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Quasi-real-time management of Electric Vehicles charging

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ABSTRACT

This work presents a methodology to manage Electric Vehicles (EVs) charging in quasi-real-time, considering the participation of EV aggregators in electricity markets and the technical restrictions of the electricity grid components, controlled by the Distribution System Operator. Two methodologies are presented in this paper to manage EV charging, one to be used by the EV aggregators and the other by the Distribution System Operator (DSO). The methodology developed for the aggregator has as main objective the minimization of the deviation between the energy bought in the market and the energy consumed by EVs. The methodology developed for the DSO allows it to manage the grid and solve operational problems that may appear by controlling EVs charging. A method to generate a synthetic EV data set is used in this work, providing information about EV movement, including the periods when EVs are parked and their energy requirements. This data set is used afterwards to assess the performance of the algorithms developed to manage the EV charging in quasi-real-time.

1. Introduction

The foreseen deployment of Electric Vehicles (EVs) will considerably affect the way distribution grids will be managed and operated in the future. The extra amount of power they will demand from the grid will oblige Distribution System Operators (DSO) to understand the impacts resulting from EV connection to distribution grids. Several approaches to this problem have been presented in literature.

In Refs. [1,2], the authors analyzed the changes in the load diagrams of distribution networks for increasing penetration of EVs. Lopes et al. [3,4], also studied the impacts of EVs on distribution grids. The innovation introduced by these authors was the evaluation of the EV charging impact on the grid technical constraints, like voltage and branches' congestion levels. Papadopoulos et al. [5], also addressed the technical challenges related to the EVs integration in a low voltage (LV) grid. Clement et al. [6,7], analyzed the plug-in hybrid EV (PHEV) impacts on energy losses and voltage deviations in distribution grids. Although the methodologies proposed in papers [1–7] revealed to be interesting approaches to evaluate EV impacts, they do not provide an adequate method to determine the optimal EV charging schedules in quasi-real-time.

It should be noted that for the purpose of this work, the term "quasi-real-time" is used in the sense of monitoring the grid and managing EVs in a short period of time, around 5–10 min (or even less, depending on the effectiveness of the communication infrastructure).

Several other works have been developed with the main purpose of determining the optimal (or near optimal) EV charging schedules [8–11]. However, some of these approaches consume a lot of computation time, being unpractical for quasi-real-time applications. Additionally, the majority of these methods were designed focusing on a single specific goal, such as minimizing violations of the grid technical restrictions, peak load, energy losses, or violations of the EV owners' requests, among others.

It should be noted that the works [3,4,6,7], referred previously, also presented methods to determine optimal EV charging schedules, but they were designed focusing only on the optimization of the grid operating conditions. They do not take into account the eventual existence of energy retailers, like EV aggregators [12], or the existence of electricity markets. This problem was tackled, in part, by Sanchez-Martin et al. [13]. These authors presented a model to control EV battery charging in real-time, but the methodology proposed was developed only for EV parking facilities.

Deilami et al. [14] also proposed a method for the EVs load management in real-time. It focuses on the minimization of the cost of producing the extra needed energy plus the energy losses, taking into account the voltage constraints. Yet, it does not consider the existence of aggregators, nor their economic interests, which are not interrelated with the optimization of the grid operating conditions.

This paper presents an innovative approach that uses a holistic methodology to manage EV charging in distribution grids in quasi-real-time, taking into account the concerns of all the players

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involved in the process: the technical restrictions of the grids (DSO concern), the periods during which EVs are parked (aggregators' concern), the EV owners' energy requests (EV owners' concern) and the operational requirements of electricity markets. The development of this work involved the creation of two expeditious methodologies to be used by aggregators and DSO to manage the EVs charging in quasi-real-time, which allow, respectively:

(1) Minimizing the aggregators' penalties for the deviations between the energy they bought in the markets and the energy sold to EV owners (imbalance settlement), thus contributing to increase the aggregators' profit.
(2) Solving technical problems related to voltages violating operational limits or overloading of branches that might appear in the grid.

In order to assess the performance of these methodologies, a synthetic EV data set was used. This dataset was created with an algorithm that uses a Markov chain to simulate the EV movement, as well as their power requirements.

In Section 2 the framework required to enable the EVs charging management in quasi-real-time is described. A description of the methodologies developed to manage the EVs charging is provided in Section 3. Section 4 describes the method used to generate the synthetic EV data set. The grid used as case study is described in Section 5, together with the description of the studies performed. The main results obtained from the simulations are presented in Section 6. Finally, the main conclusions are presented in Section 7.

2. EVs integration framework

Moving from a "fit-and-forget" policy to an active EV charging management context implies the creation of a suitable technical/commercial framework capable of dealing with the technical aspects of electricity grids and the markets operation.

2.1. Control structure to manage EVs in quasi-real-time

Under this new framework, when operating the grid in normal conditions, EVs will be managed by a new entity – the aggregator – whose main functionality will be grouping EVs, according to their owners' willingness, to exploit business opportunities in the markets [12]. If EVs entered the market individually, their visibility would be small and due to their stochastic behaviour their participation in the market would be nearly impossible. Yet, if an aggregator exists, then the services potentially provided by EVs would be more significant and the confidence on its availability much higher.

Yet, even considering the EV aggregators' activities, a high degree of uncertainty will still exist related to when and where EVs will charge. Due to these uncertainties, and assuming that grids will evolve towards a decentralized generation paradigm, the existence of a grid monitoring structure, such as the one developed for micro-grids and multi-micro-grids, will be required [15]. This structure will be controlled by the DSO and should be capable of acting over EV charging in abnormal operating conditions, i.e. when the grid is being operated near its technical limits, or in emergency operating modes, e.g. islanded operation [15]. This system should follow a hierarchical structure, from a central Distribution Management System (DMS) down to specific EV controllers to be housed in EV charging points [8].

It is important to stress that the aggregator should always take into account the EV owners' requests, which should provide information about the energy required and connection period via, for instance, the smart metering infrastructure [8]. The aggregator should have a hierarchical structure similar to the grid management architecture used by the DSO, as described in Ref. [15], to be capable of communicating and managing EV charging in quasi-real-time. Both technical and market layers will require an advanced communication infrastructure to enable information exchange between all the involved players.

2.2. Charging levels considered

There are several types of EV charging solutions being currently adopted [16], which involve distinct power levels:

(1) Level 1 – around 3 kW that can be obtained through common domestic outlets.
(2) Level 2 – 10–20 kW that can only be obtained through dedicated outlet/wiring.
(3) Level 3 – more than 40 kW that can only be obtained through dedicated outlet and wiring and using a dedicated off-board charger for DC fast charging.

The charging type classified as slow refers to level 1, while the fast charging refers to level 3. Level 2 is an intermediate level. All the three levels were considered in this work, being assumed that slow charging corresponds to level 1 – LV connections, while fast charging includes levels 2 and 3 – medium voltage (MV) connections.

Although not considered in this work, there are several studies suggesting that battery swapping can be an effective alternative to battery charging [17–22]. According to Ref. [23], swapping a battery can take less than 2 min while charging in a fast charging station can take up to 30 min. Nevertheless, this alternative also has some drawbacks, namely the capital expenditure of building the stations and having sufficient batteries in stock. Better Place filing for bankruptcy shows that this business model may be flawed [24]. Additionally, the need for standardization of battery dimensions, shape and chemistry across different manufacturers is another important issue for battery swapping that remains unsolved.

It should be noted, however, that battery swapping stations will need to absorb power from the grid for charging the batteries in stock. So from the grid point of view, a battery swapping station is not much different from a fast charging station – both are loads. For this reason, battery swapping stations could be easily integrated in the methodologies proposed in this paper, provided that the respective load diagram was available. As the batteries in stock do not have necessarily to be charged at a given time, swapping stations could even be modelled as flexible loads since the power they absorb from the grid can be controlled in order to cope with the needs of the DSO.

2.3. Charging schemes considered

Depending on the type of application, EV controllability may vary and, therefore, several control schemes may be adopted. In the solutions involving fast charging (level 2 or 3), a full charge might take less than 1 h [16]. Due to the urgent needs from the user of these types of services, especially level 3 clients, no controllability is envisaged. On the other hand, depending on the EV battery State-of-Charge (SOC) and capacity, full charge solutions involving level 1 might take up to 12 h [16]. In this charging alternative, it is assumed that EV owners can choose between three options: two passive or non-controlled (dumb charging and multiple tariff) and one active or controlled (smart charging) [8].