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INTEGRATION OF MASS AMOUNTS OF ELECTRIC VEHICLES INTO ELECTRICAL POWER SYSTEMS

Keywords

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Abstract

Electric vehicles (EVs) are widely considered as future of transportation. As most of the greenhouse emissions today come from gas-fueled vehicles, electrifying transportation is one of the most promising solutions for combating the wide-spread pollution of modern cities. However, integration of mass amounts of EVs, with their accompanying charging infrastructure, may cause serious issues to electrical power systems. As emerging super chargers for EVs consume huge amounts of electrical power (in a range of 300-400 kilowatts), their stochastic integration in large amounts would cause voltage violations, feeder overloads, harmonic distortions, etc., causing destabilization of power systems which would consequently cause blocking the further rollout of EVs. This paper summarizes the main challenges that integration of large amounts of EVs causes to electric power systems, and offers this author's viewpoint on how to overcome these challenges and enable safe electrification of a transportation sector.

1. INTRODUCTION

Electric vehicles (EVs) are widely recognized as the future of transportation. Over the past decade, EV technology has rapidly advanced, addressing key barriers such as charging time, battery capacity, and range, which previously deterred potential buyers [1-4]. Additionally, the price of EVs has significantly decreased in recent years, although it remains higher than that of traditional vehicles [5]. Given that conventional gas-fueled vehicles are significant contributors to air pollution, there are numerous government initiatives worldwide aimed at deploying and gradually electrifying the transportation sector to combat greenhouse gas emissions [1-5].

However, the advantages enjoyed by EV drivers, such as fast charging and larger battery capacities, present significant challenges to the safety and reliability of electrical power systems, particularly distribution grids [6-8]. Traditional distribution grids were originally designed as passive networks solely responsible for distributing electricity from supply substations to end customers [9-10]. For decades, these grids were managed using simple, paper-based processes, assuming one-way power flow. However, the rapid increase in distributed energy resources (DERs), particularly EVs with their dynamic and stochastic charging patterns, has transformed traditional distribution networks into complex and dynamically changing systems [10]. Such systems cannot be effectively managed using conventional tools and processes. Consequently, while the widespread deployment of EVs is crucial, their stochastic integration can give rise to critical challenges in electric power systems, hindering their further expansion.

The deployment of high-power EV chargers, reaching up to several hundred kilowatts, in a stochastic manner can lead to safety and reliability issues within power systems [11]. Areas with high EV charger penetration may experience significant peak loads, voltage fluctuations, and frequent overloading of legacy feeders originally designed to accommodate gradual load increases. Traditional planning procedures for passive distribution grids are inadequate for effectively integrating EVs and their associated charging infrastructure. Due to the dynamic nature of EV charging, a tightly integrated approach is necessary, combining electrical power system planning tools with real-time management capabilities to ensure the proper integration of EVs without violating technical constraints [11].

This article, based on the comprehensive research presented in [1], as well as in other available reference, aims to present the state-of-the-art in the integration of EVs into electrical power systems, focusing on the challenges faced in power system planning and operation.

Several studies have explored the effects of integrating varying shares of EVs into power systems, detecting challenges such as peak load rise, voltage fluctuations, and feeder overloads [12]. Computational scheduling methods for integrating plug-in EVs into power systems have been extensively reviewed, highlighting promising solutions in the literature [13]. Integration of EVs and their management through the internet of energy (IoE) has been investigated, emphasizing the need for intelligent software tools to successfully integrate and manage emerging distribution grids [14]. Methodologies for optimizing power system demand by intelligently using EV charging have been proposed, acknowledging the challenges associated with fast charging [15]. The benefits of using EVs as demand response resources have been analyzed, although challenges related to EV availability and feeder capacity were not thoroughly investigated [16]. Integration challenges and potential solutions for electric buses and taxis have been reviewed, primarily focusing on peak load rise as a major challenge [17]. The impacts of EV charging on power systems, both positive and negative, have been comprehensively reviewed, stressing the need for intelligent control and optimization tools to transform challenges into benefits [11]. Optimization models for the integration of EVs and charging stations in power systems have been explored, highlighting the necessity of digitized control centers with software tools to efficiently integrate and manage EV fleets alongside other system components [18]. A conceptual framework for EV integration, considering grid operation and electricity markets, has been proposed, emphasizing the requirement for a centralized EV charging control strategy [19]. Technical challenges to power system operation resulting from EV integration have been examined, reiterating the importance of centralized intelligent charging for operational benefits and flexibility resources [20]. Finally, V2G technology has been analyzed, focusing on optimization techniques and stakeholder coordination to enhance electrical grid operation [21].

Based on the available literature, the main aim of this paper is to summarize the main challenges that integration of large amounts of EVs causes to electric power systems. Additionally, this paper offers this author's viewpoint on how to overcome these challenges and enable safe electrification of a transportation sector.

The rest of the paper is organized as follows. In Section 2, planning challenges due to mass amounts of EVs are summarized. Section 3 summarizes operational challenges that power system operators face as a consequence of high penetration of EVs. Section 4 gives this author's viewpoint on how we can overcome the aforementioned challenges. Section 5 concludes the paper.

2. PLANNING CHALLENGES

The process of traditional distribution grid planning was characterized by its linear and straightforward nature [1, 22, 23]. Distribution utilities' planning departments would analyze the existing system conditions, utilize traditional load forecasting methods to project future load growth, and perform analyses to identify system needs, reinforcements, and replacements [22, 23]. Based on these evaluations, utilities would determine the most suitable solution, such as upgrading substations or lines, and develop an investment plan accordingly. This approach worked reasonably well for several decades, as the rate of load growth was relatively modest. However, the landscape has undergone a radical transformation with the proliferation of EVs and the accompanying charging infrastructure. The introduction of level 3 chargers, primarily used in commercial charging stations, capable of delivering up to 400 kW of power each [1, 11, 22], means that a single charging station comprising multiple level 3 chargers can reach power capacities in the range of several megawatts [1]. Consequently, integrating multiple charging stations into a distribution substation's area or a feeder is no longer a simple task. Employing traditional planning procedures would necessitate substantial investments to modify or reinforce numerous components of the grid.

For example, consider California's recent state regulation mandating that 35% of new car models sold in 2026 be zero-emission, with the goal of reaching 100% by 2035 [22]. Meeting the power demands of these vehicles while ensuring sufficient electricity supply for other customers would require the state to triple its current electric power production and comprehensively strengthen all the affected grid elements [22]. However, the challenges extend beyond financial investments. Even if utilities were to accept such an investment plan, the entire process of obtaining various permits and executing a labor-intensive project would span several years if traditional planning procedures were followed. Consequently, the widespread adoption of EVs would be postponed for years, if not decades, severely compromising the progress of electrifying and decarbonizing the transportation sector.

Therefore, there is an urgent need for new and advanced planning tools that can facilitate the integration of large numbers of EVs at a faster pace, without compromising the safety and reliability of the electrical distribution grid.

3. OPERATIONAL CHALLENGES

The integration of a large number of EVs into electrical distribution grids poses several operational challenges. One of the main challenges is the increase in peak load demand. Studies have shown that even low penetrations of EVs, if charged randomly, can lead to a peak load demand increase of nearly 60% [1, 11]. This surge in demand requires significant infrastructure investments. However, with controlled charging and centralized management of distributed energy resources (DERs) and aggregated EV flexibility, faster integration of higher quantities of EVs becomes viable [11].

Another challenge is congestions and overloads in the distribution grid. The increased load caused by EV charging can overload transformers, feeders, and cables. Even with low EV penetrations, overloading of transformers can reach up to 50% in a distribution grid [1, 11]. Unmanaged usage of level 3 charging stations would result in congestions, overloading, and destabilization of the grid. Therefore, careful planning and coordination with other flexible resources are necessary to avoid such issues.

Voltage stability is also a concern when integrating EVs into the grid. Studies indicate that even with less than 30% EV penetration, voltage issues can arise in distribution grids [1, 11]. Voltage imbalances can occur due to the installation of single-phase chargers at customers' homes. Additionally, the use of vehicle-to-grid (V2G) technology can lead to voltage rises beyond the allowed limits. Comprehensive grid management solutions are needed to ensure voltage stability [1].

Power losses are another significant challenge. The increased load from EV charging results in higher currents flowing through transformers, lines, and cables, leading to significant power losses. Studies have shown that even with less than 50% EV penetration, uncontrolled charging can cause unacceptable power losses [1, 11]. Managed charging through intelligent software solutions can effectively mitigate power losses [1].

4. POTENTIAL SOLUTIONS

Addressing the discussed challenges requires the implementation of advanced grid management solutions such as Distributed Energy Resource Management Systems (DERMS) [24-27]. These systems enable the intelligent management of EV charging, coordination with other DERs, and optimization of grid resources. By adopting such solutions, distribution system operators can integrate EVs more efficiently and ensure the reliable and sustainable operation of distribution grids [1].

A Utility DERMS, also known as a "Grid DERMS," is a centralized software solution designed for distribution grid operators, grid engineers, and network planners to assist them in the management of distribution grids with a high penetration of Distributed Energy Resources (DERs) and EVs. This solution is grid-aware and relies on an accurate network model and real-time state estimation to provide continuous awareness of the grid's operating conditions. A typical Utility DERMS comprises planning, real-time, and lookahead modules, each equipped with sophisticated functionalities. These modules enable utilities to plan new DER and EV integrations, conduct what-if analysis, and implement non-wires alternatives. Additionally, they facilitate real-time control, optimization, and protection of dynamic distribution grids. A Utility DERMS offers a comprehensive toolkit for utilities, encompassing the entire process from planning the integration of new DERs or EV charging stations to incorporating these devices into the distribution grid's ecosystem and utilizing them as flexible resources for control and optimization purposes.

Thus, DERMS enables advanced management solutions, such as active network management (ANM) and non-wires alternatives (NWAs), which offer alternative approaches to planning and utilizing grid resources. These methods leverage the flexibility provided by aggregated DERs and EVs to defer capital investments and enable a more expedited integration process [1]. By using DERMS software, distribution system operators (DSOs) and planning departments can gain access to a comprehensive set of ANM and NWA tools, empowering them to intelligently plan and integrate mass amounts of EVs without the immediate need for extensive capital expenditures and the associated time-consuming procedures.

It is essential to recognize, however, that as the number of Electric Vehicles (EVs) increases, the existing grid infrastructure may need hardware upgrades to enhance its capacity and effectively support the complete transition to electric transportation. However, the implementation of a DERMS offers a promising solution for Distribution System Operators (DSOs) to navigate this transitional phase and prepare for a future where EVs constitute a significant portion of the vehicle fleet. By intelligently managing the evolving distribution grid, DSOs can bridge the gap between the present and an inevitable future with high EV penetration, without the need to delay the further deployment of EVs until the grid is fully reinforced.

By leveraging a DERMS, DSOs gain the ability to optimize grid operations and effectively balance the growing demand from EVs with the available grid resources. This approach ensures reliable and efficient power distribution while maintaining system stability. It empowers DSOs to proactively manage the integration of EVs into the grid, making the most efficient use of existing infrastructure and avoiding unnecessary delays in the adoption of EVs. With a DERMS in place, DSOs can navigate the challenges of high EV penetration and pave the way for a sustainable and electrified transportation future.

5. CONCLUSIONS

In this paper, main challenges that power systems are facing due to the integration of mass amounts of EVs are presented and discussed. These challenges range from planning issues, where the traditional planning procedures are not applicable for proper planning of the required expansions to accommodate mass amounts of EVs, to operational challenges, faced by grid operators. Main operational challenges are peak load rise, congestions due to stochastic charging of EVs, voltage fluctuations, increased power losses, and potential destabilization of power systems, due to unmanaged charging. All of these issues need to be properly addressed in order for power systems to be prepared to host even partially electrified transportation.

In the second part of the paper, this authors' view on how to address these challenges is presented. This includes deploying emerging software solutions, called DERMS, training the utility personnel to use these novel software solutions, as well as grid expansions in the most critical and congested areas.

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