate buildings, and other concentrated environments can create significant challenges for existing electrical systems. In particular, simultaneous charging of multiple EVs can increase the overall power demand and place additional stress on the grid.

A. Problem of Uncontrolled EV Charging

Traditional electrical grids are designed for relatively predictable load patterns. When multiple EVs are connected and charged simultaneously, especially during peak-demand periods, the resulting load can cause peak demand spikes. For example, the paper notes that a single EV may require approximately 7–11 kW,

meaning that charging ten EVs simultaneously could add around 70–110 kW to the grid load. Such increased demand can contribute to voltage fluctuations, frequency variations, and transformer overloading.

Uncontrolled EV charging can also increase electricity costs because charging may occur during high-tariff periods. Therefore, an intelligent charging strategy is required to shift EV charging toward suitable time periods while satisfying the charging requirements of users.

B. Renewable Energy Integration

Renewable energy sources such as solar and wind power can reduce dependence on conventional grid electricity. However, their intermittent nature creates challenges for energy management. Solar generation varies throughout the day and wind generation is also variable, while renewable generation may not always coincide with EV charging demand. Without proper coordination, available renewable energy may remain unused.

C. Proposed AI-Based Approach

To address these challenges, this work proposes an AI-based EV charging scheduling system that integrates EV charging demand, campus electrical loads, renewable energy generation, and energy storage within a unified framework. The system uses forecasting techniques to estimate future campus load, EV charging demand, and renewable energy availability. A Genetic Algorithm (GA) is then used to determine suitable charging schedules based on multiple objectives, including reducing electricity cost and peak load while increasing renewable energy utilization.

The proposed system also supports real-time monitoring and load balancing through IoT-enabled hardware and communication technologies. A MATLAB-based platform performs data processing, forecasting, optimization, and monitoring, while field devices such as energy meters, renewable sources, EV chargers, and battery storage provide operational data.

II. LITERATURE REVIEW

[1] Sunil S K et al. uses a Genetic Algorithm to optimize EV charging schedules. The methodology focuses on minimizing energy cost and peak load while maximizing renewable-energy utilization and maintaining grid stability. A limitation identified is that the performance depends on data accuracy and availability.

[2] H. Shareef et al. proposes a scalable AI-driven EV charging framework for smart-city applications. It focuses on scalability, cost reduction, and sustainable energy utilization. Implementation complexity and high initial investment are identified as limitations.

[3] John Smith et al. integrates solar and wind energy with EV charging using optimization techniques. It aims to reduce grid dependency and emissions, while renewable-energy intermittency remains a limitation.

[4] Rohan Mehta et al. applies Particle Swarm Optimization to charging scheduling. It aims to minimize energy costs and load peaks and provides improved convergence speed. A limitation is the possibility of becoming trapped in a local optimum.

[5] Nikhil Roy et al. combines IoT sensors with AI algorithms for real-time monitoring and control. It improves overall system efficiency, although IoT security issues are identified as a limitation.

[6] Young Lee et al. uses reinforcement learning to dynamically adjust charging decisions according to environmental conditions. It improves adaptability and efficiency but requires continuous training.

[7] R. K. Singh et al. uses IoT and AI for campus energy management. It prioritizes critical loads and optimizes EV charging, but its applicability is limited to campus-scale systems.

[8] Jae Park et al. uses deep reinforcement learning for adaptive charging decisions and optimal scheduling policies. It improves efficiency and user satisfaction but requires training data.

[9] X. Liu, Z. Chen et al. uses predictive analytics to forecast EV charging demand, helping improve planning, scheduling, and resource allocation. Its accuracy depends on the quality and quantity of historical data.

[10] Liang Zhao et al. uses pricing-based scheduling to encourage off-peak charging and reduce electricity costs. Its effectiveness depends on user behavior.

The literature shows that AI, IoT, and optimization techniques are central to the development of intelligent EV charging systems. AI techniques such as deep learning, reinforcement learning, and predictive analytics can support real-time demand forecasting and intelligent charging scheduling. Optimization techniques such as Genetic Algorithms and Particle Swarm Optimization help balance loads, reduce electricity costs, and improve grid resilience. IoT-based systems provide real-time monitoring, communication, and control.

The literature also explores smart-grid integration, vehicle-to-grid scheduling, demand response, renewable-energy integration, and time-of-use pricing. Collectively, these studies provide the foundation for AI-driven and IoT-enabled EV charging infrastructure. The proposed project applies AI to schedule EV charging by analyzing vehicle demand, battery status, electricity price, and grid condition.

III. PROPOSED SYSTEM

The proposed system presents an AI-based smart EV charging station for efficient charging-slot allocation and intelligent scheduling of EV charging requests.

It considers battery SOC, user priority, slot availability, station load, and energy conditions to optimize the charging process.

A. System Overview

The proposed system presents an AI-based smart EV charging station designed to manage the charging requests of electric vehicles efficiently. Unlike conventional charging systems, where vehicles are generally charged on a first-come-first-served basis, the proposed system considers factors such as battery state of charge (SOC), user charging request, charging-slot availability, energy demand, priority, and electricity usage period to determine an appropriate charging schedule.

The system consists of a charging station controller, EV charging slots, battery-status monitoring, user request interface, display unit, and an AI-based scheduling and optimization module. The controller collects the required information and sends it to the scheduling module. Based on the available charging slots and charging requirements, the system assigns a suitable slot and controls the charging process.

The main objective is to reduce unnecessary waiting time, avoid excessive load on the power system, improve utilization of charging slots, and support cost-efficient energy usage.

B. System Architecture

The proposed system consists of several interconnected functional blocks. The major blocks include:

1. User/EV Request Module
2. Battery Status Monitoring Module
3. AI-Based Scheduling and Optimization Module
4. Charging Station Controller
5. Charging Slot Management Module
6. Load Management Module
7. LCD/LED Display Module
8. Wi-Fi/Communication Module

The user provides the charging request along with relevant EV information such as battery level and required charging. The charging station controller receives this information and checks the availability of charging

slots. The AI-based scheduling module analyzes the collected information and determines the appropriate charging sequence. The controller then activates the selected charging slot while the display provides the current status to the user.

C. User Request and Battery Information

When an EV arrives at the charging station, the system receives the charging request from the user. The request may include information such as:

- EV identification
- Current battery level
- Required charging level
- Charging priority
- Expected charging time
- User charging request

The battery condition of the EV is considered before generating the charging schedule. The system obtains the current State of Charge (SOC) and determines the approximate charging requirement.

The charging requirement can be represented as:

$$E_{req} = C_{bat} \frac{SOC_{target} - SOC_{current}}{100}$$

where:

- E_{req}= required charging energy
- C_{bat}= battery capacity
- SOC_{target}= desired battery SOC
- $SOC_{current}$= present battery SOC

This information helps the scheduling algorithm determine the charging requirement of each EV.

D. AI-Based Scheduling and Optimization

The main feature of the proposed system is the AI-based scheduling mechanism. The scheduler evaluates multiple parameters before assigning a charging slot.

The scheduling decision can consider:

- Battery State of Charge (SOC)
- Charging requirement
- Charging-slot availability
- User priority
- Estimated charging duration
- Station load
- Energy demand
- Electricity tariff period

Based on these parameters, the system generates an optimized charging sequence. The objective is not simply to charge vehicles in their arrival order but to distribute the charging demand according to the current station and energy conditions.

A generalized scheduling objective can be represented as:

$$F = w_1 T_w + w_2 C_e + w_3 L_o + w_4 P$$

where:

- T_w= waiting time
- C_e= charging energy cost
- L_o= overload/load penalty
- P= priority-related penalty
- w_1, w_2, w_3, w_4= weighting factors.

The optimization process attempts to minimize the overall objective function while satisfying the charging requirements of the connected EVs.

E. Charging Slot Allocation

After receiving the scheduling decision, the charging station controller checks the availability of charging slots.

If a suitable slot is available, the controller assigns the slot to the corresponding EV. If all slots are occupied, the request is placed in a waiting queue according to the scheduling priority.

The charging slot status can be represented as:

- Available
- Reserved
- Charging
- Completed

LED indicators and an LCD can be used to display the status of each charging slot

F. Load Management

The system evaluates the total charging demand before activating a charging slot. When multiple EVs are connected, simultaneous charging can increase the station's electrical load.

Therefore, the controller checks the available power capacity and distributes the charging requests accordingly.

If:

$$P_{demand} > P_{available}$$

the system can delay or reschedule selected charging requests to prevent excessive loading.

This methodology helps in:

- Reducing peak charging demand
- Preventing overload
- Improving utilization of available power
- Maintaining stable charging operation

G. Off-Peak Energy Optimization

The proposed system can also consider electricity tariff periods while generating the charging schedule. When charging is not urgent, the system can schedule the EV during a lower-demand or off-peak period. This provides an opportunity to reduce the operating cost of charging.

For example, if two EVs have similar charging requirements but one vehicle has sufficient remaining battery capacity, the system can schedule that vehicle during a more suitable low-demand period.

Thus, the scheduling mechanism can balance user requirements, battery condition, station load, and energy cost.

H. Charging Control and Monitoring

Once the charging schedule is generated, the microcontroller controls the corresponding charging slot. The system continuously monitors the charging status and updates the display.

The controller can provide information such as:

- EV currently being charged
- Selected charging slot
- Charging status
- Battery level
- Available slots
- Completed charging
- Waiting requests

When charging is completed, the controller releases the slot and makes it available for the next scheduled EV.

I. Communication and Wi-Fi Integration

A Wi-Fi communication module can be incorporated to enable communication between the charging station and the user interface or cloud-based system.

The communication layer can be used to transmit:

- Charging requests
- Battery information
- Slot availability
- Charging status
- Scheduling information
- Energy-related data

This provides a pathway for future integration with a mobile application, web dashboard, or cloud-based energy management platform.

IV. METHODOLOGY

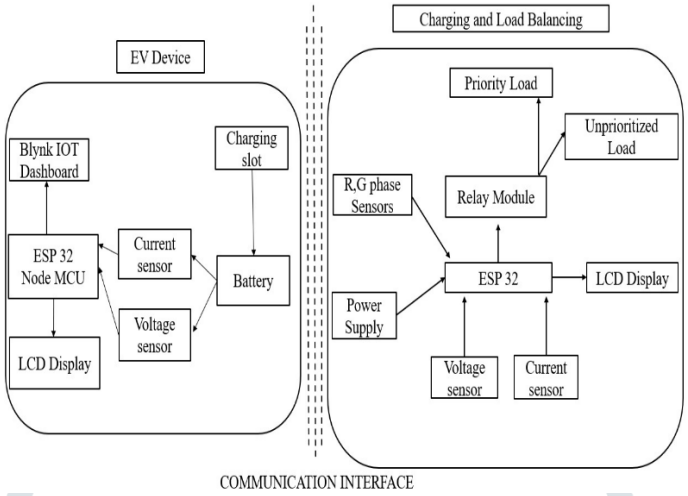


Fig 4.1: BLOCK DIAGRAM

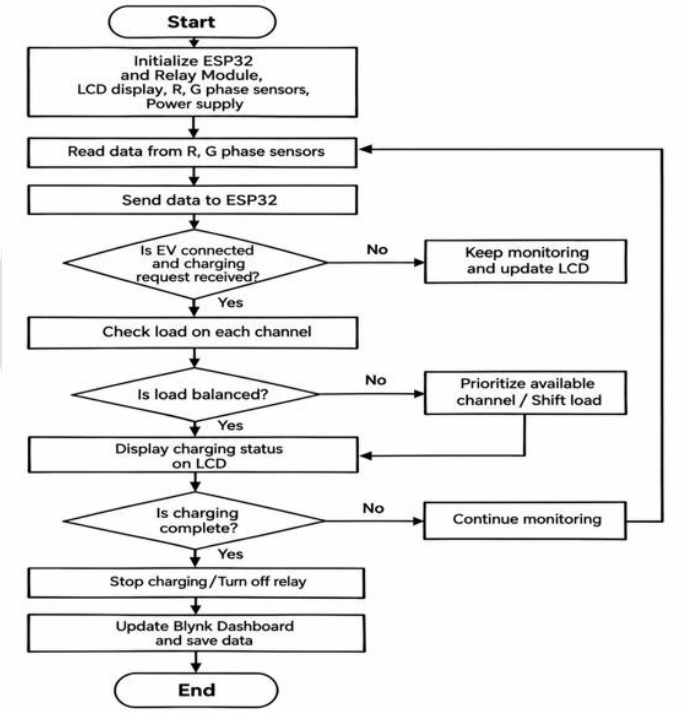


Fig 4.2: FLOW CHART

The proposed system begins with EV data collection, where the connection of the electric vehicle is detected and real-time parameters such as battery status, voltage, current, and charging demand are collected using integrated sensors. The collected data is then transmitted through the ESP3266 NodeMCU, which sends the information to the control system and IoT platform using Wi-Fi connectivity.

The system performs grid and load monitoring using an Arduino UNO to monitor the available power, phase condition, and connected electrical loads. Based on the load conditions, the system identifies priority and non-priority loads. The collected EV, grid, and load information is then provided to the AI-based demand analysis module, which analyzes parameters such as EV charging demand, battery status, electricity price, and grid condition to determine the appropriate charging requirements.

Based on this analysis, the optimal charging schedule is generated using an AI-based optimization approach. The scheduling process aims to reduce peak load and charging cost, minimize EV waiting time, and improve overall energy utilization. The optimized schedule is then applied through the load balancing and charging control unit, where the relay module controls EV charging and non-priority loads according to the scheduled requirements.

For IoT-based monitoring, Blynk IoT and an LCD display provide real-time information regarding EV charging status, voltage, current, and load conditions. Finally, the system performs continuous monitoring, in which sensor and grid data are continuously updated. This enables the controller to monitor changes in EV demand and grid conditions and adjust the charging operation according to the updated requirements, thereby achieving efficient and adaptive EV charging management.

V. SYSTEM IMPLEMENTATION

The proposed system is implemented by integrating Arduino UNO, ESP3266 NodeMCU, sensors, relay module, LCD, and Blynk IoT for real-time EV charging and load monitoring. The developed prototype collects system parameters, performs AI-based scheduling, controls charging loads, and displays the charging and grid status in real time.

A. Hardware Implementation

The list of the components are:

- ESP3266
- Arduino UNO
- LCD display
- LED indicators
- charging-slot representation
- relay module
- Wi-Fi communication
- power supply
- switches/buttons
- wiring

1. ESP3266

The ESP3266 Wi-Fi module is used as the wireless communication unit of the proposed EV charging system. It provides Wi-Fi connectivity between the charging station controller and the IoT/user interface. The ESP3266 can receive charging requests, transmit charging-status information, and communicate scheduling-related information. Its built-in Wi-Fi capability makes it suitable for remote monitoring and control of the charging station.

2. LCD Display

An LCD display is used to provide real-time information about the charging station. It can display the status of individual charging slots, charging requests, battery-level information, charging progress, or system messages. This provides a simple local interface for monitoring the charging process.

4. LED Indicators

LED indicators are used to visually represent the condition of each charging slot. Different LEDs or LED states can indicate whether a slot is available, occupied, charging, or completed.

5. Charging-Slot Representation

Since your prototype is a demonstration model rather than a commercial EV charger, the actual EV charging points can be represented using individual charging-slot sections.

Each slot represents a location where an EV can be assigned for charging. The slot representation can include an LED, connection point, label, and switching mechanism.

6. Relay Module

The relay module provides electrically controlled switching between the controller and the charging-load representation. Since the Arduino operates with low-voltage control signals, the relay can be used to switch the corresponding load or prototype charging circuit.

7. Wi-Fi Communication

Wi-Fi communication provides wireless data exchange between the charging station and the user/IoT system. In your prototype, the ESP3266 provides the Wi-Fi functionality.

8. Power Supply

The power supply provides the required electrical power to the Arduino UNO, ESP3266, LCD, LEDs, relay module, and other low-voltage components used in the prototype.

9. Switches / Buttons

Switches or push buttons are used to provide manual inputs to the prototype. They can represent EV charging requests or allow the user to interact with the system.

10. Wiring and Connecting Wires

Connecting wires are used to establish electrical connections between the Arduino UNO, ESP3266, LCD, LEDs, relay module, switches, and power supply.

B. Software Implementation

The proposed EV charging and scheduling system is implemented using embedded programming, wireless communication, and an intelligent scheduling algorithm. The software controls the hardware components, processes charging requests, monitors charging-slot status, and determines the appropriate charging sequence.

VI. RESULTS AND DISCUSSION

A. Prototype Performance

The developed prototype was tested under different EV charging requests and load conditions. The system successfully collected battery status, voltage, current, charging demand, and load information using the integrated sensors. The Arduino UNO and ESP3266 NodeMCU coordinated the monitoring and communication operations, while the LCD and Blynk IoT platform displayed the system parameters in real time.

B. Charging Scheduling and Load Management

The AI-based scheduling module analyzed battery state of charge, charging requirements, priority, available charging slots, electricity price, and grid conditions to determine a suitable charging sequence. The relay control mechanism managed the charging and non-priority loads according to the generated schedule. The

testing demonstrated systematic charging-slot allocation and helped avoid unnecessary simultaneous loading when charging demand increased.

C. Discussion of Results

The experimental observations demonstrate the feasibility of integrating AI-based scheduling, sensor-based monitoring, microcontroller control, load management, and IoT communication for smart EV charging. The system provides organized charging management while supporting reduced waiting time, improved energy utilization, and cost-aware charging. Further quantitative evaluation of parameters such as peak load, charging cost, waiting time, and energy consumption can be carried out in future testing.

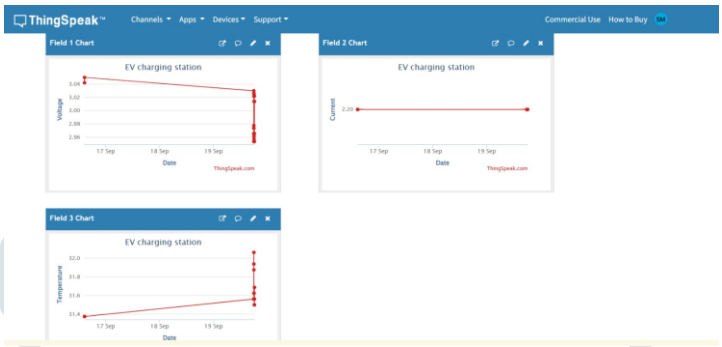


Fig 6.1: EV PARAMETERS GRAPH

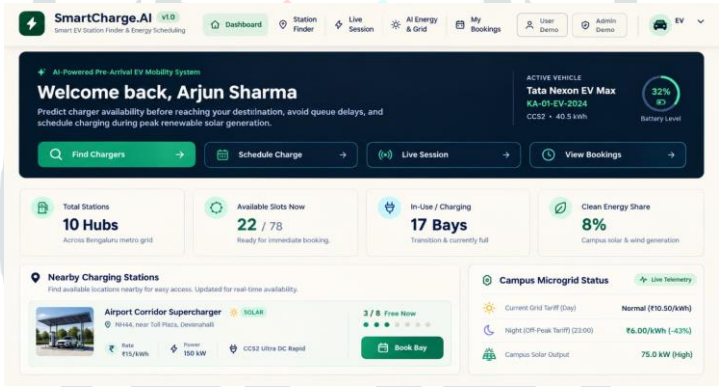


Fig 6.2: WEB APPLICATION



Fig 6.3: OUTPUT DISPLAY

VII. APPLICATIONS AND FUTURE SCOPE

A. Applications

The proposed AI-based EV charging and scheduling system can be applied in public EV charging stations, residential charging facilities, commercial buildings, office parking areas, shopping malls, educational institutions, and smart-grid environments. It can be used to manage multiple EV charging requests by considering battery status, charging priority, available slots, energy demand, and grid conditions. The IoT-based monitoring capability can also support remote observation of charging status and electrical parameters. The system can further be integrated with renewable energy sources such as solar photovoltaic systems to coordinate EV charging with locally available energy and improve energy utilization.

B. Future Scope

The proposed system can be further enhanced by incorporating advanced machine-learning and optimization algorithms for more accurate charging-demand prediction and scheduling. Future development can include integration with real EV batteries and commercial charging equipment, dynamic electricity pricing, renewable energy generation, battery energy storage systems, and vehicle-to-grid (V2G) operation. A dedicated mobile or web application can also be developed to allow users to submit charging requests, reserve charging slots, monitor charging progress, and receive notifications remotely. Cloud-based data storage and historical charging-data analysis can additionally be used to improve demand prediction and optimize charging schedules under changing grid conditions.

VIII. CONCLUSION

The proposed AI-based EV charging station and scheduling system provides an intelligent approach for managing EV charging requests, charging slots, and energy demand. The system integrates Arduino UNO, ESP3266 NodeMCU, sensors, relay control, LCD display, and Blynk IoT to enable real-time monitoring, communication, and charging control. The AI-based scheduling mechanism considers parameters such as battery state of charge, charging demand, priority, slot availability, electricity price, and grid conditions to generate an appropriate charging sequence. The developed prototype demonstrates the feasibility of systematic charging-slot allocation, load management, and real-time IoT-based monitoring. By coordinating charging according to demand and available power conditions, the proposed system provides a framework for reducing peak load, minimizing waiting time, improving energy utilization, and supporting cost-aware EV charging. The system can be further enhanced through advanced optimization algorithms, renewable energy integration, dynamic pricing, cloud-based monitoring, and real-time EV charging infrastructure for large-scale smart-grid applications.

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