Electric Vehicle Charging on Residential Distribution Systems: Impacts and Mitigations

ABSTRACT This paper aims to understand, identify, and mitigate the impacts of residential electric vehicle (EV) charging on distribution system voltages. A thorough literature review on the impacts of residential EV charging is presented, followed by a proposed method for evaluating the impacts of EV loads on the distribution system voltage quality. Practical solutions to mitigate EV load impacts are discussed as well, including infrastructural changes and indirect controlled charging with time-of-use (TOU) pricing. An optimal TOU schedule is also presented, with the aim of maximizing both customer and utility benefits. This paper also presents a discussion on implementing smart charging algorithms to directly control EV charging rates and EV charging starting times. Finally, a controlled charging algorithm is proposed to improve the voltage quality at the EV load locations while avoiding customer inconvenience. The proposed method significantly decreases the impacts of EV load charging on system peak load demand and feeder voltages.

INDEX TERMS Electric vehicle charging, TOU pricing, controlled charging, power quality, voltage quality, distribution system, dynamic programming.

I. INTRODUCTION

The promise of clean and efficient transportation coupled with the advances in battery technologies and generous federal incentives are promoting transportation electrification [1]–[4]. In the near future, electric vehicles (EVs) are expected to dominate the vehicle market. However, the success of EV technology depends on the availability of EV charging stations. To meet this demand, utilities are installing EV charging stations at residential and commercial locations. A residential EV charging station in North America provides a 120V (Level-1) or a 240V (Level-2) voltage supply to the connected EV through either a normal wall outlet or a dedicated charging circuit. Commercial chargers are generally high-powered, fast AC/DC chargers and installed in heavy traffic corridors and at public charging stations. However, because commercial chargers are still in the primary stages of deployment, EV owners typically charge their EVs overnight at residential charging stations primarily using Level-2 chargers. Unfortunately, the increasing number of residential EV chargers may cause several challenges for the distribution system. Therefore, both a system level analysis of the impacts of EV integration on the residential distribution circuit and solutions to address their impacts are needed.

EV integration studies in the literature have primarily focused on evaluating the impacts of EV loads on 1) electricity generation adequacy [4]–[10], 2) transformer aging [10]–[14], and 3) distribution system power quality [10]–[28]. In section II, a short literature review of these three issues is presented. In short, it is speculated that if charging infrastructure is not planned properly, the widespread adoption of EVs over the distribution circuit can significantly increase the substation load demand. In turn, the generation capacity of the existing distribution grid may need to be expanded. Furthermore, the increased peak load demand due to EV load charging may overload service transformers, resulting in transformer overheating, thus deteriorating the transformer's life and increasing the economic burden on distribution utility companies. Finally, increased EV penetration may result in sustained secondary service under-voltage conditions, violation of under-voltage limits, and three-phase power supply unbalance, which would deteriorate the service voltage quality.

In the literature, several methods are proposed to mitigate the impacts of EV charging on the distribution grid. The mitigation strategies are primarily grouped into two categories. In the first approach, utilities indirectly control EV charging using Time-of-Use (TOU) pricing [29]–[36]. The decreased off-peak electricity rates in a TOU pricing scenario motivates EV owners to charge their vehicles during off-peak hours. This method significantly decreases the