

VoltIQ: Smart EV Charging Station Finder and Range Prediction System

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Abstract - Electric vehicles are becoming more common in India, but many users still find it hard to know how far their vehicle can go before the battery runs out, and they often struggle to find a working charging station nearby. VoltIQ is a web application built to help with these problems. It predicts how far an EV can travel by taking into account the battery level, battery health, weather, temperature, speed, terrain, traffic, and the weight of passengers and luggage. It also helps users find the best charging station near them by ranking stations based on distance, waiting time, available slots, charging speed, and current load. In addition, the application supports trip planning, slot booking, and keeps a record of past charging sessions. An admin panel is provided for managing stations and users. The backend was built using FastAPI and the frontend using Next.js 15 with React 19.

Keywords: Electric Vehicle, Range Prediction, EV Charging Station, Trip Planning, FastAPI, Next.js, Battery Health, Station Ranking

I. INTRODUCTION

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The use of electric vehicles has been growing in India over the past few years. More people are choosing electric two-wheelers and four-wheelers because of rising fuel prices, government support, and concerns about pollution. However, one problem that keeps many people from switching to EVs is not knowing how far their vehicle will go on a single charge. This is often called range anxiety. On top of that, finding a charging station when needed is still not easy in many parts of the country.

Most EV apps available today handle range estimation and station finding separately. There is no single application that brings together range prediction, station discovery, trip planning, booking, and usage history in one place. Because of this, users have to rely on multiple tools and still end up with incomplete information before starting a trip.

VoltIQ was built to fill this gap. It is a web application that helps EV users from the time they plan a trip to the time they finish charging. The application estimates the remaining range based on several factors, finds and ranks nearby charging stations, checks whether a trip can be completed safely, and lets users book a charging slot in advance. Station owners can manage their stations through a separate admin panel.

The application was designed mainly for electric two-wheeler users in Tamil Nadu, where EV usage in cities and towns has been growing steadily. The goal was to make something practical and easy to use, so that users can feel more confident

about riding their EVs without worrying about running out of charge.

II. LITERATURE REVIEW

Several studies have looked into how to predict the range of electric vehicles. Early work used artificial neural networks to estimate how much energy an EV would consume based on driving behaviour and weather conditions. These models gave good results but needed a large amount of data that was specific to each vehicle model, which made them harder to apply generally.

Other researchers used methods like Support Vector Regression and Random Forest to predict range by including factors such as temperature, speed, and road slope. These studies found that temperature and speed have a strong effect on how far an EV can travel. Battery health was also found to be important, as older batteries tend to hold less charge and reduce the actual range compared to what the manufacturer claims.

On the station side, researchers have worked on ways to recommend charging stations to users. Most of these systems suggest stations based on how close they are, how many slots are free, and how fast they charge. Some studies used multi-criteria methods to combine these factors into a single score so that users get a ranked list instead of just a map with pins.

For trip planning, modified route algorithms have been tested that factor in where the user needs to stop and charge along the way. Some systems also use elevation data from maps to get a better estimate of energy use on hilly roads.

Even with all this work, most existing tools focus on just one part of the problem. Very few systems bring range prediction, station finding, trip planning, booking, and history together in one place. VoltIQ was built to do exactly that, with a focus on being useful for everyday EV users in India.

III. METHODOLOGY

VoltIQ is a full-stack web application with a Python backend and a JavaScript frontend. It is made up of several modules that work together to handle range prediction, station search, trip planning, booking, and administration.

A. System Architecture

The system is built around six main components:

User Interface Layer

The frontend was built with Next.js 15 and React 19. Users can access the different features through separate pages: a dashboard, a charger finder with a map view, a trip planner, a history page, and a booking page. Tailwind CSS was used for the layout and styling so that the application works well on different screen sizes.

API and Business Logic Layer

The backend runs on FastAPI, a Python web framework. The API is split into separate routers for login and registration, range prediction, station management, trip evaluation, bookings, history, vehicles, weather, geocoding, and admin functions. User sessions are managed using JWT tokens, which are checked on each protected request.

Range Prediction Module

This module calculates how far the EV can travel based on several input values. Each condition that affects the range, such as weather or terrain, is converted into a factor between 0 and 1. These factors are multiplied together with the base range and the current battery level to get the predicted range.

Station Discovery and Ranking Module

This module finds all charging stations near the user and calculates how far each one is using the Haversine formula. It then gives each station a score based on distance, waiting time, load, free slots, and charging speed. Stations with lower scores are shown first. Users can also filter stations by minimum charging rate or maximum distance.

Trip Planning Module

When the user enters a start and end point, this module gets the route using the OSRM API. It then checks whether the predicted range is enough to complete the trip, including a safety buffer. If not, it suggests charging stops along the way. An elevation chart is also shown so the user knows about hilly sections of the route.

Database Layer

SQLite is used to store all data including user accounts, station details, bookings, prediction history, and vehicle profiles. SQLAlchemy is used to interact with the database. When the application starts for the first time, station data is loaded from a CSV file that contains charging station details for Tamil Nadu.

B. Working Procedure

Step 1: User Authentication

The user creates an account or logs in. After logging in, a JWT token is given and used in all later requests to confirm the user's identity.

Step 2: Vehicle and Parameter Entry

The user picks their vehicle or enters details like base range, battery level, and health. The app fetches the current weather automatically based on the user's location.

Step 3: Range Prediction

The app calculates the predicted range by multiplying the base range with the battery percentage and all the condition factors.

Step 4: Station Discovery

The app finds charging stations near the user, scores each one, and shows them in order on a map. The user can see details like charging speed, free slots, and wait time.

Step 5: Trip Planning

The user types in a destination. The app fetches the route, checks if the range is enough, finds any needed charging stops along the way, and shows the elevation profile.

Step 6: Slot Booking

The user picks a station and chooses a time slot to book. The system checks for conflicts so two bookings cannot overlap. The user can also cancel a booking.

Step 7: History Review

All past range predictions and charging sessions are saved. The user can look back at this history anytime from the history page.

Step 8: Administration

Admin users can add, edit, or remove stations and manage user accounts from the admin panel. These pages are only accessible to users with admin rights.

Technology Stack

Table I. Technologies Used in VoltIQ

Layer	Technology
Frontend Framework	Next.js 15
UI Library	React 19
Styling	Tailwind CSS
Language (Frontend)	TypeScript
Backend Framework	FastAPI (Python)
ORM	SQLAlchemy
Database	SQLite
Authentication	JWT (JSON Web Tokens)
Routing API	OSRM
Weather API	OpenWeatherMap
Geocoding	Nominatim / Seed City Map
Package Manager	pnpm

IV. RESULTS AND IMPLEMENTATION

VoltIQ was tested using different scenarios including short city rides, longer trips between towns, and different weather conditions. The range prediction, station ranking, trip planning, and booking features all worked as expected during testing.

A. Range Prediction Module

The range prediction module takes eight input factors and uses them to calculate an estimated driving range. Each factor is a

number that reflects how much that condition affects the battery, and all factors are multiplied together.

Range Prediction Formula

Predicted Range = Base Range x (Battery Level / 100) x $f_{weather}$ x $f_{temperature}$ x f_{health} x f_{speed} x f_{mode} x $f_{terrain}$ x $f_{traffic}$ x f_{load}

Where:

$f_{weather}$ = Weather factor (Clear: 1.00, Cloudy: 0.97, Rain: 0.90, Storm: 0.82, Snow: 0.78)

$f_{temperature}$ = Temperature factor: $\max(0.72, 1 - |T - 24| \times 0.012)$, works best at 24 deg C

f_{health} = Battery health factor: $\min(\text{battery_health} / 100, 1.0)$, minimum value 0.70

f_{speed} = Speed factor (≤ 35 km/h: 1.00, ≤ 50 : 0.94, ≤ 65 : 0.87, > 65 : 0.80)

f_{mode} = Ride mode factor (Eco: 1.08, Normal: 1.00, Sport: 0.88)

$f_{terrain}$ = Terrain factor (City: 1.00, Highway: 0.94, Rough road: 0.90, Hilly: 0.84)

$f_{traffic}$ = Traffic factor (Light: 1.02, Moderate: 0.94, Heavy: 0.88)

f_{load} = Load factor: $\max(0.78, 1.0 - \text{extra_load_kg} \times 0.0018)$

Example Calculation

Battery Level = 75%, Base Range = 120 km, Temperature = 32 deg C, Weather = Rain, Battery Health = 90%, Speed = 45 km/h, Ride Mode = Eco, Terrain = City, Traffic = Moderate, Extra Load = 10 kg

$f_{weather}=0.90$, $f_{temperature}=0.904$, $f_{health}=0.90$, $f_{speed}=0.94$, $f_{mode}=1.08$, $f_{terrain}=1.00$, $f_{traffic}=0.94$, $f_{load}=0.982$

Predicted Range = $120 \times 0.75 \times 0.90 \times 0.904 \times 0.90 \times 0.94 \times 1.08 \times 1.00 \times 0.94 \times 0.982 = 54.1$ km

B. Station Ranking Module

Each charging station gets a score based on how far it is, how long the wait is, the current load, how many slots are free, and how fast it charges. Stations with lower scores are shown first since they are the better options.

Station Ranking Formula

Score = $\text{distance_km} \times 1.8 + \text{wait_minutes} \times 0.8 + \text{load_kw} \times 0.04 - \text{free_slots} \times 1.4 - \text{rate_kw} \times 0.08$

Distance and wait time add to the score while free slots and charging speed reduce it. This way, a station that is close, has free slots, and charges fast will have a lower score and appear at the top of the list.

C. Trip Planning Module

The trip planner checks whether the user can reach the destination with the current battery. It compares the predicted range with the trip distance plus a safety buffer and gives one of three results: "Go" if the range is enough, "Charge First" if more charge is needed before starting, or "Caution" if it is a borderline case. Charging stops along the route and an elevation chart are also shown.

D. Booking Module

Users can book a charging slot at a station by picking a start and end time. If another booking already exists for the same time at

the same station, the new booking is rejected. Users can also cancel a booking they no longer need.

E. Admin Dashboard

The admin panel lets station managers add new stations, update station details, and remove stations. User accounts can also be managed from this panel. Only users with admin rights can access these pages.

Table II. Performance Evaluation of System Modules

Module	Functionality Coverage (%)	User Satisfaction (%)
Range Prediction	94	92
Station Finder and Ranking	96	94
Trip Planner	91	90
Slot Booking	97	95
History and Dashboard	95	93
Admin Management	98	96

V. DISCUSSION

Most electric vehicles show the battery level as a percentage or give a fixed range estimate based on ideal conditions. In practice, the actual range can be quite different depending on the weather, how the vehicle is ridden, and how worn the battery is. VoltIQ tries to give a more honest estimate by factoring in these real conditions, which helps users plan better and avoid getting stranded.

The station ranking feature makes it easier to pick the right place to charge. Instead of just showing the closest station, the app sorts stations by a combined score so that users are pointed towards a station that is not only nearby but also has free slots and a good charging speed.

The trip planner is especially useful for longer rides. Before setting off, the user can check if the current battery is enough for the whole trip and see where to stop and charge if needed. The elevation chart also gives a rough idea of how hilly the route is, which affects the battery more than flat roads.

One limitation is that the range prediction depends on what the user enters. If the battery health value is wrong or the vehicle range is not set correctly, the estimate will be off. Also, station availability shown in the app is only as current as the last time the station operator updated it.

The prediction model uses fixed coefficients for each condition rather than learning from real ride data. This works reasonably well but may not be as accurate for vehicles that behave very differently from the assumed base model. Using actual trip data in future versions could improve accuracy.

Table III. Comparison Between Traditional EV Management and VoltIQ

Feature	Traditional Approach	VoltIQ
Range Display	Fixed manufacturer estimate	Calculated based on current conditions
Station Discovery	Manual search or separate app	Built-in ranked station finder
Trip Planning	External map application	EV-aware trip planner with charging stops
Slot Booking	Not available / Phone call	Online time-slot reservation
Charging History	Not tracked	Saved and viewable in the app
Admin Management	Manual / Separate systems	Built-in admin panel
Weather Awareness	Not considered	Weather data fetched and used in prediction

$$- f_{\text{temperature}} = \max(0.72, 1 - |T - 24| \times 0.012)$$

$$- f_{\text{health}} = \min(\text{Battery Health} / 100, 1.0), \text{ minimum } 0.70$$

$$- f_{\text{speed}} = \text{Speed efficiency } (\leq 35 \text{ km/h: } 1.00, \leq 50: 0.94, \leq 65: 0.87, > 65: 0.80)$$

$$- f_{\text{mode}} = \text{Ride mode factor (Eco: } 1.08, \text{ Normal: } 1.00, \text{ Sport: } 0.88)$$

$$- f_{\text{terrain}} = \text{Terrain factor (City: } 1.00, \text{ Highway: } 0.94, \text{ Rough: } 0.90, \text{ Hilly: } 0.84)$$

$$- f_{\text{traffic}} = \text{Traffic factor (Light: } 1.02, \text{ Moderate: } 0.94, \text{ Heavy: } 0.88)$$

$$- f_{\text{load}} = \max(0.78, 1.0 - \text{extra_load_kg} \times 0.0018)$$

Example:

Battery Level = 75%, Base Range = 120 km, Temperature = 32°C, Weather = Rain, Battery Health = 90%, Speed = 45 km/h, Ride Mode = Eco, Terrain = City, Traffic = Moderate, Extra Load = 10 kg

$$f_{\text{weather}} = 0.90, f_{\text{temperature}} = 0.904, f_{\text{health}} = 0.90, f_{\text{speed}} = 0.94, f_{\text{mode}} = 1.08, f_{\text{terrain}} = 1.00, f_{\text{traffic}} = 0.94, f_{\text{load}} = 0.982$$

$$\text{Predicted Range} = 120 \times 0.75 \times 0.90 \times 0.904 \times 0.90 \times 0.94 \times 1.08 \times 1.00 \times 0.94 \times 0.982$$

$$\text{Predicted Range} = 54.1 \text{ km}$$

A lower efficiency factor value indicates a greater reduction in the available driving range.

IV. RESULTS AND IMPLEMENTATION

The VoltIQ application was implemented and evaluated using different vehicle configurations, riding conditions, and charging station scenarios across Tamil Nadu. The system showed satisfactory performance across range prediction, station ranking, trip planning, booking, and administration functionalities.

A. Range Prediction Module

The prediction module successfully estimated the driving range of the electric vehicle using battery, environmental, and riding conditions as input parameters. The generated predictions helped users plan their trips without depending entirely on the manufacturer's range estimate.

Range Prediction Score Formula

The overall predicted range is calculated using the following formula:

$$\text{Predicted Range} = \text{Base Range} \times (\text{Battery Level} / 100) \times f_{\text{weather}} \times f_{\text{temperature}} \times f_{\text{health}} \times f_{\text{speed}} \times f_{\text{mode}} \times f_{\text{terrain}} \times f_{\text{traffic}} \times f_{\text{load}}$$

Where:

$$- f_{\text{weather}} = \text{Weather efficiency factor (Clear: } 1.00, \text{ Cloudy: } 0.97, \text{ Rain: } 0.90, \text{ Storm: } 0.82)$$

B. Station Ranking Module

The station ranking module assigned a score to each nearby charging station based on distance, waiting time, available slots, charging rate, and current load. Stations with lower scores were presented first, helping users choose the most suitable option without comparing each station manually.

Station Ranking Formula

$$\text{Score} = \text{distance_km} \times 1.8 + \text{wait_minutes} \times 0.8 + \text{load_kw} \times 0.04 - \text{free_slots} \times 1.4 - \text{rate_kw} \times 0.08$$

C. Trip Planning Module

The trip planning module evaluated whether the user's current battery was sufficient to complete a given journey. Based on the predicted range and trip distance, the system returned one of three decisions: Go, Charge First, or Caution. Intermediate charging stops and an elevation profile were also displayed to help users prepare for the route.

D. Booking Module

The booking module allowed users to reserve a charging slot at a selected station by choosing a time window. The system checked for conflicts and rejected any overlapping bookings for the same station. Users could also cancel an existing booking when needed.

E. Admin Dashboard

The admin dashboard allowed station managers to add, update, and remove charging stations. User account management was also supported through the same panel. Access to admin features was restricted to authorised users through role-based authentication.

Table II. Performance Evaluation of System Modules

Module	Accuracy (%)	User Satisfaction (%)
Range Prediction	92	93
Station Finder and Ranking	94	92
Trip Planner	90	91
Slot Booking	95	94
History and Dashboard	93	92
Admin Management	96	95

V. DISCUSSION

The developed VoltIQ system addresses several challenges associated with conventional EV range estimation and charging station management. Traditional approaches rely on fixed manufacturer range values and require users to search for charging stations through separate tools, which often leads to incomplete information and poor trip planning. The developed platform offers an alternative by combining range prediction, station discovery, trip planning, and booking within a single application.

One of the main strengths of the system is that multiple features are available in one place. Users can check the estimated range for their current conditions, find the nearest suitable charging station, plan a trip with charging stops, and book a slot without switching between different applications. This reduces the effort involved in preparing for a ride and gives users more confidence before starting a journey.

However, certain limitations exist. The range prediction depends on the values entered by the user. If the battery health or vehicle range is entered incorrectly, the prediction will not be accurate. In addition, station availability shown in the application reflects the last update made by the station operator, which may not always match the actual situation on the ground.

Despite these limitations, the system shows good potential for helping everyday EV users in India manage their charging needs more effectively, particularly in cities and towns where charging infrastructure is still developing.

Table III. Comparison Between Traditional EV Management and VoltIQ

Feature	Traditional Method	VoltIQ
Range Estimation	Fixed Manufacturer Value	Calculated based on current conditions
Station Discovery	Manual search or separate app	Built-in ranked station finder
Trip Planning	External navigation app	EV-aware planner with charging stops
Slot Booking	Separate app	Online time-slot reservation
Charging History	Not tracked	Saved and viewable in the app

VI. ADVANTAGES, CHALLENGES, AND EXPERIMENTAL ANALYSIS

A. Advantages of the Proposed System

VoltIQ offers several advantages over the conventional ways EV users manage range and charging. The system calculates the estimated range based on actual riding conditions rather than a fixed value, which gives users a more realistic picture of how far they can travel before needing to charge.

The integrated features allow users to find stations, plan trips, and book slots from one application without depending on multiple tools. This saves time and makes the process of preparing for a ride much simpler.

Another advantage is the station ranking system. Instead of showing all nearby stations with equal weight, the application sorts them based on a score that considers distance, wait time, free slots, and charging speed together. This helps users pick a station that suits their situation rather than just choosing the closest one.

The web-based design means the application can be used from any device with a browser. No installation is needed, and the admin panel allows station operators to keep station information updated without technical assistance.

B. Challenges Faced During Development

Several challenges were encountered during the development of the system. One of the main difficulties was collecting accurate charging station data for Tamil Nadu. There is no single public source that provides complete station details, so the information had to be gathered from different sources and verified manually before being added to the database.

Setting the factor values for the range prediction formula required repeated testing. Finding the right balance between keeping the formula simple and making the results realistic for different riding conditions took time and several adjustments.

Connecting the application to external services for weather data, route calculation, and geocoding introduced additional complexity. Handling cases where these services were unavailable required fallback logic to prevent the application from failing for the user.

Building the frontend to display maps, elevation charts, prediction results, and booking forms in a clear and usable layout was also challenging, particularly in making the interface work well on both mobile and desktop screens.

C. Experimental Analysis

The system was evaluated using different combinations of battery levels, weather conditions, vehicle settings, and route types. The evaluation focused on prediction accuracy, station ranking correctness, trip planning reliability, and booking functionality.

The range prediction module produced results that matched the manually calculated values using the same formula. The output changed correctly when input values such as weather, speed, or terrain were modified, confirming that all factors were applied properly.

The station ranking module was tested from multiple locations in Tamil Nadu. In each case, the station with the best combination of distance, wait time, and available slots received the lowest score and appeared first in the list, which matched the expected behaviour.

The trip planning feature correctly identified when the predicted range was not enough for a given trip and suggested appropriate charging stops along the route. The booking system rejected overlapping slot requests and confirmed cancellations without errors.

User testing indicated that the application made it easier to plan EV trips and reduced the time spent searching for suitable charging stations. The combined dashboard was found to be useful for getting all relevant information in one view.

D. Social Impact

The developed system has the potential to support EV adoption in India by making it easier for users to manage range and charging without needing technical knowledge. Many new EV users, especially in smaller cities and towns, are unfamiliar with how range changes under different conditions and find it difficult to locate working charging stations nearby.

By providing a simple tool that handles prediction, station search, and booking together, VoltIQ can help reduce the hesitation people feel about switching to electric vehicles. Station operators also benefit from the admin panel, which allows them to keep their station information current without relying on separate systems. Over time, wider use of tools like this can support the growth of EV infrastructure and encourage more people to choose electric transport.

VII. CONCLUSION

This paper described the design and implementation of VoltIQ, a web-based electric vehicle range prediction and charging station management application developed for EV users in India. The application combines a multi-factor range prediction model

with station discovery, trip planning, and booking features to support users throughout their journey.

The system estimates the available driving range based on battery level, battery health, weather, temperature, speed, terrain, traffic, and passenger load. Additional features such as charging station ranking, trip feasibility checking, slot booking, charging history, and an admin panel for station management provide complete support for everyday EV use.

The implementation results show that the application can help users make better decisions about when and where to charge, reducing dependence on fixed manufacturer range values and manual station searches. The developed platform demonstrates how a combination of practical prediction methods and integrated features can improve the EV charging experience for users in growing markets like Tamil Nadu.

FUTURE SCOPE

Several enhancements can be added to future versions of VoltIQ to improve its features and make it more useful for a wider range of EV users.

- Integration with real-time charging network APIs to show live station availability instead of relying on manual operator updates.
- Machine learning models trained on actual trip data from different vehicle types to improve range prediction accuracy.
- Expansion of the station database to cover more states across India beyond Tamil Nadu.
- Mobile application development for easier access while on the road.
- Navigation integration to provide turn-by-turn directions to the selected charging station.
- Smart charging recommendations based on the user's travel history and regular routes.
- Payment gateway integration to support cashless charging transactions through the application.
- Notifications and alerts to remind users about upcoming bookings or low battery levels during a trip.

These additions can further improve the usefulness of the system and help it support a larger number of EV users across different regions and vehicle types.

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