AI – Enabled Dynamic EV Route Optimization with Real-Time Traffic and Charging Constraints

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Abstract: Electric vehicles (EVs) are becoming more popular, but many people still worry about limited battery range and finding reliable charging stations. Most navigation systems focus only on finding the shortest route and do not consider whether the battery will last for the entire trip. This can lead to range anxiety and inefficient travel. In this paper, we present a route planning system designed especially for electric vehicles as it considers the vehicle's battery percentage. This approach checks whether a route is feasible based on the vehicle's battery level before suggesting it. Energy usage is estimated using travel distance, and charging stations along the route are identified when necessary. The system also uses real-time routing services to generate optimized paths and can adjust the route if the traffic conditions change. Haversine distance computation is used to determine geographic distances when identifying charging stations near the travel route. The system allows users to define a minimum battery reserve percentage that should remain upon reaching the destination. In addition to route planning, the system maintains a database of charging stations and provides a charging slot booking feature that allows EV users to reserve available charging slots in advance. It also lets users create accounts for secure access, sends email confirmations and billing details after booking, and shows routes and charging stations on a map. Users can view their past trips and bookings. The results show that our method improves route reliability and makes better use of available battery power compared to traditional shortest- path navigation systems. The proposed framework is a practical and efficient solution for real-world EV navigation applications.

Keywords: *Route Planning, Battery Management, Haversine Distance, Heuristic Algorithm, Charging Stations, Charging Feasibility Search, Charging Slot Booking.*

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I. INTRODUCTION

The increasing use of electric vehicles (EVs) is changing modern transportation. Despite this growth, electric vehicles face challenges. Limited driving range and the uneven availability of charging infrastructure affects user preference for long-distance travel.

Unlike traditional petrol and diesel vehicles, EVs have strict energy constraints. Drivers must ensure that sufficient battery charge is available throughout a trip and plan charging stops when necessary.

Range anxiety is one of the most common concerns among EV users. Drivers often worry about battery depletion before reaching a charging station or their destination. This creates a need for route planning systems that incorporate battery awareness and charging feasibility into navigation decisions.

Although several studies have explored energy-aware routing and charging optimization, many proposed solutions rely on complex mathematical models. Implementing them in real- time navigation systems requires solutions that are efficient, and easily integrable with existing routing services.

In this paper, we present a battery-aware route optimization system designed specifically for electric vehicles. The proposed system integrates distance-based energy estimation, charging station identification, and real-time routing APIs to generate feasible and reliable travel paths by considering traffic conditions. Instead of focusing only on the shortest route, the system evaluates battery consumption along the route and identifies necessary charging stops when required. The proposed framework aims to provide reliable and safe EV navigation.

In addition to route planning, the system incorporates a charging station management module that stores station information in a database and allows EV users to reserve charging slots before reaching the station. This feature helps reduce waiting time at charging stations. The system also ensures safe travel by maintaining a minimum battery level and identifying charging stations along the travel route when the remaining battery level becomes insufficient. The proposed system incorporates several features to improve real-world EV navigation. These include charging connector compatibility filtering, user-defined minimum battery reserve levels, charging slot availability consideration, and removal of duplicate charging station entries along the route. The system also estimates the expected battery level at arrival and the required charging amount to ensure safe continuation of the journey. Additionally, the system allows users to create accounts for secure access, sends email confirmations and billing details after booking, and displays routes and charging stations on a map. Users can also view their past trips and bookings.

II. LITERATURE SURVEY

Electric Vehicle (EV) route optimization is an important research area due to the increasing number of EV users. However, several challenges such as range anxiety, limited charging stations, and the need for energy-efficient transportation still exist. To address these issues, researchers have developed various algorithms and optimization techniques that improve EV routing by considering battery limitations and charging constraints.

Earlier studies applied shortest-path algorithms to energy- aware routing. Dastpak et al. (2023) proposed a dynamic routing approach for the Electric Vehicle Shortest Path Problem (EVSPP) that considers charging station visits and uncertain waiting times during long-distance travel [1]. Their method uses real-time charging station occupancy information to update routes dynamically and reduce waiting time but it does not give detailed energy optimization or traffic prediction.

Milinović et al. (2025) proposed a Trilevel Memetic Algorithm for the Electric Vehicle Routing Problem (EVRP). The method integrates genetic algorithms and dynamic programming to optimize customer sequencing, route assignment, and charging station insertion [2]. This approach targets multi-vehicle routing scenarios rather than single-vehicle navigation systems.

Rajan et al. (2021) used the Shortest Feasible Path Problem (SFPP) by introducing robustness generalizations to address uncertainty in energy consumption [3]. They proposed Starting Charge Maps and Buffer Maps to incorporate safety margins and user-defined risk tolerance. However, this framework relies on detailed energy modelling and involves complex algorithms.

Houalef et al. (2025) proposed a data-driven and personalized route planning method for electric vehicles [4]. This approach combines energy consumption prediction, traffic conditions, and charging station availability to find optimal routes. They used a hybrid model that blends physics-based methods and machine learning, along with driver behaviour analysis, to improve energy prediction accuracy. An adapted Bellman- Ford algorithm with bidirectional search helps select routes and charging stations efficiently. However, the system is complex because it involves multiple models, real-time data processing, and advanced algorithms.

Even though many researchers have improved EV routing, most of their work focuses on complex mathematical models or routing for many vehicles at once. Only a few systems provide a simple, practical solution that uses real-time APIs and combines route planning, battery calculation, charging stop prediction, and map visualization. The proposed Dynamic EV Route Optimization System addresses these limitations by combining real-time routing APIs, Haversine-based distance estimation, battery consumption modelling, and charging stop prediction within a computationally efficient and deployable architecture suitable for real-world applications.

III. PROPOSED SYSTEM

The proposed system provides route planning solution for electric vehicles by considering battery constraints, distance, traffic conditions, and charging station availability. The system is divided into the following modules:

- *Route Planning and Battery Evaluation:*

Here, the system generates routes between the source and destination using real-time routing APIs while considering current traffic conditions. Battery consumption is estimated based on the travel distance and compared with the available battery percentage. A minimum battery safety threshold is also maintained. If the battery level is insufficient to reach the destination directly, the system identifies suitable charging stations along the route. The route and identified charging stations are visualized on a map, which allows users to view the path and available charging stations. The final optimized route along with charging stops is clearly visualized on an interactive map interface for better user understanding.

- *Charging Station Identification:*

Charging stations that are located along or near the planned route are identified using geographic distance calculations. Charging station information is obtained through charging station APIs and integrated into the system for route analysis. The Haversine distance formula is used to determine the distance between the route and available charging stations. The charging stations that are close to the route are selected as potential charging points. Only stations that are close to the route are considered to avoid large deviations from the planned path. The system can also filter charging stations based on user preferences such as the type of charger and whether the station is public or private.

- *Charging Slot Booking:*

The system allows users to reserve charging slots before reaching a station. Slot availability is checked before confirming a reservation, and the user can reserve a slot for a specific time period. This helps reduce waiting time at charging stations.

➢ *Database Management*

A database is used to store charging station information and booking records. It maintains details such as charging station

➢ *User Interaction and System Support:*

The system includes login and registration features to ensure secure access for users. It sends confirmation emails along with billing information after a charging slot is reserved.

Users can review their previous routes and reservations to manage their travel history efficiently. The user can also download invoice of their previous bookings.

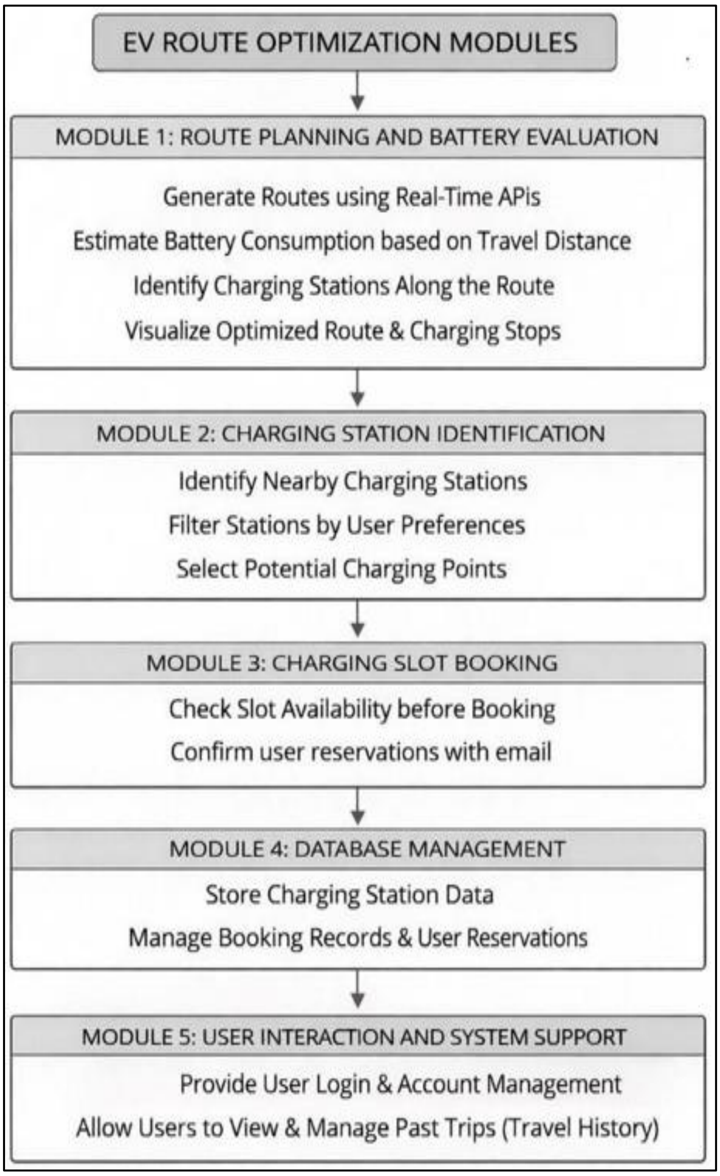

Fig 1 Module Diagram of EV Route Optimization System

IV. SYSTEM ARCHITECTURE

The proposed system architecture for EV route optimization involves collecting user inputs such as starting location, destination, and type of electric vehicle. The system processes this information using various APIs to obtain road network data, traffic conditions, and nearby electric vehicle charging station details. The route optimization process is performed using algorithms such as the A* algorithm for shortest path calculation, while the Haversine formula is used to compute the distance between locations and charging stations. Based on these calculations, the system identifies optimal routes and prioritizes charging stations along the path. The system also checks real-time slot availability at charging stations through API integration. If slot availability is not found at a required charging station, the system recommends charging at the previously available station to avoid travel interruption. The system also provides slot booking confirmation with booking and billing details sent via email. Thus, the proposed system helps the user plan an efficient route and ensures that the location, available charging slots, and user reservations, enabling efficient management of charging infrastructure.

Electric vehicle can reach the destination safely without running out of charge.

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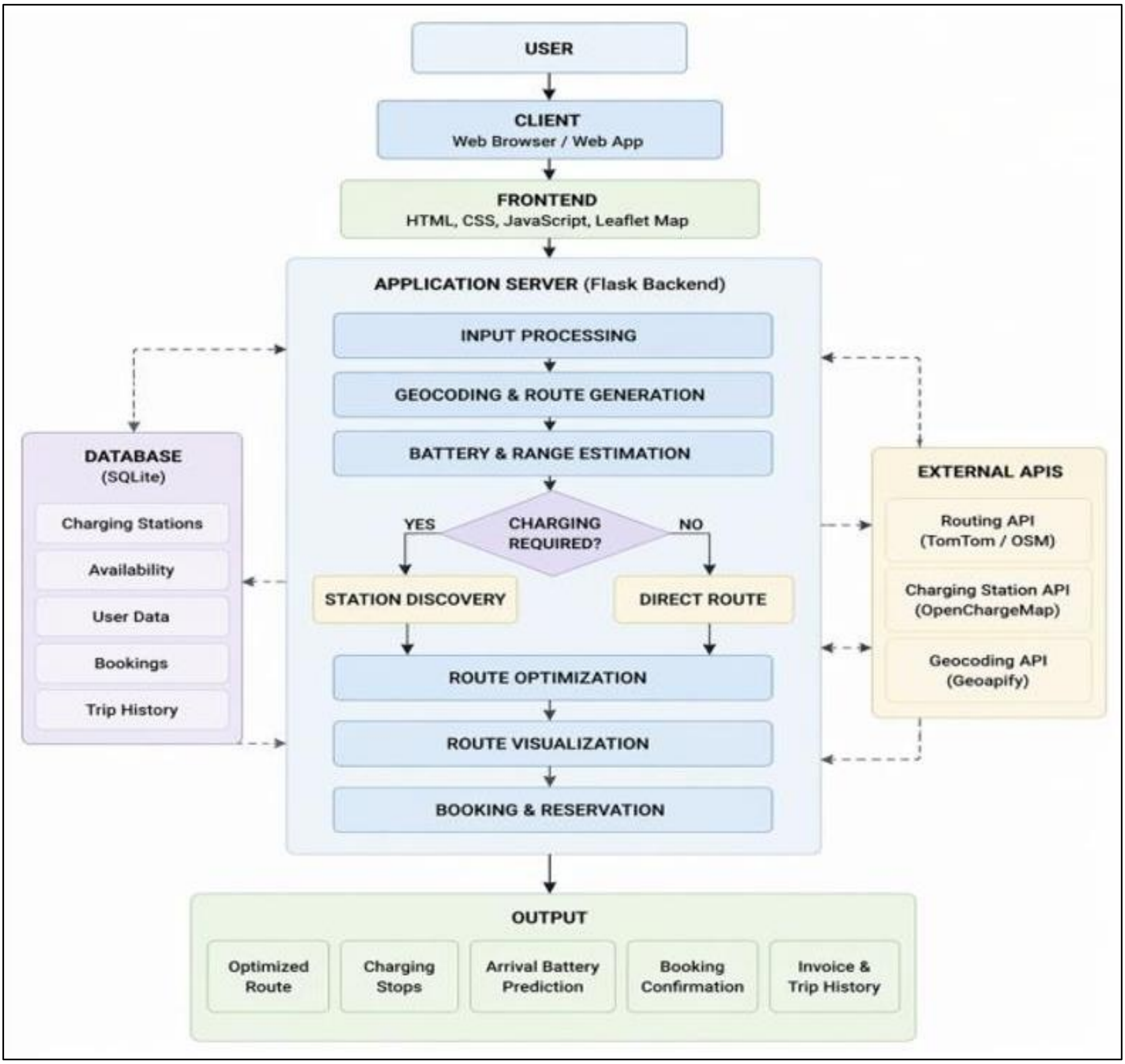


Fig 2 System Architecture Flowchart for EV Route Optimization Framework

V. IMPLEMENTATION DETAILS

➢ *Python:*

We have developed this system using Python. Python is efficient for backend development and API integration. It is used to process user inputs and perform route optimization and distance calculations and generate booking confirmations with billing details sent via email.

➢ *Flask:*

Flask is used as the web framework for building the application. It handles server-side operations such as processing user requests, API communication, and charging slot booking.

➢ *Web Technologies:*

The user interface is developed using HTML, CSS, and JavaScript. These technologies help in creating interactive web pages and displaying route and charging station information.

➢ *Mapping and APIs:*

Leaflet is used to display interactive maps and visualize optimized routes. External APIs such as TomTom Routing API, OpenChargeMap, and Geoapify are used to obtain routing and charging station data.

➢ *Database:*

A SQLite database is used to store charging slot booking details and station availability. It helps the system manage reservations and update slot status dynamically.

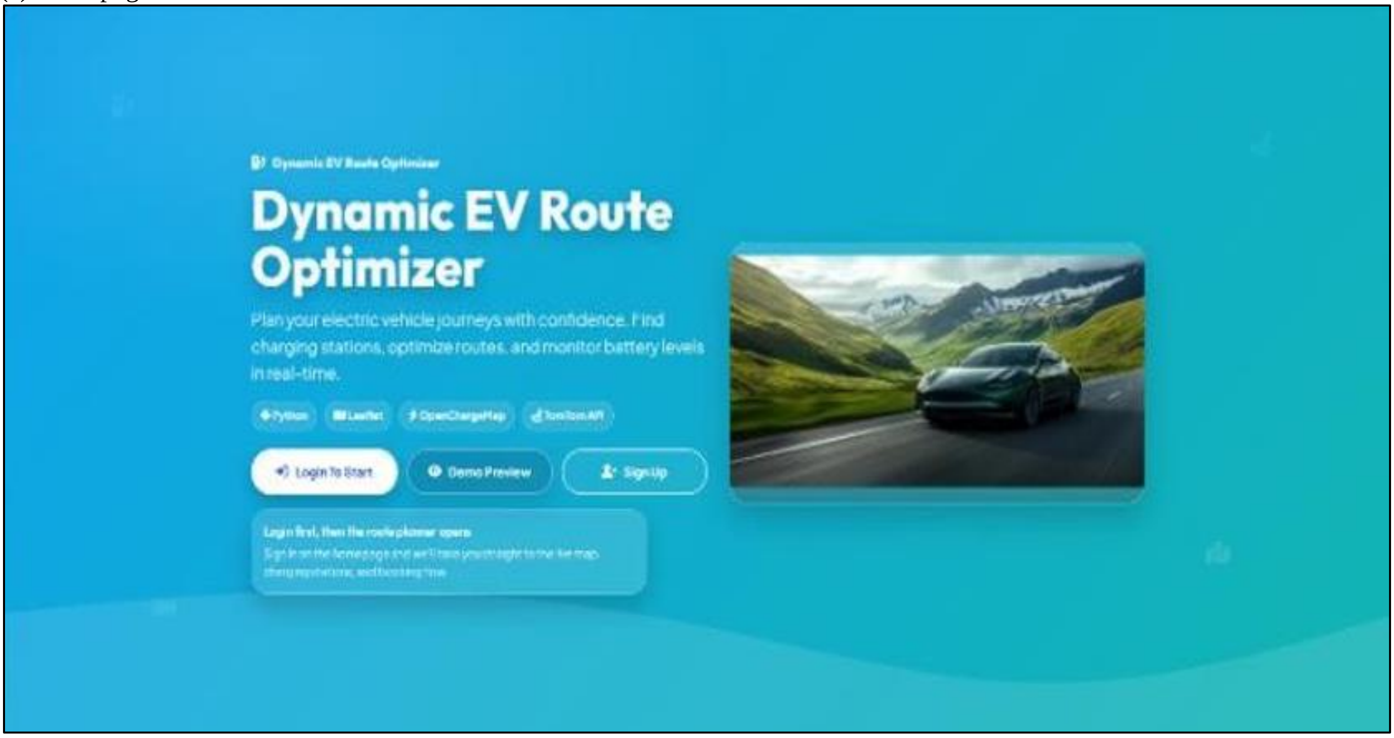
VI. RESULTS

This section describes the results obtained after implementing the Dynamic EV Route Optimization and Charging Slot Booking System. Different travel routes and battery levels were tested to observe how optimized routes are generated, how charging stations are identified along the route, and how arrival reserve is maintained for safe travel. The system was also evaluated for its slot booking, billing, and priority-based charging recommendation features. The results indicate that EV users can plan their trips more efficiently, reduce waiting time at charging stations, and minimize range anxiety using the proposed system.

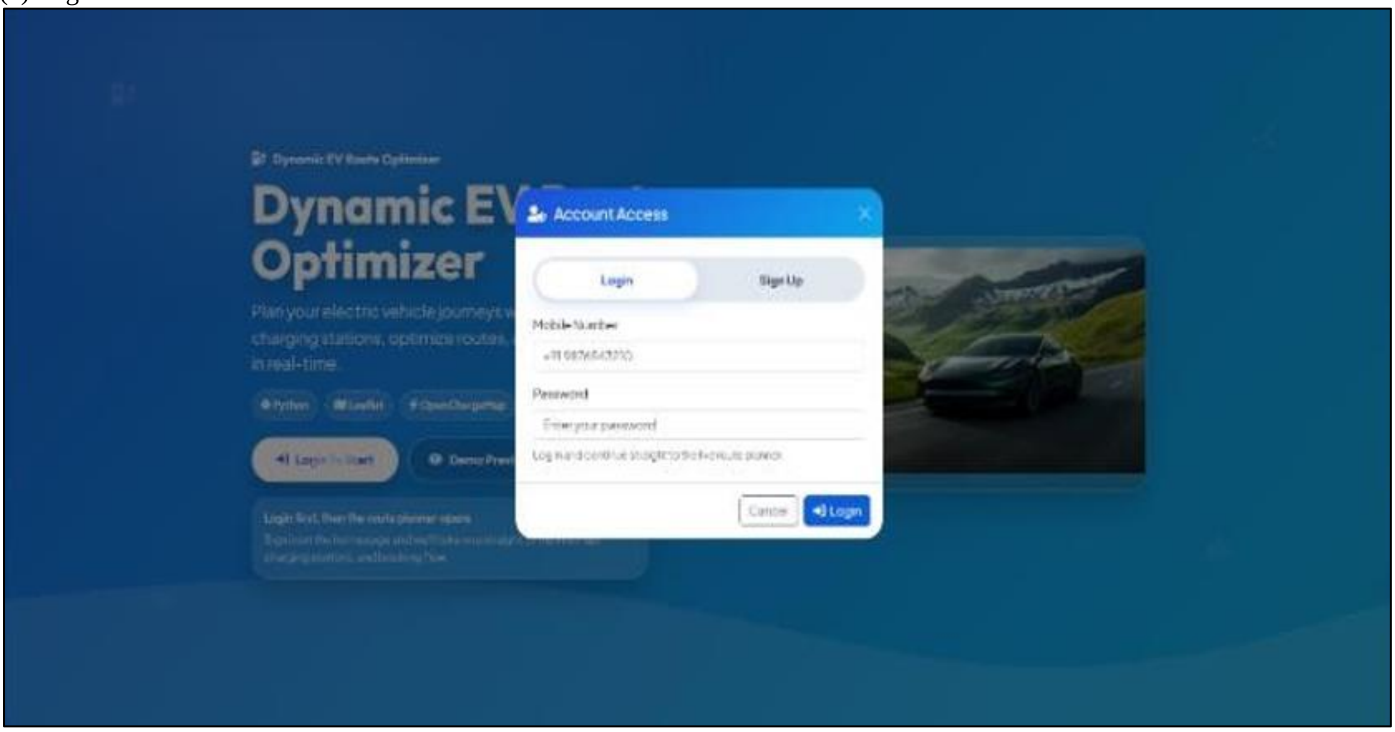
➢ *System Interface and User Access*

The system provides a web-based interface that includes Login, Demo Preview, and Sign-Up options. Users can create an account using their personal details and securely log in to access the application. The demo preview allows users to understand the functionality before actual usage. This interface ensures secure access and smooth navigation to the route planning system.

(a) Homepage



(b) Login



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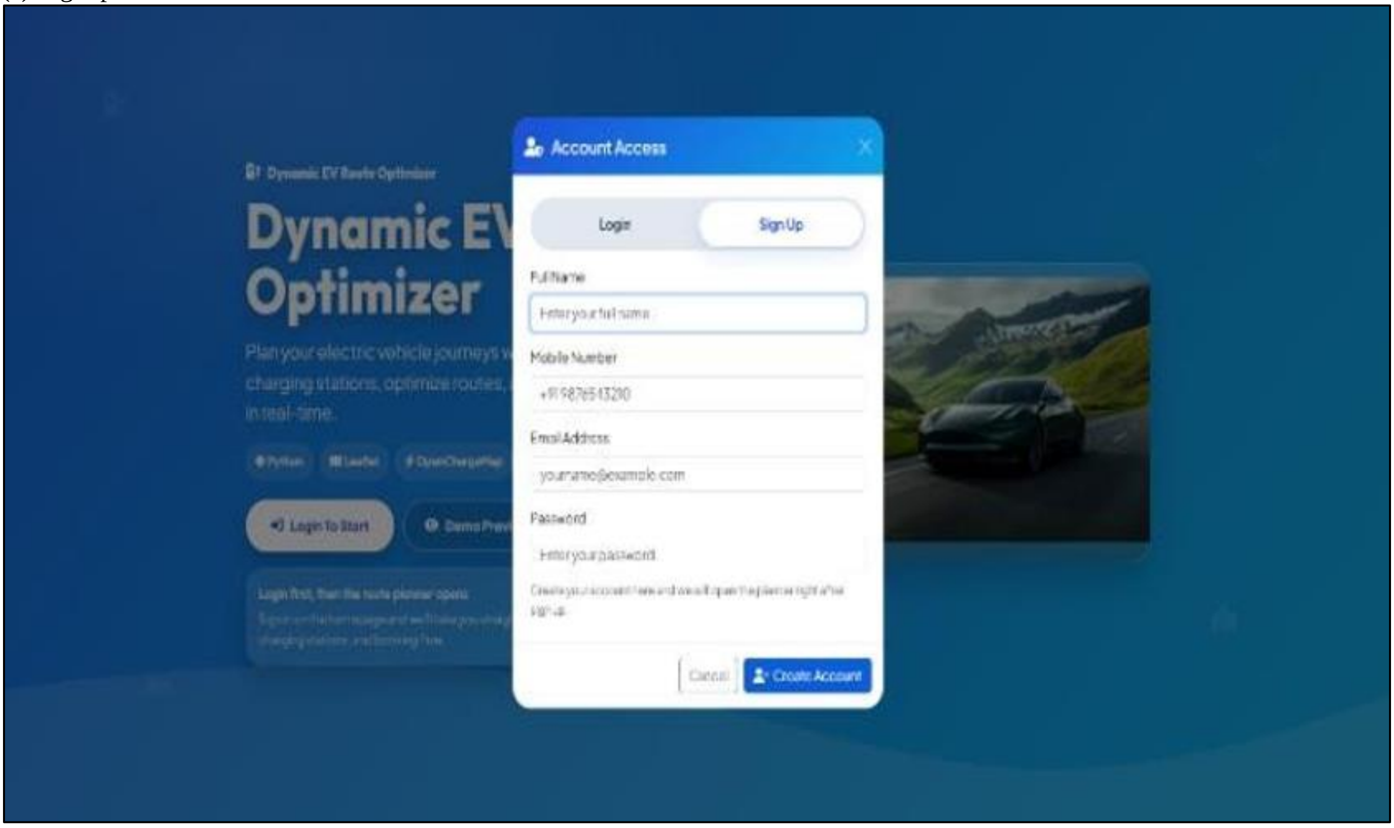
(c) Signup



(d) Demo Preview

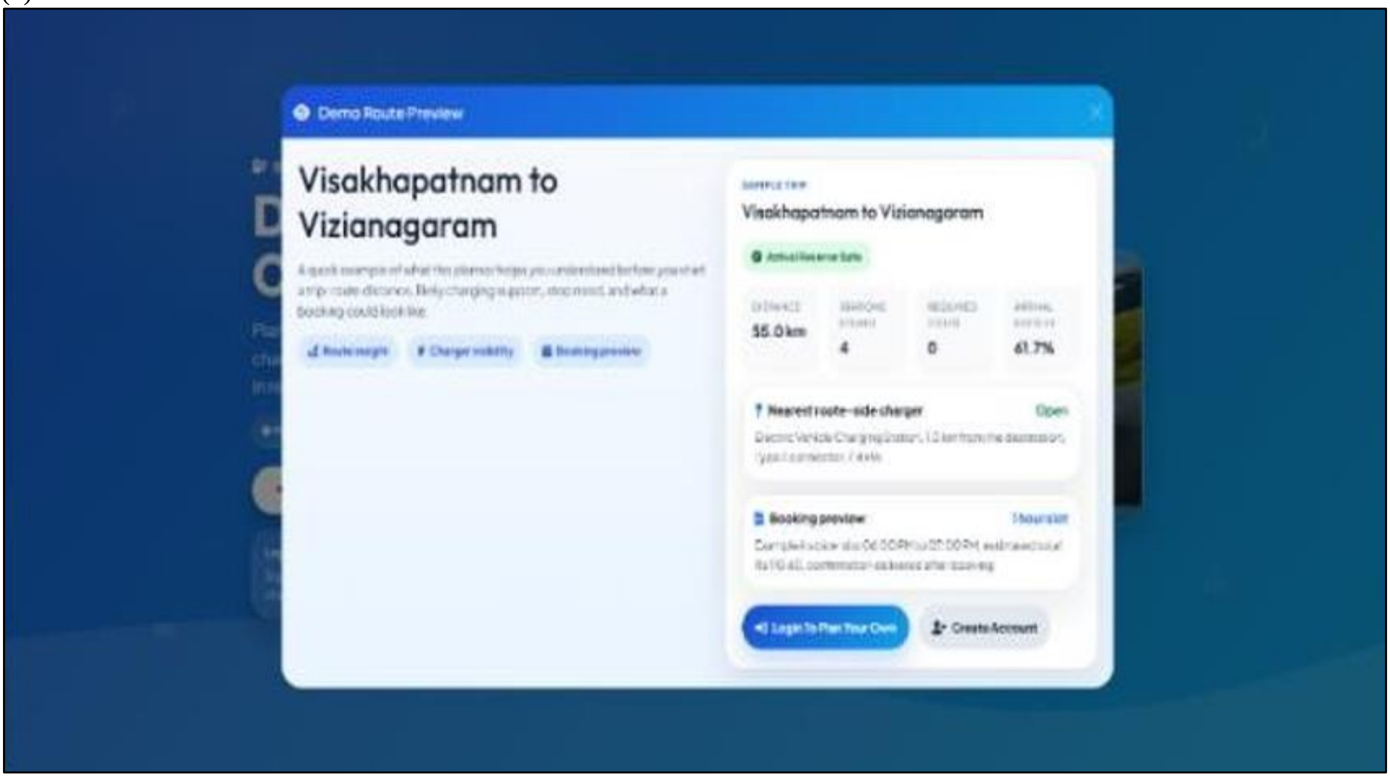


Fig 3 System Interface

➢ *Route Input and Visualization*

The system allows users to enter inputs such as start location, destination, battery level, vehicle range, battery capacity, and connector type. After submitting the inputs, the optimized route is generated and displayed on the map along with charging stations present along the route. The system also indicates the number of charging stations found and highlights stations that are already filled. This visualization helps users clearly understand the route and available charging options.

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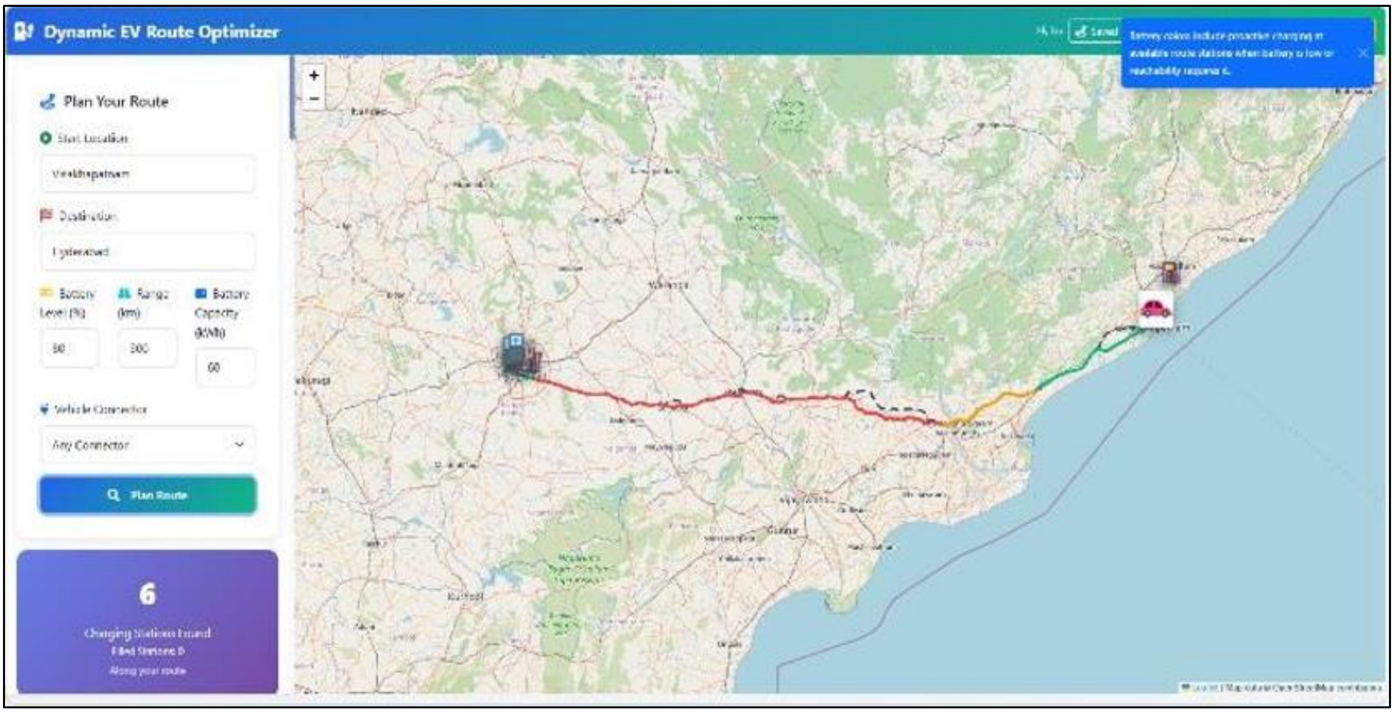

Fig 4 Route Input Interface and Optimized Route Visualization with Charging Stations.

➢ *Route Information and Arrival Reserve Analysis*

After generating the route, the system calculates important travel and battery-related information. It estimates the battery level at arrival and maintains an arrival reserve target to ensure safe travel beyond the destination. The system also identifies the nearest charging station after the destination and displays the route connecting the destination to that charging station. This ensures that users can safely reach a charging point even after completing their journey.

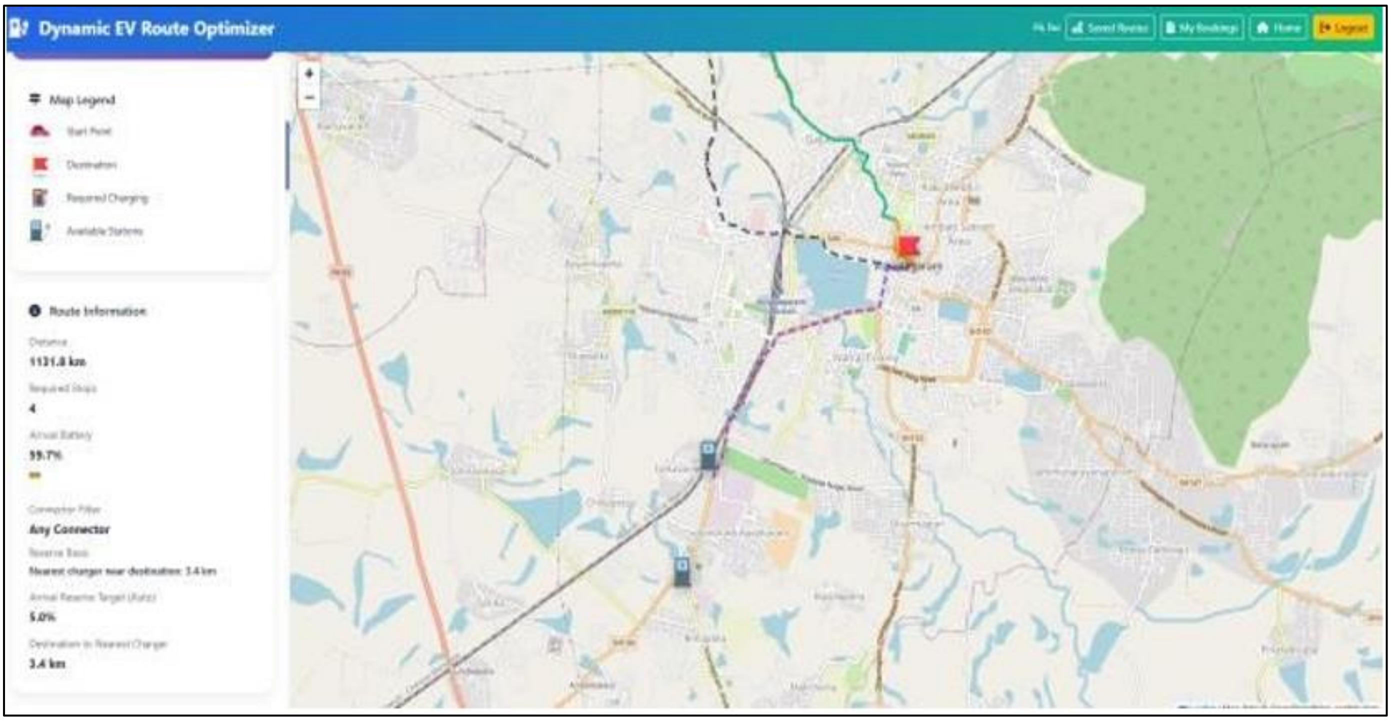

Fig 5 Route Information Panel Showing Arrival Reserve and Destination to Nearest Charging Station Route.

➢ *Charging Station Details and Status*

Each charging station displayed on the map provides detailed information such as station name, connector type, charging power, cost per unit, charging time, and approximate charging cost. The system also indicates the current status of the station, such as busy or available, and displays additional details like distance from the route and booking availability. This helps users select the most suitable charging station.

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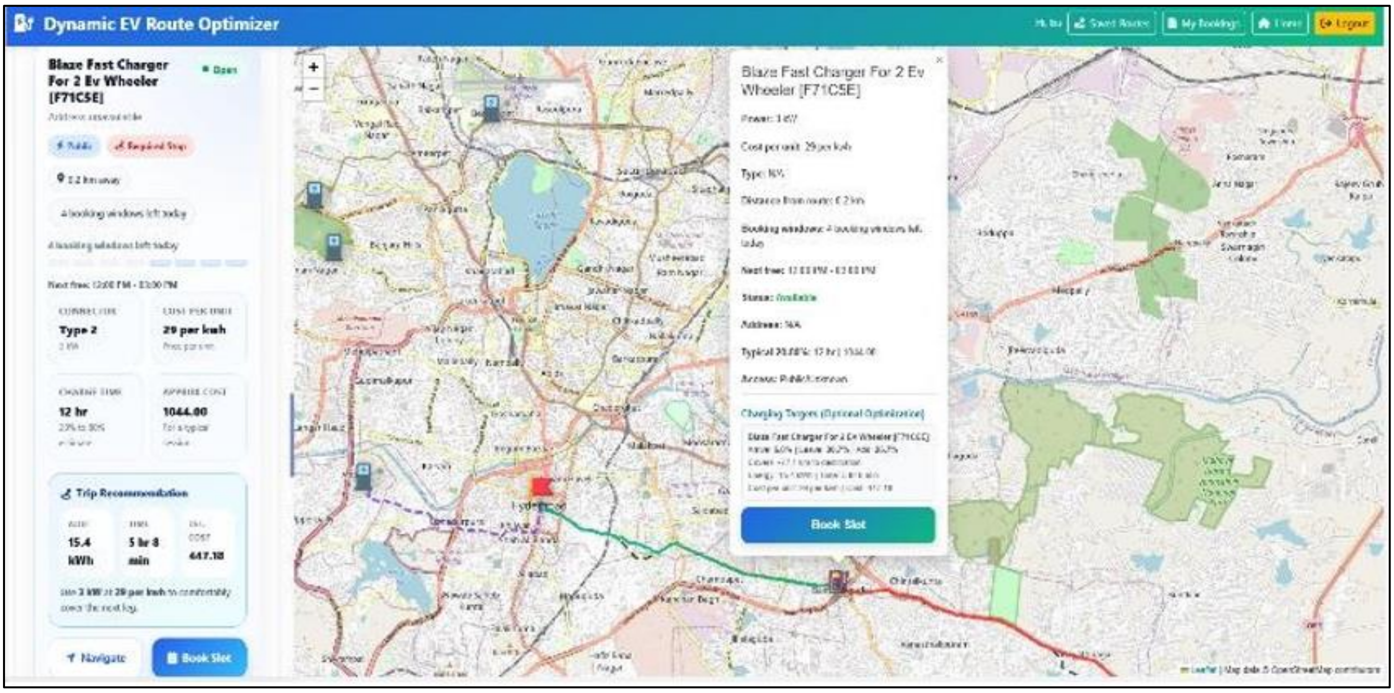

Fig 5 Charging Station Details Including Status, Cost, Connector Type, and Availability.

➢ *Charging Slot Booking System*

The system provides a charging slot booking interface where users can reserve charging time at selected stations. It displays available time slots divided throughout the day, and users can select a slot and charging duration based on availability. The system ensures that users can book slots in advance, reducing waiting time at charging stations.

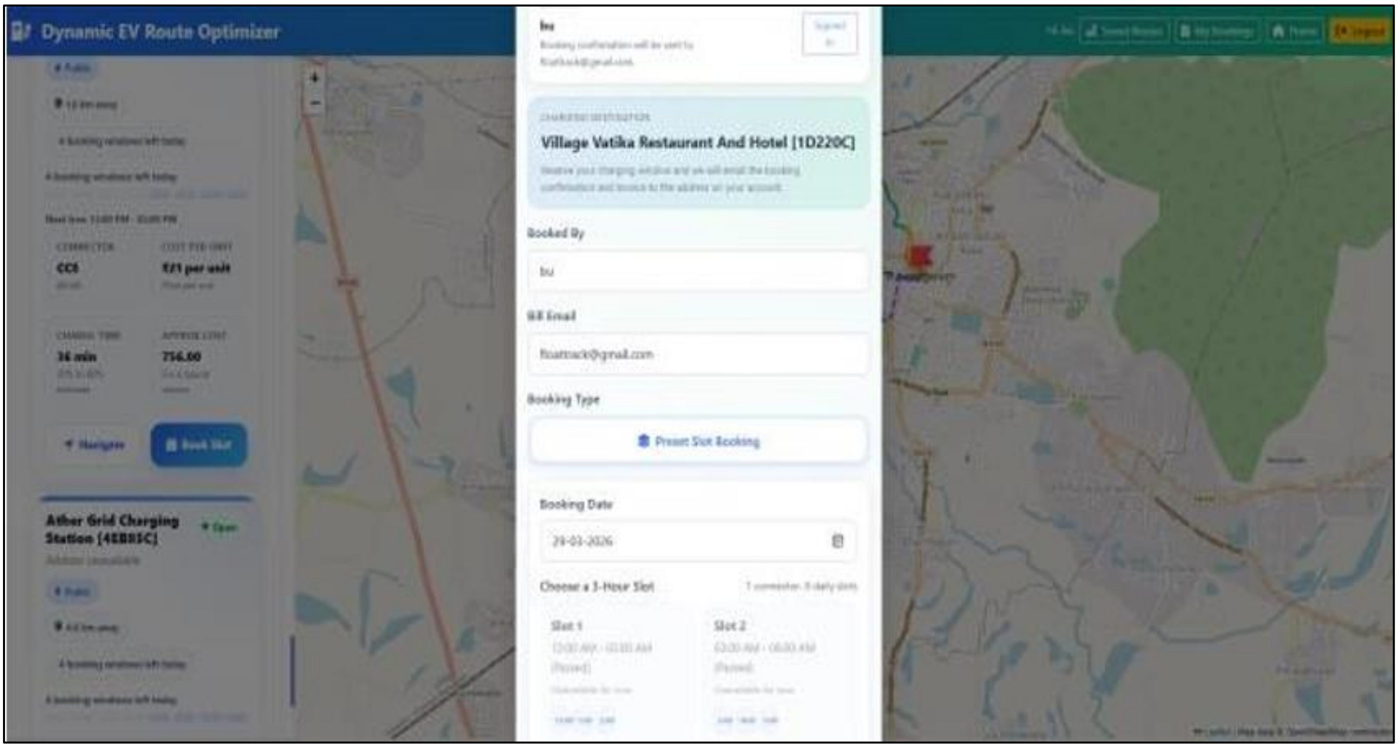

Fig 6 Charging Slot Booking Interface Showing Slot Selection and Booking Details.

Table 1 Charging Slot Booking Test Results

Charging Station	Total Slots	Booked Slots	Status
Blaze Fast Charger	8	8	Filled
Village Vatika Station	8	3	Available
HP Charging Station	8	5	Available

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The results confirm that slot availability is updated correctly.

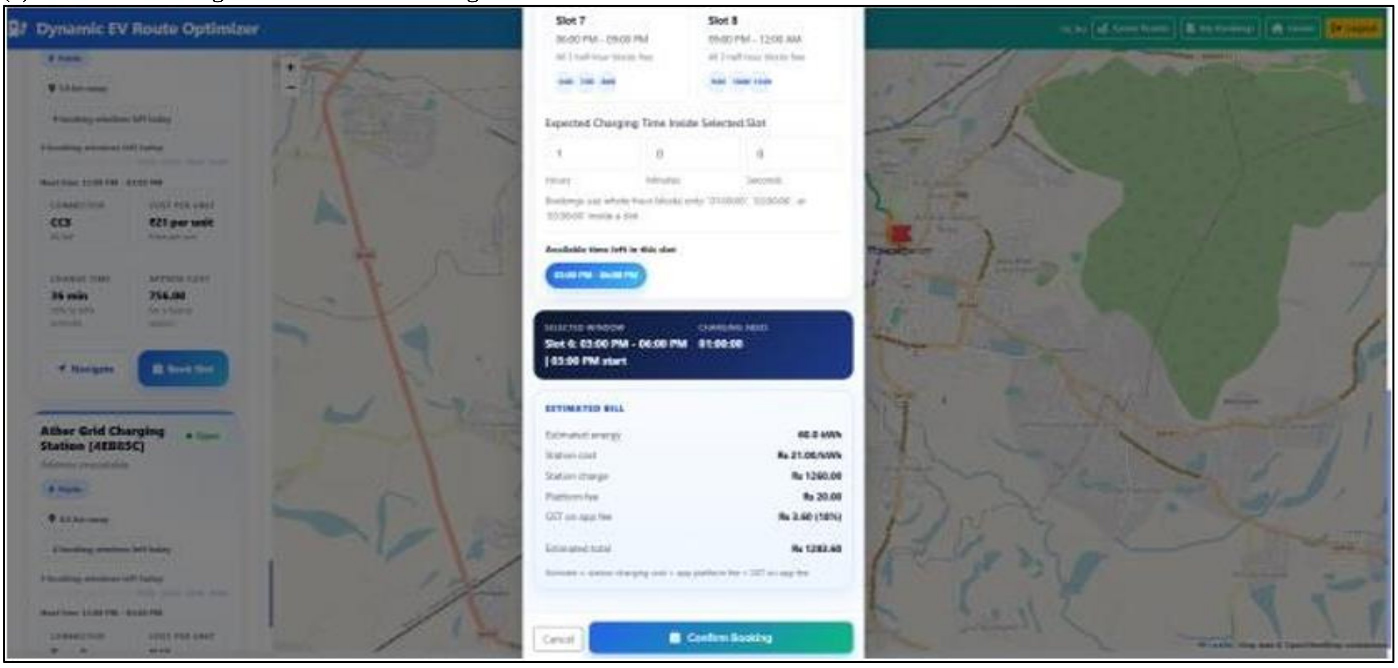
➢ *Priority-Based Charging Recommendation*

In situations where a required charging station is fully occupied, the system recommends an alternative charging after each booking and prevents additional bookings when all slots are filled.

➢ *Billing and Email Confirmation*

After confirming a booking, the system calculates the estimated bill based on energy consumption, charging cost per unit, platform fee, and applicable taxes. The complete billing details are displayed to the user before confirmation. Once the booking is completed, a confirmation message along with the invoice is sent to the user's registered email address.

(a) Estimated Billing Details Before Booking



(b) Email Confirmation Received After Successful Booking

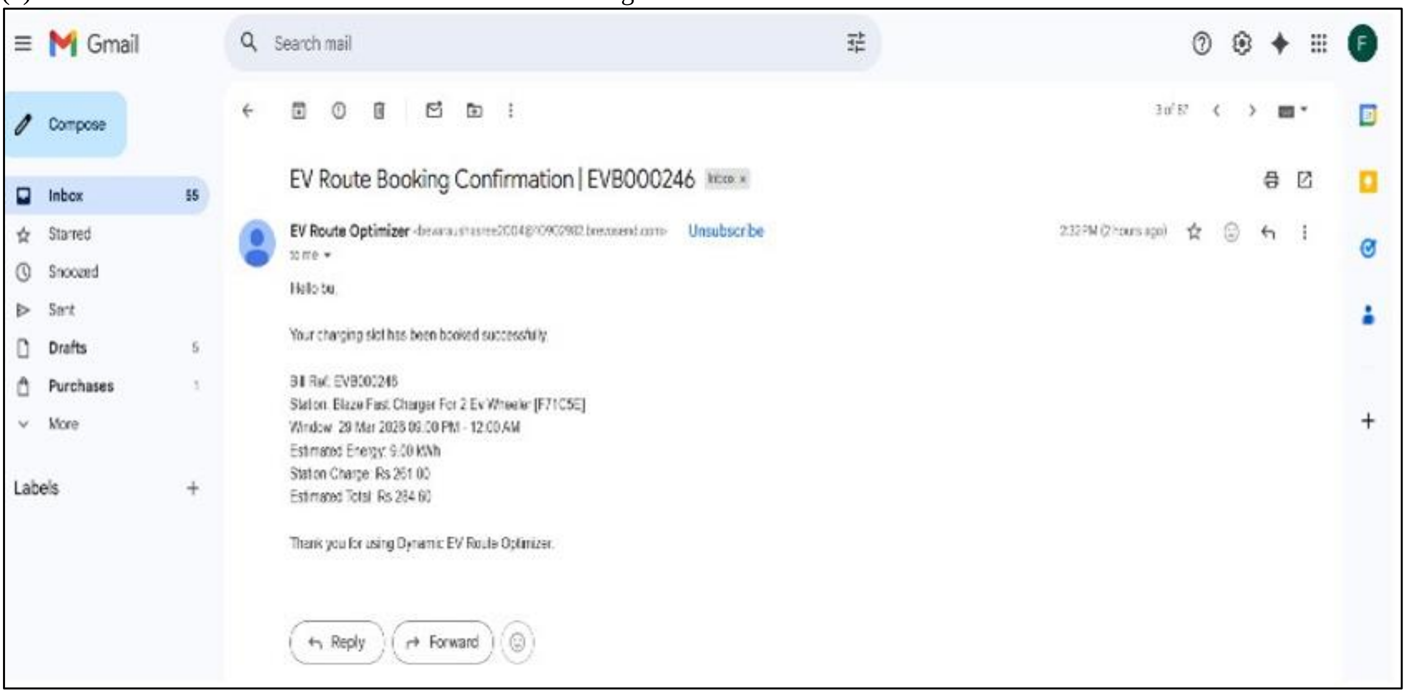


Fig 7 Billing and Confirmation Process

➢ *Slot Availability and Full Station Handling*

The system continuously tracks slot availability for each charging station. When all slots at a station are booked, the station is marked as filled, and further bookings are restricted. This prevents overbooking and ensures that users receive accurate information about slot availability.

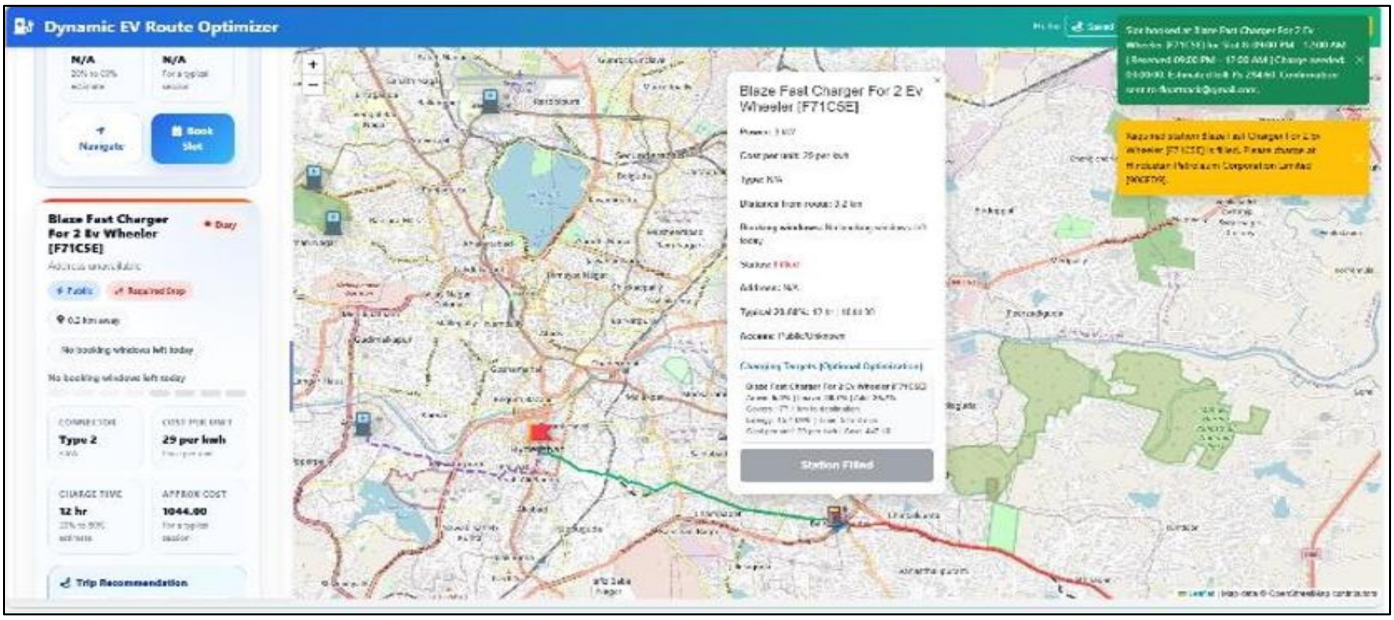


Fig 8 Charging Station Showing Fully Booked Status with No Available Slots

Station Located Earlier Along the Route. This Ensures That Users can Charge Their Vehicles Before Reaching A Full Station, thereby preventing battery depletion and ensuring uninterrupted travel.

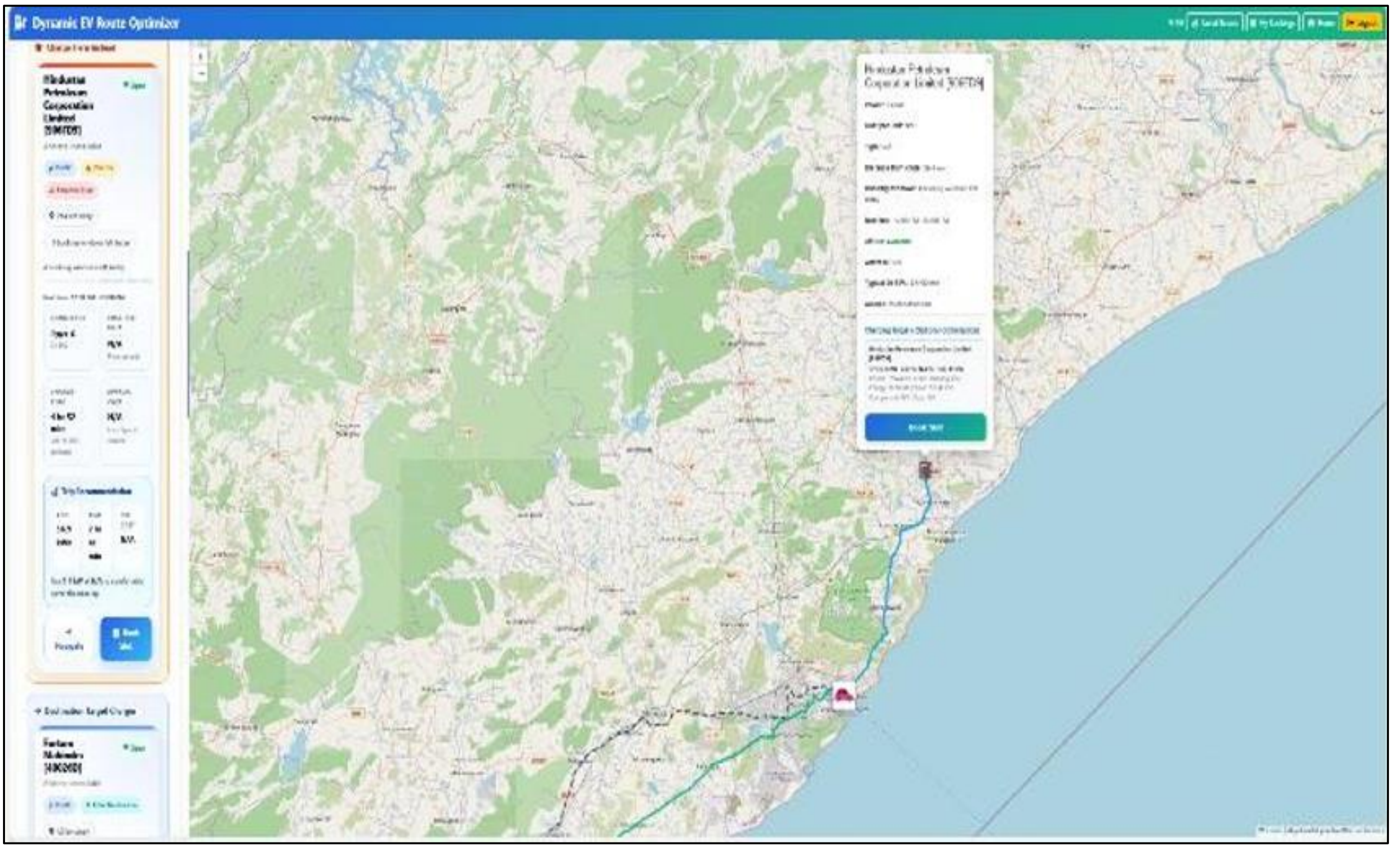


Fig 9 Priority-Based Charging Station Recommendation When Selected Station Is Full.

➢ *Route Visualization from Charging Station to Main Route*

The system displays the route from the selected charging station to the main route and vice versa. This helps users understand the deviation required to reach the charging station and how the route reconnects after charging.

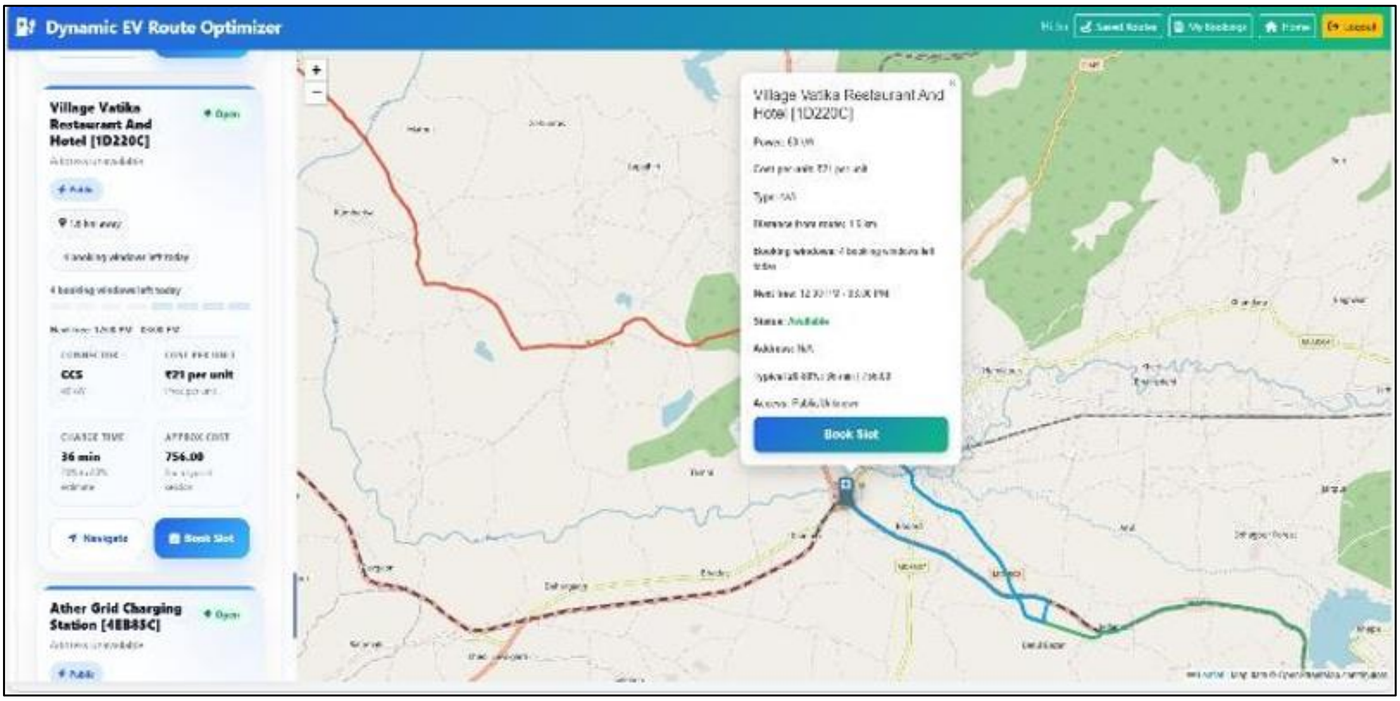


Fig 10 Route Visualization from Charging Station to Main Route.

➢ *Saved Routes and Trip Management*

The system stores previously planned routes as saved routes and recent trips. Users can easily access these routes and reuse them without entering the details again. This improves usability and saves time for frequent users.

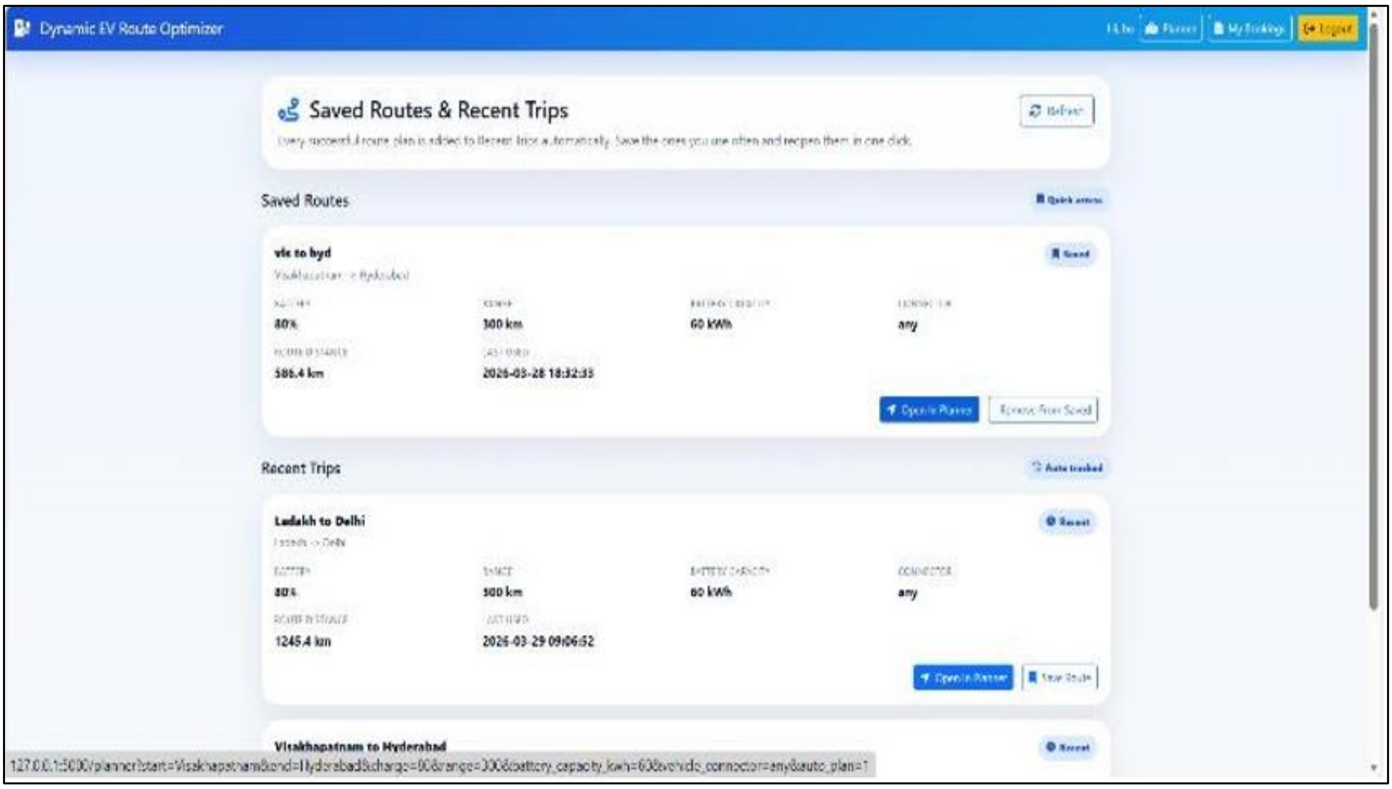


Fig 11 Saved Routes and Recent Trips Interface.

➢ *Booking History and Invoice Management*

The system maintains a record of all bookings, allowing users to view their booking history. Users can also download invoices for completed bookings, ensuring transparency and proper record management.

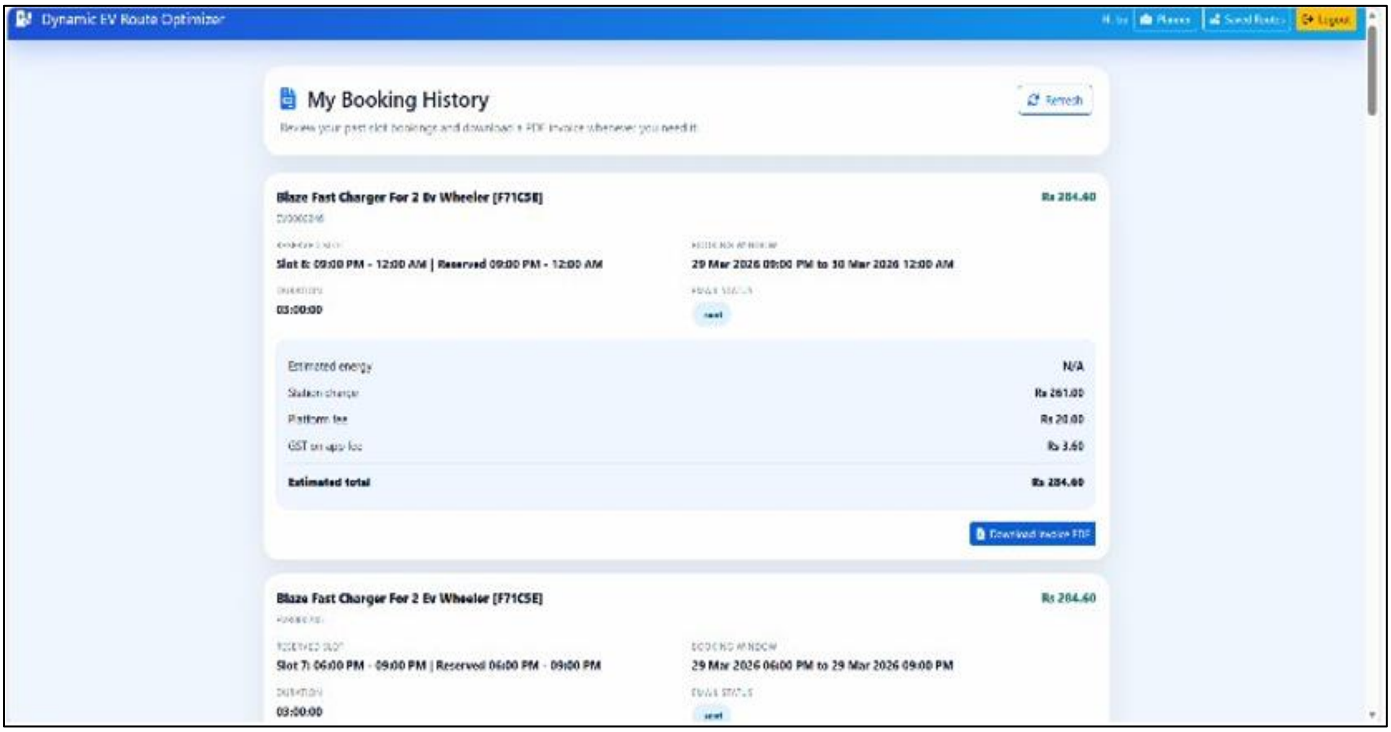


Fig 12 Booking History and Invoice Download Interface.

Table 2 Route Planning and Charging Recommendation Evaluation

Test Case	Route Distance (km)	Initial Battery (%)	System Decision	Result
1	Short distance	High	No charging required	Successful
2	Medium distance	Moderate	Charging recommended	Successful
3	Long distance	Low	Charging required	Successful

The results show that the system correctly determines when charging is required based on route distance and battery level. The relationship between route distance and charging requirement is shown in Fig. 12.

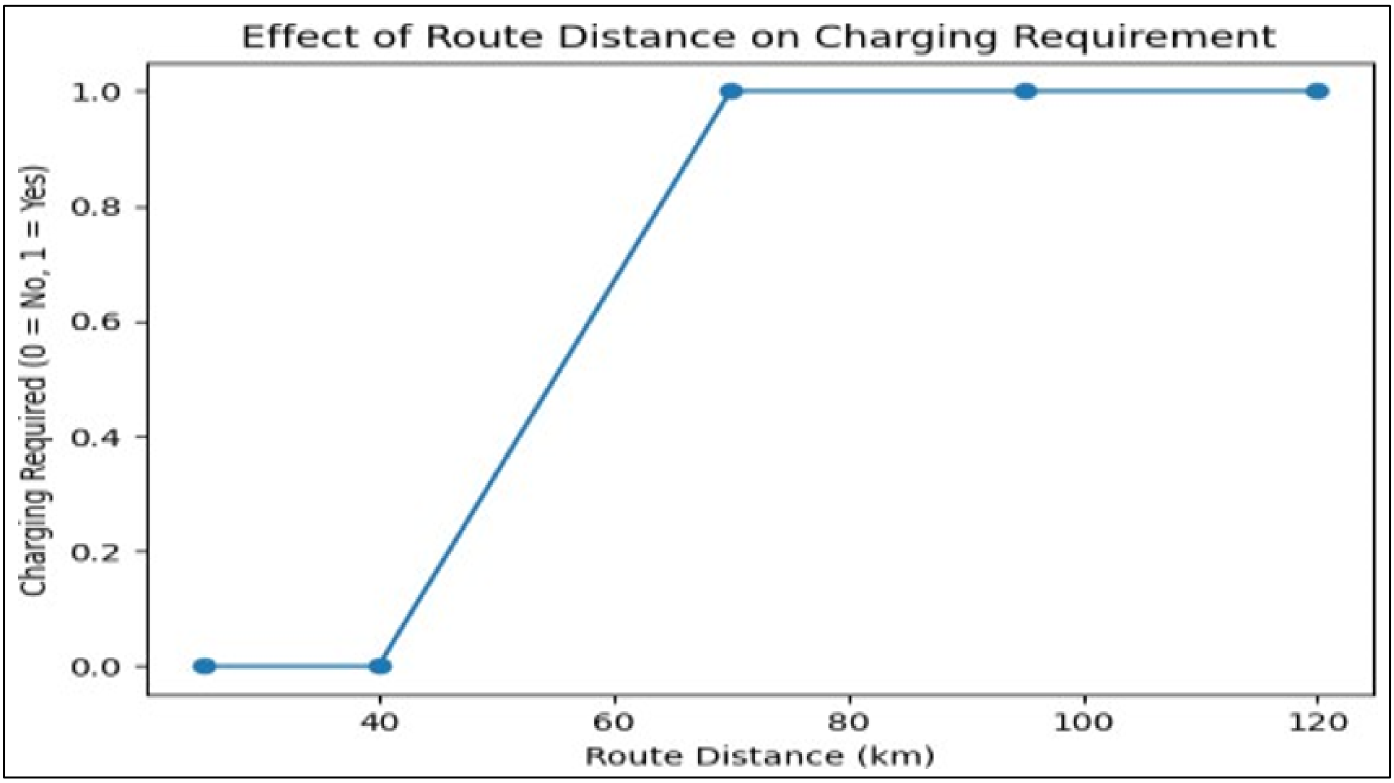


Fig 13 Effect of Route Distance on Charging Requirement in the Proposed System.

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As the route distance increases, the need for charging also increases. This shows that the system effectively predicts charging requirements based on battery level and travel distance.

VII. CONCLUSION

The proposed Dynamic EV Route Optimization System provides a simple and effective solution for planning electric vehicle trips. It combines route optimization, charging station identification, arrival reserve calculation, and slot booking into a single platform. Based on user inputs, the system generates optimized routes and suggests suitable charging stops to ensure that the vehicle maintains a safe battery level throughout the journey. The addition of slot booking and billing features makes the process more convenient by reducing waiting time at charging stations. The results show that the system can accurately determine when charging is required based on route distance and battery level, helping to reduce range anxiety. Overall, the system offers a practical, reliable, and user-friendly approach that supports the increasing use of electric vehicles.

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