Machine Learning Methods to Predicting Electric Vehicle Charging Behavior

## Introduction

The automotive industry is undergoing a profound transformation, driven by the rapid growth of electric vehicles (EVs). In 2021, global EV sales reached a new peak, doubling from the previous year to a record 6.6 million units. This surge in EV demand has been accompanied by a swift expansion of the necessary charging infrastructure, with the number of chargers installed worldwide reaching 1.8 million by the end of 2021, including a 37% increase in public charging stations[1]. Electric vehicles have emerged as a promising solution to the environmental challenges posed by the transportation sector, since EVs have the potential to reduce carbon emissions by up to 45% compared to conventional internal combustion engine (ICE) vehicles[2].

Despite the promising advancements, several challenges remain. Most EVs require lengthy charging times, causing significant inconvenience, and many EV owners lack the ability to charge their vehicles at home, relying on public charging stations[3], [4], [5]. The high-power demands of EVs, when integrated on a large scale, will place substantial constraints on the power distribution grid, potentially leading to further degradation and instability. The power limitations make it virtually impossible to increase charging station capacity to meet the growing demand. In contrast to conventional gas stations, where refueling takes minutes, EVs often require hours to recharge. Deploying more charging stations is not a feasible solution, as this is limited by both power requirements and physical space constraints. Therefore, the optimal approach lies in better managing the scheduling of existing charging infrastructure to ensure the efficient and reliable operation of the distribution grid.

Advancements in battery capacity and fast charging enhance EV convenience, but also strain electricity grids. To address the challenges posed by the large-scale integration of EVs, researchers have turned to data-driven approaches, leveraging the power of big data analytics and machine learning (ML) techniques. By analyzing historical data on charging load and user behavior, ML algorithms can be trained to identify patterns and trends, enabling accurate predictions of future charging behavior[6], [7], [8]. These predictions can then be utilized to enhance EV charging scheduling strategies, optimizing the utilization of the existing infrastructure, and mitigating the strain on the power grid.

Traditional methods, such as qualitative studies and modeling simulations, have limitations in integrating their findings into practical applications[9]. In contrast, ML-based models can incorporate a wider range of variables, including weather conditions and traffic patterns, to provide more accurate forecasts of charging behavior. These data-driven approaches have the potential to revolutionize the management of EV charging, ensuring efficient and sustainable integration of electric vehicles into the transportation ecosystem.

This review aims to explore the various machine learning techniques that have been employed to address the challenges surrounding EV charging behavior. By delving into the current state of the art, the review will provide valuable insights into the potential of ML-based solutions to optimize the integration of electric vehicles and support the transition towards a more sustainable transportation future.

## Machine Learning Approaches

* Supervised Learning
  + Linear Regression (LR)
  + Random Forest (RF)
  + Support Vector Machine (SVM)
  + Decision Tree (DT)
  + K-Nearest Neighbors (KNN)
* Unsupervised Learning and Statistical Models
  + K-Means Clustering (K-Means)
  + Gaussian Mixture Model (GMM)
  + Kernel Density Estimator (KDE)
* Deep Learning
  + Deep Neural Networks (DNN)
  + Long Short-Term Memory (LSTM)
  + Recurrent Neural Networks (RNN)

EV charging has different patterns. On the one hand, different charging levels provide different charging rates by varying the voltage or current. On the other hand, charging duration varies from user to user, due to vehicle model, charging position, time period, etc. Therefore, it may be important to understand the charging behavior in order to enable more precise scheduling.

## Conclusion

This article provided a comprehensive survey on the use of machine learning for EV charging behavior analysis and prediction. The common supervised and unsupervised ML algorithms used for prediction of EV charging behavior were defined. The survey provided a comparative analysis of various works using supervised, unsupervised, and deep learning methods for EV charging prediction. The key challenges were also discussed which include the lack of public charging datasets and the lack of high dimensional data. Recommendations for future work based on the existing work were also provided. The research directions that this article provide include the need for a comprehensive cluster analysis and the use of reinforcement learning for EV scheduling.

## Reference

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