IMPACT OF ELECTRIC VEHICLES ON DISTRIBUTION NETWORK OPERATION: REAL WORLD CASE STUDIES

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ABSTRACT

This paper studies the impact of electric vehicles (EVs) in real distribution networks. In particular, the impact of the penetration of EVs and its flexibility on the distribution network is studied. In addition, the benefits of EV flexibility in solving the rising challenge of increasing DER penetration are analysed. If managed properly, EVs will have a positive impact in supporting the network and in increasing its sustainability, especially in the presence of large penetration of distributed energy resources (DER) such as photovoltaics (PVs).

INTRODUCTION

The inclusion of Electric Vehicles (EVs) in the distribution network is a topic of rising importance [1-7]. EVs are generally considered either as fixed or as controllable loads within a power system. In addition, there is an increasing penetration of distributed generation especially based on renewables. The intermittency of this type of generation poses challenges to the operation of the electrical distribution network. In this context, the controllability of the charge of EVs in networks with or without distributed generation is interesting for both power balancing and renewable energy integration in the system. The study of EV's impact in supporting the network and its sustainability, is a topic of practical relevance in the foreseeable future scenarios of mass roll out of EVs.

This paper aims at studying the impact of EVs in real distribution networks. The paper is organised as follows. The first section states the problem under consideration. Then, the methodology adopted to solve the problem is described. Two real world test cases used for simulation are presented, after which the impact of the penetration of EVs and their flexibility on the distribution network is studied. In addition, the benefits of EV flexibility in solving the rising challenge of increasing DER penetration are analysed. The results of the study are followed by the conclusions drawn.

PROBLEM STATEMENT

EV charging will have an impact in the distribution grid, as it is a relatively high-power load and consumes a significant amount of energy. In addition, distributed energy resources (DER) such as photovoltaic (PV) systems are already widely rolled out today. Distribution system operators have to manage the operation of the grid in accordance with standards such as EN50160 [8], which defines minimum levels of quality of supply for end-users. In this context, it is important to study the impact of EV penetration and its flexibility on the distribution network.

METHODOLOGY

A distribution grid simulation tool, developed as part of the PlanGridEV project [9],[10] is used to study the operation and planning of real-world distribution networks. The tool is built around a multi-period AC optimal balanced power flow calculation for radial grids. It includes a library of flexible models for generic loads and generators, as well as a library of technology-specific models for PV, EVs, etc. It integrates a number of stochastic profile generation methods for EV mobility, solar irradiation, etc.

TEST CASES

In order to assess the impact of EV penetration and its flexibility on the distribution network, the real world network shown in Figure 1 is simulated. The network includes a HV/MV node, MV lines, MV/LV nodes and LV lines. EV flexibility in the network is realised by modulating the charging power of the EVs as described below. Two modes of charging are compared in this paper, namely, Conventional versus Smart charging. For the Conventional charging mode, each EV has to be charged at maximum battery charging power (3.3kW or 6.6kW as the case may be) and the charging starts as soon as the EV comes to rest. Consumer's comfort maximisation is the goal of Conventional charging and can be considered as 'dumb' charging. However, for Smart charging mode, the charging power can be modulated to any value between 0 and 3.3 (or 6.6) kW. Smart charging aims at reducing the operating cost by modulating the charging power.

To assess the impact of EV charging mode on DER penetration, a real world LV network with two feeders as shown in Figure 2 is used. The first feeder includes 18 households and the second feeder includes 32 households with different distribution of consumer profiles. For the scenario used at hand a charging power of 6.6 kW has been fixed in the simulation, as it has a greater influence on the simultaneous usage of PV feed-in. This scenario shows the effects of Conventional and Smart charging because of EV flexibility in the second mode.

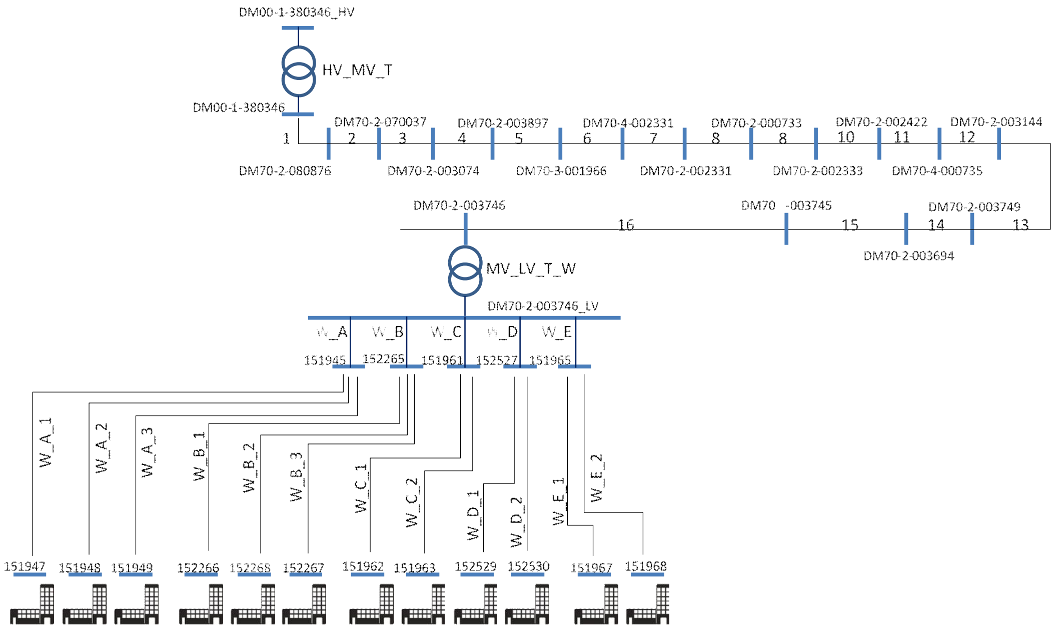

Figure 1: A real world MV-LV network

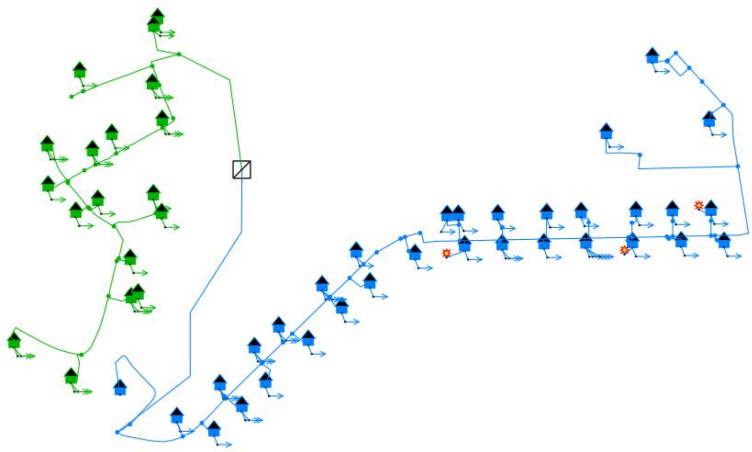

Figure 2: A real world LV network with two feeders: 18 households (green) and 32 households (blue)

RESULTS

Impact of EV flexibility (Smart charging mode) on distribution network

Figure 3 shows the comparison of power consumption for the charging of 800 EVs under the Conventional and the Smart charging scenario simulated for the network shown in Figure 1. During the peak-load hours in the evening, it can be seen that the peak power of Smart charging is relatively lower when compared to the peak power of Conventional charging. Smart charging shifts charging from peak to off-peak hours of the conventional load as can be seen in Figure 3, thus helping to reduce the operating cost which otherwise would have required the running of costly peaking power plants. This could also help in reducing the investments to be done on grid reinforcement. In addition, the number of EVs that can be simultaneously charged is higher under the Smart charging mode than under the Conventional charging mode, as shown in Figure 4. This means that several customers will be able to recharge according to their needs creating minimum violations in the grid.

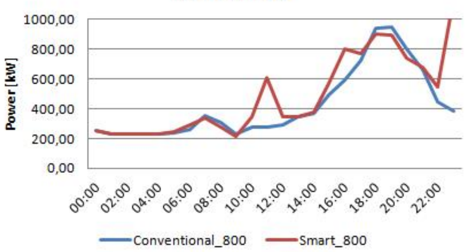

Figure 3: Power Consumption of 800 EVs

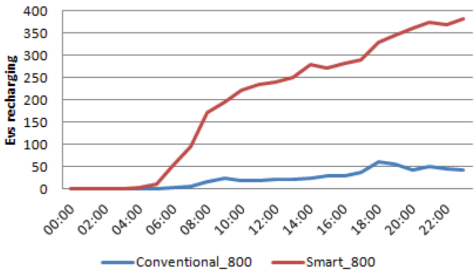

Figure 4: Number of EVs charging simultaneously with a penetration of 800 EVs

Impact of EV penetration on distribution network

Figure 5 illustrates the power consumption for different EV penetrations in Smart charging mode, simulated for the network shown in Figure 1. As expected, the power consumption grows while increasing the EV penetration. It can be noticed that a lot of EVs are charging at the end of the day. This is a consequence of setting the 100% state of charge at midnight in the simulation. Also, in this scenario the case of simultaneous charging while increasing the EV penetration has been studied as shown in Figure 6. As expected, the simultaneous charging increases with the EV penetration.

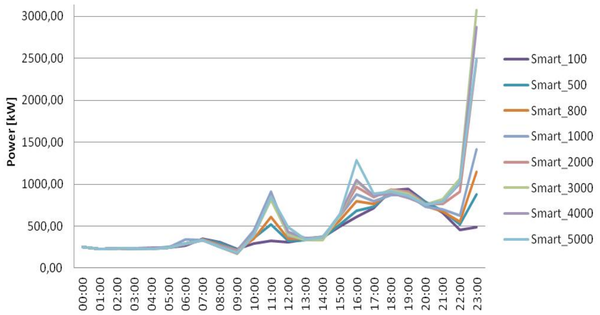

Figure 5: Total power consumption with Smart Charging as a function of EV penetration

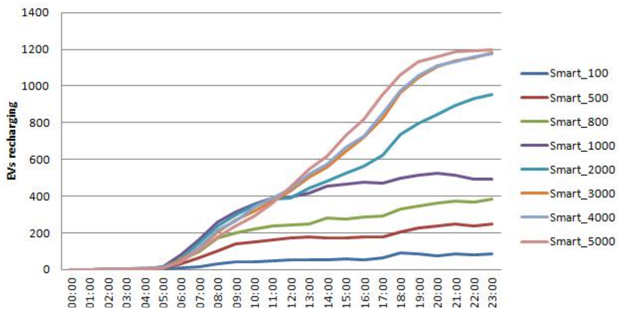

Figure 6: Number of EVs charging simultaneously with Smart charging as a function of EV penetration

Impact of EVs on DER penetration

In order to show the impact of simultaneous EV loads and PV feed-in, the scenario takes a closer look on a PV penetration of 50% and an EV penetration of 100% for the network shown in Figure 2. A PV penetration of 50% implies 18 PVs and an EV penetration of 100% implies 32 EVs. The scenario stands for private charging and an arrival at home between 4 pm and 7 pm.

The result of the second feeder with 32 households and Conventional charging is shown in Figure 7. The general load fluctuates around 60 kW whereas the PV feed-in is close to 150 kW and can be justified through the sum of 16 households, each with a PV feed-in up to the maximum of 10 kW. The EV charging starts at 4 pm (with 8 EVs) and ends one hour after the last EV arriving at home. The residual load shows that the high PV feed-in leads to an injection into the grid in the afternoon (until 4.30 pm) and that the Conventional EV charging generates a peak at the evening at 7 pm (135 kW) when PV feed-in disappears.

In order to analyse various possibilities of Smart charging, this same scenario is simulated with flexible Smart EV charging. Both the general load and the PV feed-in stay unchanged.

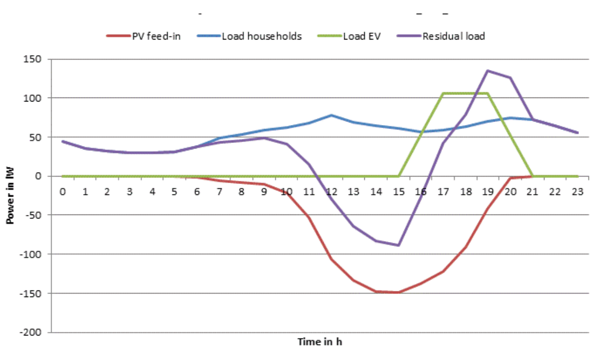

Figure 7: Power profile under Conventional charging mode

The result of the simulation with PV 50%, EV 100% and Smart charging is shown in Figure 8. The residual load has a lower peak with Smart charging compared to Conventional charging. The residual load stays continuous from 6 pm onwards, so that the peak of the residual load at 7 pm seen in the Conventional charging mode is shaved. In addition, in the Smart charging scenario the EV load curve decreases at 6 pm, one hour earlier than in the Conventional case, and follows the falling PV feed-in till 8 pm. At this time, the PV feed-in is zero. This depicts how EVs in general, and Smart charging in particular, can aid the integration of DER in the distribution network.

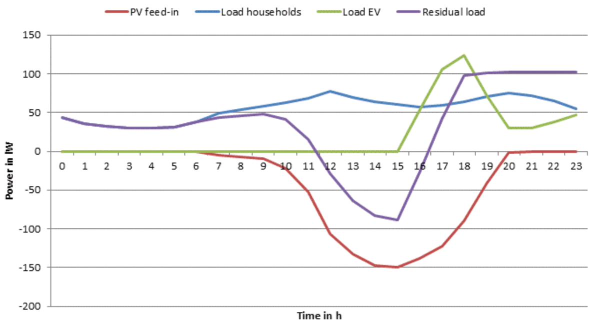

Figure 8: Power profile under Smart charging mode

In Smart charging, EVs start to charge at the same time as in the Conventional charging scenario, but the EV charging power profile reaches over 100 kW and is therefore higher than in the Conventional mode. This is because Conventional mode supports only complete transactions and fractions of 6.6kW charging cannot be simulated. However, in Smart Charging, a partial charge of, for example, 2 kW (that is, a charging power other than 6.6 kW) is possible. This aids the full charging of the battery in Smart charging mode.

CONCLUSIONS

During the conventional peak-load hours in the evening, it can be seen that the peak power of Smart charging is relatively lower when compared to the peak power of Conventional charging. Smart charging shifts the peak charging hours to the off-peak hours of the conventional load, thus helping to reduce the operating cost which otherwise would have required the running of costly peaking power plants. This will also help in reducing the investments to be done on grid reinforcement. In addition, the number of EVs that can be simultaneously charged is higher under the Smart charging mode than under the Conventional charging mode. This means that several customers will be able to recharge according to their needs creating the minimum violations in the grid.

For the same type of EV flexibility, e.g. Smart charging, both the power consumption and the number of simultaneous charging increase with EV penetration.

In the presence of DER (for example PV) in the network, the residual load has a lower peak in Smart charging compared to Conventional charging. This is primarily because Smart charging allows the EV charging profile to follow the PV (DER) profile and, hence, facilitates DER penetration in the network.

ACKNOWLEDGMENT

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