Using Vehicle-to-grid Technology to Defer Distribution Grid Expansions from Integrating Renewable Generation

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Overview

Increasing renewable energy generation (REG) and electrification of the transportation sector are key environmental efforts. Volatile REG creates electric power load peaks which result in expansion needs for the distribution grids. I evaluate the potential to defer these expansion investments with controlled vehicle-to-grid (V2G) and grid-to-vehicle (G2V) charging. I show that G2V charging reduces expansion investments by more than 14% if PEV penetrations exceed 10% and about 30% if penetrations are 40% and higher. V2G charging adds 10 percentage points to this benefit. This investment deferral is highly dependent on PV generation levels and ranges from 4% to 47% for G2V and 7% to 63% for V2G at PEV penetrations of 10%. Overall, the benefits are highest at medium PV generation levels, where the utilization of additional lines and transformers would be low.

The main contributions I make are (1) to create an understanding of the effectiveness of G2V, and the additional benefit of V2G to defer expansion investments and (2) to evaluate how the available PEV penetration and the amount of REG to be integrated effect the expansion investment savings. In contrast to previous papers, distribution grid expansion needs from the integration of REG are the focus, rather than increased demand loads.

Methods

I apply a modelling and subsequent case study simulation approach. I model the driving and charging behaviour of PEV based on empirical driving data collected in the German households' mobility survey "German Mobility Panel" (German Federal Ministry of Transport and Digital Infrastructure, 2017). For the driving patterns of PEV the trip distance distribution and typical departure and arrival times of PEV are based on conventional combustion engine vehicles (see e.g., (Broneske & Wozabal, 2017; García-Villalobos, Zamora, Knezović, & Marinelli, 2016)). I introduce two controlled charging strategies, G2V and V2G, which focus on reducing load peaks and consequently expansion investments. I model this controlled charging as a decentral strategy where each distribution system node controls only the PEV that are connected at the respective location. This reduces the computational burden of the control system and the complexity of the necessary communication network to achieve an implementable solution (Nafisi, Mousavi, Askarian Abyaneh, & Abedi, 2016). The controlled charging strategies are optimized using a genetic algorithm.

Nearly all distribution grid expansion needs from REG are expected in the rural areas. Consequently, I run a case study simulation of a typical rural medium voltage distribution system with variations of the PEV penetration and REG levels in the form of photovoltaic energy generation. Finally, I assess the impact that both controlled charging strategies have on the necessary distribution system investment cost compared to the uncontrolled charging scenario for all PEV and REG penetration levels.

Results

I find that the expansion of a mid-voltage distribution grid can only be avoided at medium REG levels and rises with increasing PEV penetrations. Uncontrolled charging (UCC) does reduce expansion investments from REG in summer slightly but creates expansion needs when demand is high, i.e. in winter. G2V charging reduces expansion investments by 14% compared to UCC if PEV penetrations are at 10%. Savings increase to about 30% if PEV penetrations are higher than 40%. V2G charging adds roughly 10 percentage points to this benefit at all PEV penetration levels.

The overall investments that are necessary in the test system to integrate PV generation are at a maximum of 2.14 mio. EUR for a PV level of 3.0 (yearly peak PV generation is 3.0 times as high as yearly peak demand) if no PEV are present. In this case the expansion investments constitute more than half the initial value of test system before any REG related expansions, which is 4.04 mio. EUR. Introducing 10% PEV penetration reduces this investment by 2%

(0.05 mio. EUR) with UCC, 100% PEV penetration results in 20% (0.42 mio EUR) savings. Compared to UCC, G2V reduces expansion investments on average (across PV and PEV penetration levels) by 26%; V2G by 37%. V2G adds on average 10 percentage points in investment reductions over G2V.

For PEV penetrations of 10%, investments are reduced on average by 14 respectively 23% (0.08 respectively 0.15 mio. EUR). If PEV penetration is at 100%, 32 respectively 44% (0.17 respectively 0.28 mio. EUR) of investment savings are achieved on average. The highest share in investment savings occurs at medium PV levels between 1.8 and 2.1, where at its maximum controlling the charging process with G2V produces up to 78% in investment savings (93% for V2G). At a 10% PEV penetration G2V produces between 4 - 47% (up to 0.17 mio. EUR for the test system) in investments saving and V2G increases that to 7 - 64% (up to 0.30 mio. EUR) compared to UCC. At PV levels larger than 2.4 the savings drop to 5 - 14% for G2V and 7 - 23% for V2G. In this case, G2V saves about 10% at PEV penetrations of 30% where it remains stable, independent of further increases of the PEV penetration. For V2G the same saturation effect occurs at PEV penetrations of 70% and above where savings remain around 20%.

Conclusions

I attempt to create an understanding for a novel solution to reduce distribution grid expansion investments from the increased integration of REG in mid voltage distribution systems. I build knowledge on how effective controlled charging of PEV is at mitigating the increased integration of REG in distribution systems. By modeling multiple PEV charging strategies, I analyze the additional benefit of V2G over G2V charging. Finally, I assess influence factors by simulating test cases with various PEV penetration and PV levels.

I show that controlled charging adds value by reducing the resulting distribution grid investments, depending on the level of REG that is to be integrated and the available number of PEV, up to 78% in investment savings are possible with G2V and up to 93% with V2G. The currently available PEV, e.g., less than 1% in Germany, do not yet allow for significant deferral of distribution grid investments with controlled charging. However, predictions show that PEV penetrations of 10% will be reached by 2025 to 2030 with significant increases thereafter (Gerhardt et al., 2018). With investment savings upwards of 14% distribution system operators should consider this alternative. These savings are highly dependent on the individual situation in the distribution system, especially on the ratio between peak REG and peak demand load. Consequently, a controlled charging strategy may not constitute a viable option for all medium voltage grid situations. Distribution system operators need to take their individual situation into account with availability of PEV, the type of demand in the system and especially the amount of REG to be integrated.

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