Electric Vehicle Charger Reservation Service

1st Chandler Justice§ chandler.justice@usu.edu
2nd Max Ramsdell§ a02237674@usu.edu
3rd Stockton Smith stockton.smith@usu.edu
4th Nate Stott 0009-0003-6264-0468
5th Mario Harper mario.harper@usu.edu

***Abstract*—The Electric Vehicle Charger Reservation (EVCR) service is a comprehensive tool designed to address the challenges of integrating electric vehicle (EV) charging into modern power systems. By enabling granular control over charger reservations and dynamic power management, the EVCR service supports operators in aligning charging demand with grid conditions. The platform leverages Open Charge Point Protocol (OCPP) for individual charger control and OpenADR for site-wide energy management, providing dynamic curtailment capabilities to reduce peak demand and enhance grid stability. Additionally, a Random Forest Regression-based price forecasting model offers predictive insights into reservation costs, encouraging users to charge during periods of lower grid demand and higher renewable energy availability.**

This innovative framework goes beyond conventional charging applications by integrating distributed energy resources (DERs), supporting time-of-use pricing, and enabling grid-responsive charging. The EVCR service is critical for energy management systems (EMS), helping operators optimize charging infrastructure while minimizing energy costs and environmental impact. Currently implemented at Utah State University's Electric Vehicle Roadway (EVR) facility, the EVCR service demonstrates significant potential for advancing grid resilience and operational efficiency in electrified transportation.

***Index Terms*—Electrified Transportation, Electric Vehicles, Resource Management, Random Forest Regression**

I. Introduction

The rapid growth of electric vehicle (EV) adoption presents both an opportunity and a challenge for modern power systems. As EVs become integral to transportation, their charging demands increasingly influence grid stability, energy management, and infrastructure planning [2]. The Electric Vehicle Charger Reservation (EVCR) service addresses this critical intersection of intelligent transportation systems and power system controls, offering a solution that enhances user convenience and directly integrates with grid operations to improve energy efficiency and reliability.

The EVCR service is designed to optimize charging behavior through dynamic scheduling, price forecasting, and real-time energy management, leveraging protocols like Open Charge Point Protocol (OCPP) and OpenADR. By aligning EV charging with periods of lower grid demand and higher renewable energy availability, this tool provides essential insights and controls to operators managing distributed energy resources (DERs) and high-power charging hubs. Furthermore, its ability to model and predict energy pricing using Random Forest Regression algorithms makes it invaluable for power system stakeholders seeking to balance load demands and mitigate peak usage.

In a power systems context, the EVCR service is not merely a charging management platform—it is a critical tool for facilitating the broader integration of EVs into the grid. It enables intelligent load management, supports infrastructure resilience, and provides data-driven insights for the deployment of advanced grid controls. By fostering a more sustainable and cost-effective EV ecosystem, this tool highlights the potential for innovative technologies to drive the evolution of modern power systems.

Alongside controls and grid coordination, understanding the behaviors and patterns of electric car users is crucial for developing effective technologies in the EV industry [1]. The EVCR not only honors time-of-use electricity prices but also considers the availability of DERs connected to the facilities housing the chargers. By enabling operators to promote charging during periods of lower costs and higher power availability through dynamic price signals and a charger curtailment option leveraging the Open Charge Point Protocol (OCPP), the EVCR service optimizes both economic and energy efficiencies.

Our approach represents a significant improvement over standard charger interface applications, which primarily offer basic availability checks. The EVCR service allows operators far greater control over their pricing, utility bills, and the management of DERs associated with their facilities. This sophisticated level of management provides operators with a powerful tool to better align charging demand with grid conditions, ultimately enhancing the sustainability and cost-effectiveness of their operations.

The service is facilitated and managed entirely through the web and is accessible via most modern desktop and mobile web browsers. From an administrative perspective, EVCR grants the ability to manage chargers on both an individual charger and charging site level, allowing a charging facilitator to adjust parameters such as price, maximum power output, and the behavior of the chargers in various OCPP charging profile states. Users themselves can also adjust specifications when making a reservation, including its timeframe and duration. This, in turn, affects the cost of the reservation, which is dependent on the grid demand that exists during the requested time window.

Overall, the current EVCR feature set allows for advanced functionality, including site-wide and individual charger curtailment, management of reservations, price forecasting, and on-the-fly data aggregation.

§Equal Contributions. All Authors from Utah State University Department of Computer Science

II. Architecture

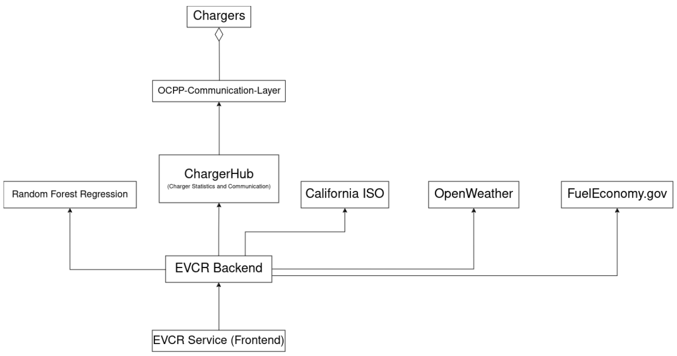

Fig. 1: A diagram of the relationships between services used by EVCR.

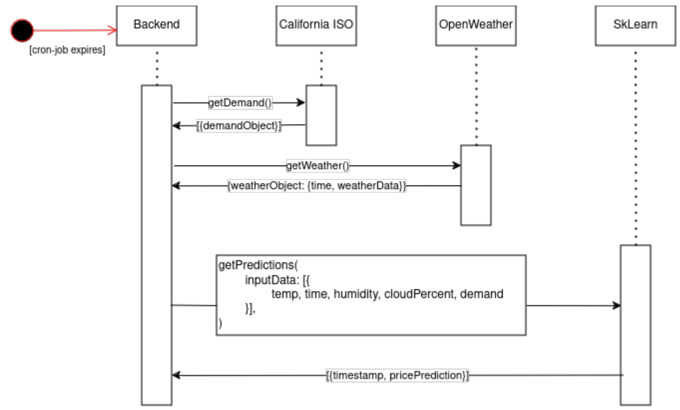

Fig. 2: States between random forest regressor model and backend. Predictions provided by Scikit-learn layer after processing all input data

A. Architecture Overview

The EVCR service is built to be modular to support a wide array of charger setups, ranging from interfacing with chargers directly to interfacing with an entire charging site[1]. In some scenarios, such as when the power grid expects a significant and sudden increase in demand, it makes sense for a site-wide authority to control curtailment of all chargers [4]; while in other situations, such as a long reservation, it is more appropriate to curtail an individual charger using Open Charge Point Protocol (OCPP) [5].

Beyond the core functionality of making reservations, the EVCR service also connects to other APIs and services to help facilitate several quality-of-life features. We have built this system to be stable regardless of the stability of external services. Utilizing server side caching, we can minimize latency for the end-user.

The following sections will detail the architectural overview of the EVCR service, including its modular design and integration with various APIs. This comprehensive approach ensures that the system remains flexible, scalable, and reliable, meeting the diverse needs of charging operators and users alike.

B. Technology Stack

To most effectively fulfill EVCR's implementation requirements, we chose Meta's React library as the foundation for our frontend development. React offers several advantages that we leveraged throughout the implementation of the service, including state management, functional components, and the ease of creating reusable UI components.

The backend of the EVCR service is built with `Express.js` to facilitate our REST API and database connections, `PostgreSQL` is used as the production database while a `SQLite` database is used for development. Price predictions are facilitated by a model built in `Scikit-learn`. Designed to be lean and expandable, it allows easy addition of features such as PayPal payments and optimal reservation calculations.

[1]A charging site is a collection of chargers all interfaced with some central authority; IE, OpenADR.

Key in-house developments include asynchronous logic for verifying reservation availability, which queries the reservation database and notifies users of conflicts.

Routine tasks, like a rolling 48-hour power cost prediction, are handled efficiently by bundling data for batch processing with our random forest regressor. This reduces communication overhead, addressing latency and bandwidth concerns at scale. Overall, our backend aims for minimal bidirectional communication to enhance efficiency and scalability.

The EVCR backend integrates several external services (Figure 1) to enhance its functionality. The California ISO provides real-time energy price information, which is critical for making informed pricing decisions. A Weather API supplies projections on solar generation and thermal conditions, impacting both demand and generation forecasts.

Internally, the backend connects to a Facility Energy Management System (EMS) that manages building battery storage, solar inverters, and charger state. Additionally, it interfaces with OpenADR, which receives signals from site-level control and includes the Virtual End Node (VEN) housing OCPP power curtailment capabilities for modulating charger power. These communications are all facilitated by our site communication layer, `ChargerHub`. Beyond controls, The system also maintains a database containing historical user charging behavior and actual charging costs, enabling more accurate predictions and optimized operations over time.

III. Features

A. Intelligent Charging Curtailment

By using our price forecasting model (which is elaborated on further in this section), the EVCR service is able to anticipate a potential spike in grid demand. This spike would result in an increase in the cost of power for both the energy provider and charging facilitator, ultimately increasing the price for charger users [6]. To help remedy this problem, our program offers an on-the-fly curtailment algorithm, which determines the lowest possible rate of EV charge that still guarantees a sufficiently high battery level by the end of the user's reservation.

As shown in Figure 3, users are given the choice between "Maximum Power Charge" and "Intelligent Power Charge" each time they schedule a reservation. If the intelligent charge option is selected, the service invokes `ChargerHub` to generate a charge profile incorporating curtailment behavior.

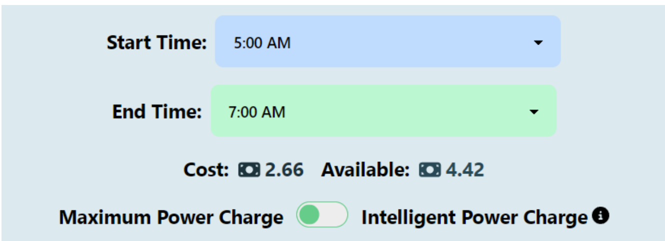

Fig. 3: Choosing the "Intelligent Power Charge" option enacts the EVCR curtailment algorithm.

B. Reservation Check-ins and Billing Methodology

Among the most important goals of the EVCR service is to provide a means for EV users to more easily find an available charging station, especially as EVs are becoming a more widespread mode of transportation [7], [8]. Reservation capabilities have been implemented since the original iteration of the app [3], but at the time were only compatible with artificial funds in the form of "tokens". https://ieeexplore.ieee.org/document/8974024The newest version of EVCR now supports handling of account funds through PayPal, making the app available for legitimate public use.

Users are free to cancel any of their reservations at any time, with full refunds being given for cancellations that occur sufficiently far in advance. Partial refunds are given for cancellations made just before reservation start times, and no refunds are given for cancellations of active reservations. This system is designed to discourage users from making EV chargers needlessly unavailable for others.

C. Optimized Reservation Window Recommendations

The price forecasting model enables the EVCR service to compute an optimized reservation window for a given calendar date. This optimized window is a continuous block of time that is predicted to be the most cost-effective available reservation window (that is, the period in which the cost of power is at its lowest). The purpose of this window is to encourage users to charge EVs during periods other than during peak grid demand, thereby conserving energy and minimizing financial losses [9].

In order to entice users to adhere to optimal charging windows, user reservations are made cheaper during times that assist power providers in conserving energy. Before confirming a reservation, users are informed of the cost-effectiveness of their chosen charging window, making them aware of potential money they could save by shifting their reservation to a different time of day. Additionally, users are given controls to provide the time range in which they would like to charge their vehicle, and the service will determine the optimal time window within their desired timeframe. This provides a direct benefit to the user for assisting EVCR in its long-term objectives. A button that automatically selects this optimal window is also provided to users.

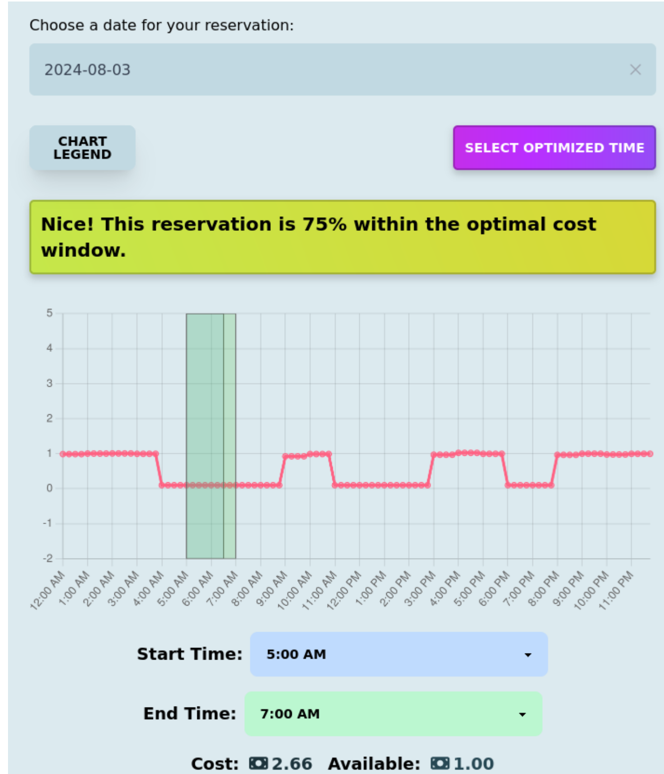

Fig. 4: EVCR UI encouraging optimal window selection. The optimal window is shown in blue, and the user's proposed reservation is shown in green.

IV. Methods

A. Understanding User Behavior

In order to determine if EVCR is successful in its objective to minimize peak grid demand by altering user behavior, it is necessary to quantify user behavior in terms of power usage [10]. Specifically, data analysis would need to show whether EV users who use the app place less strain on the power grid than those who do not, as well as whether the difference is statistically significant [4], [11]. Currently, EVCR utilizes a voluntary questionnaire that occasionally appears after a user makes a reservation. The survey questions focus on behavioral changes, as they ask users whether the app encouraged them to make their reservation at a more cost-effective time of day. The responses to these survey questions are stored in a database, allowing administrators to easily observe trends in user behavior.

However, in order to quell any fears of human bias, we additionally aim to understand user behavior through more objective measurements. By nature of its functionality, information on each reservation made by EVCR users is also stored in a database. This information includes the timeframe and power cost of the reservation. For an effective analysis, EVCR would need to collect this data from a sufficiently large active user base for a sufficiently long period of time. Due to the recency of the app's development, this information has not yet been collected, so conclusions about its effectiveness are only speculative. Obtaining the necessary data and conducting statistical tests are future ambitions of this project.

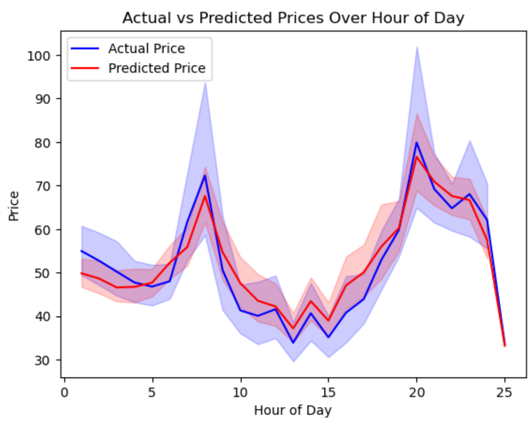

Fig. 5: Actual versus predicted price using random forest regression model on real-world data.

A distinctive feature of the EVCR service is the included price prediction model. To facilitate price predictions a random forest regressor is utilized, which We trained on a dataset of historical price, demand, and weather data from the years 2019-2024 in Logan, Utah; we created the dataset by aggregating data from OpenWeather [12] and CAISO [13] using a custom build `Rust` aggregator. After training, the model is able to make predictions on the price of power using power demand and weather data.

B. Managing Charger Reservations

Managing charging reservations brings a challenge in that we must keep accurate records of the state of a charger (reserved or available) while still working with site-wide services like OpenADR, which keep their own records of reservations. Our implementation overcomes this challenge by interfacing directly with an OpenADR server and querying its database asynchronously alongside EVCR's own backend [14]. This means when a database entry is created or changed on the service's internal backend, an identical call is made to the OpenADR server; the same behavior is followed when checking if a desired reservation conflicts with an existing reservation. These communications are handled automatically by `ChargerHub`, alleviating developer strain. This flexibility regarding the charging site's setup allows the EVCR service to be utilized in several use cases and allows for the same instance of the service to be used across many charge sites.

V. Example Usage

The envisioned usage for this service generally follows this pattern:

- A user discovers the reservation app via a sign posted near a charger or via word-of-mouth.
- After creating an account and adding a vehicle to the user's profile, they are able to make complimentary reservations using funds provided at account creation. This gives the user a chance to use the app with minimal risk and determine if it provides value in their EV ownership experience.
- A user will then navigate to the reserve screen and select a charger that fits their location and charging capability needs. This will allow them to select the details of their reservation.
- Once a user has confirmed the details of their reservation, including time and charging type (maximum or intelligent), they can reserve under a complimentary balance if a balance exists; otherwise, the user can make a one-time payment via PayPal.
- The user arrives at their reservation and uses the "check-in" button on the home screen to confirm they are at their reservation. This puts the charger in a state where it is ready to charge.
- The user completes the charge, and the reservation is persisted in their account history, which they can reference with a unique identifier if needed.

This usage pattern will be fairly consistent across users, as it is simple while still offering granularity from the user's perspective. It also allows for clear indication of changes in user behavior, as shifts in typical reservation times and charge type preferences (i.e. maximum power vs. intelligent curtailment) are easily measurable.

VI. State of the System and Future Iterations

The EVCR service has added several new features that enhance the experience of EV ownership and utilizing public chargers. The user experience is improved for both charger providers and customers by providing more granular controls for both sides; charging facilitators are able to more closely configure the usage patterns of the chargers and users are able to decide the behavior of the charger during their reservation. Users are also able to get context on the current state of the power grid, and are visually shown the optimal reservation time. Finally, the random forest regression model allows for accurate predictions of the cost of power for up to 48 hours in advance; allowing a user to make reservations days ahead.

While the newest iteration of EVCR has fulfilled several lingering aspirations of the original app [3], there still remain a number of capabilities left to be desired. Among these are additional features to improve the user experience, such as options to edit scheduled reservations (as opposed to having to remove a reservation and create an entirely new one). We aim to have this solved in future iterations of EVCR.

Furthermore, the app in its current state does not allow for reservations to cross midnight and enter into the following day.

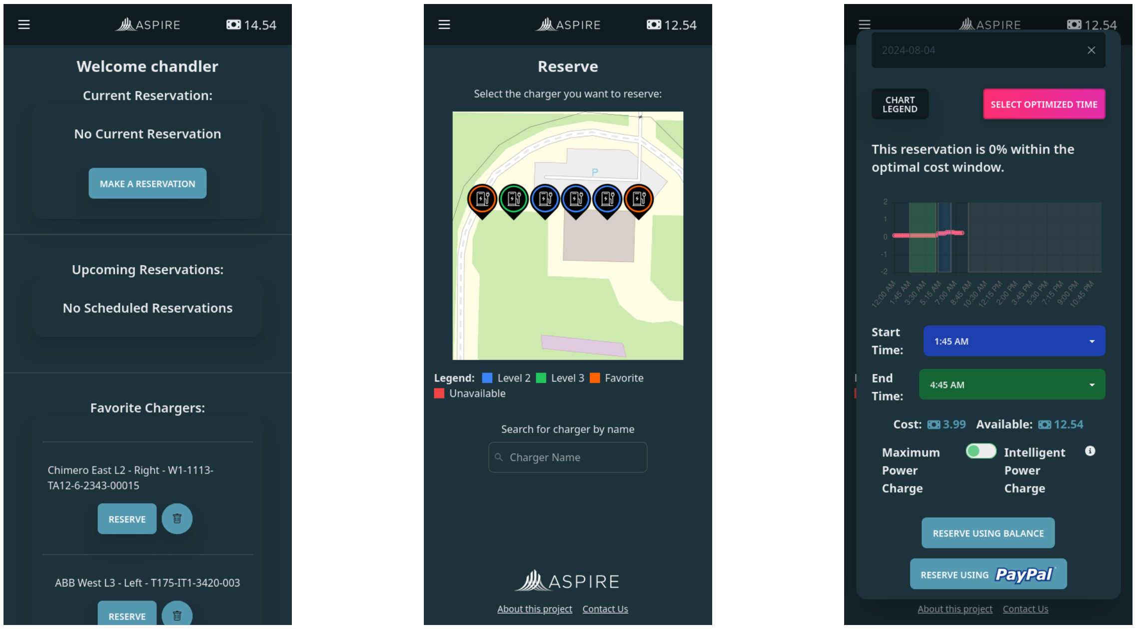

Fig. 6: Screen grabs showing various screens from the EVCR Service.

We would like to account for this in a future EVCR update in order to accommodate users who prefer to charge their vehicles overnight.

VII. Acknowledgement

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