Machine Learning Methods to Electric Vehicle Charging Behavior

Introduction

The automotive industry has undergone a significant transformation in recent years, driven by the growing prominence of electric vehicles (EVs). In 2021, EV sales achieved a new peak, doubling from previous years to a record 6.6 million units. This upsurge in EV demand has been paralleled by a swift expansion of the necessary charging infrastructure. By the end of 2021, there were 1.8 million chargers installed worldwide, which included a 37\% rise in public charging stations compared to the previous year. Projections indicate that by 2030, 43 million electric vehicles will have been sold worldwide, accounting for 30\% of all vehicles.

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. 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 it 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.

The rise of EVs is not solely driven by industry trends but also by the pressing need to address the environmental impact of the transportation sector. Climate change has become a growing concern, with the United Nations (UN) placing combatting climate change as one of the sustainable development goals (SDGs). The transportation sector is responsible for over a quarter of the world's energy consumption and greenhouse gas emissions. As the global population becomes increasingly urbanized, with two-thirds expected to live in urban areas by 2050, the demand for vehicles to provide urban mobility is set to increase, further exacerbating the environmental impact. However, studies have shown that EVs have the potential to reduce carbon emissions by up to 45% compared to conventional internal combustion engine (ICE) vehicles, considering the entire lifecycle from production to usage. As such, EVs have emerged as a promising solution to address the environmental challenges posed by the transportation sector.

Advancements in battery technology have been instrumental in driving the growing adoption of EVs. Improved energy density and expanding charging infrastructure have made EVs a more practical and reliable option for both short and long-distance travel. Additionally, the declining costs of EV batteries have made them more economically viable and accessible to a wider consumer base, further boosting market acceptance. Fast charging stations capable of providing over 350 kW of power can significantly reduce charging times, minimizing the disruption to users' daily activities. These advancements have enhanced the overall usability and appeal of electric vehicles. However, the high energy required to charge these vehicles places significant stress on the distribution grid.

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. 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. 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.