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An optimal solution for charging management of electric vehicles fleets

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ABSTRACT

Electric vehicle (EV) is an advanced solution by car manufacturers to gradually replace the conventional vehicle and reduce our dependence on petroleum. Nevertheless, an EV need many hours for a full charge, and reducing charging time and energy consumption of EVs are among the major challenges for promoting this type of vehicles. Disturbed traffic conditions such as traffic jam, roads with sever slopes may affect seriously the energy consumption and then the performances of EVs. In this paper, scheduling and suitable assignment of EVs to charging stations (CSs) is approached as an optimization problem, formulated as linear programming problem. The assignment of EVs should satisfy certain constraints related to CSs status, the EV conditions, traffic conditions, etc. The proposed approach will be illustrated considering two operating modes of the system. The assignment of EVs to CSs under normal conditions (driving without using electrical accessories, roads without slops and traffic jam, etc.), and under disturbed conditions for the second mode. For this first scenario, the two main components of the system are supposed to be homogeneous (EVs have the same characteristics, and the same for CSs). For the second scenario, we focus on a charging system with heterogeneous components. As we will show, the suitable assignment of an EV is when the state of charge (SoC) of its battery remains at its highest possible level at the destination (assigned CS). Keeping the battery SoC at a high level allows to reduce consumed energy and required charging time, and consequently ensures a flexibility in the management of system charging.

1. Introduction

Performance of electric vehicles depends mainly on traction batteries and their characteristics. With the development of EVs, several traction battery technologies have emerged. These technologies include lead acid batteries [1], nickel and cadmium [2], lithium ion/polymer [3], lithium iron phosphate($LiFePO_4$) [3], sodium/nickel chloride(the so-called ZEBRA) [4], and zinc-air batteries [5]. The autonomy of a EV depends mainly on the battery capacity, type of traveled routes (route with/without slopes, urban areas), driving mode and usage of electrical accessories (lights, heating, air conditioning, wipers, etc.)

Charging stations provide power supply for EVs batteries. So, the deployment of complete infrastructures with sophistic equipment is unavoidable for promoting EVs [6]. EVs need often many hours for charging. This means that the time spent for charging in CSs is long and consequently provokes the long queues within these stations as well as unsupportable waiting times. This is one of the main problems that may slow the promotion of EVs. Reducing required charging times is the challenge of many researchers. One of the proposed solutions in the literature to remedy to this problem is to change discharged batteries by fully charged batteries. It would practically take few minutes to change a battery instead of re-fuelling an internal combustion engines. This operation can be done only in dedicated service stations [7,8].

For a driver of EV, finding not only most nearest CS but free and most relevant (with additional capabilities and points of interest) is one of the most important issues. This requires finding a path with a minimum distance to travel in order to reach a free and suitable CS. As traffic conditions change regularly and number of charging requests is unstable, suggesting adequate CSs for EVs is required in order to ensure an acceptable quality of service.

To remedy to this problem, we already proposed in our previous work an optimization approach based on mathematical programming allowing to assign EVs to CSs with minimum energy consumption and minimum waiting times. The aim is to reach this objective while satisfying many constraints related to EVs characteristics, charging infrastructures and traffic situation on the roads.

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The proposed approach gives a solution for optimal charging managing for a fleet of EVs in a system with homogeneous components (all EVs have the same characteristics and technologies, CSs provide the same charging power), and under normal conditions such as normal traffic on the roads, itineraries without severe slopes, without excessive use of electric accessories of the EV, etc. An extended study of this case is proposed in [9]. In fact, we proposed in this study the optimal charging management of a fleet of EVs in a system with homogeneous components functioning under disturbed conditions.

In the current paper, we extend our efforts in this field by proposing a new optimization approach for a charging system with heterogeneous components. Indeed, we consider a great number of EVs with various and different technologies and characteristics. Moreover, CSs have different characteristics. With these heterogeneous components, we will compare the performances of the system in both cases under normal and disturbed conditions as defined previously and we will report and analyze the obtained results. In this study we will introduce a major constraint related to the minimum SoC of the batteries. In fact, the assignment of EVs to charging stations will be done while ensuring that the SoC of each EV battery remains superior to a minimum threshold. For each battery technology, this threshold is defined by manufacturers. This threshold is noted SoC_{min} in the rest of the paper.

The reminder of this paper is organized as follows: Section 2 presents an overview of the related work. Assignment problem with more details about the charging system is addressed in Section 3. The formulation of the problem is introduced in Section 4. An illustrative example with analysis of obtained results for homogeneous system components are addressed in Section 5. A case study representing the system with heterogeneous components is given in Section 6. An illustrative example with analysis of obtained results are addressed in the same section. Finally, Section 7 concludes this work and gives some future research directions.

2. Related work

In the literature, the charging management of EVs has been largely addressed by many researchers. Particularly, several research works focused on optimization of charging and discharging strategies of EVs. We focus in this related work on some developed works about the management and optimal charging/discharging strategies of EVs.

In [10], the authors have presented a scheduling strategy based on moving window optimization scheme. This strategy shows a fast convergence characteristic and is more robust against the global optimization scheme. So, a reliable determination of optimum charging schedules with low costs has been done. As well as, moving window optimization scheme was suitable for online applications due to continuously information update pattern and a fixed forecasting horizon.

A framework for optimization charging/discharging of EVs given variations in electricity spot prices and driving patterns of vehicles is presented in [11]. The proposed optimization approach in this work shows that low prices provide an incentive to charge EVs at night time although day time charging occasionally occurs in spite of high prices. It shows also the incentive to discharge the EVs with favorable taxes while considering the difference between the night time and day time.

A supervised predictive energy management framework is presented in [12]. This framework aims to improve the fuel economy of a power-split plug-in hybrid electric vehicle (PHEV) by incorporating dynamic traffic feedback data. It is evaluated in three cases: without traffic information, with static traffic information, and with dynamic traffic information.

In [13], the authors have presented a scheduling optimization problem for charging/discharging EVs. The charging powers are used to minimize the total costs of all EVs performing charging and discharging during the day. The global optimal solution provides the global minimal total cost and it is impractical since it assumes that the arrivals of all EVs and the base loads during the day are known in advance. Moreover, a local scheduling optimization problem is formulated. It aims to minimize the total cost of EVs in the current ongoing EV set within the local group.

A decentralized algorithm to optimally schedule EV charging is proposed in [14]. The algorithm uses the elasticity of EV loads to fill the valleys in electric load profiles. The scheduling problem of EVs charging is formulated as an optimal control problem, whose objective is to impose a generalized notion of valley-filling, and study properties of optimal charging profiles.

In [15], the authors have proposed an online energy management to economize the cost of using energy and to minimize the capacity fade of a lithium-ion battery bank used for a photovoltaic-based system. Another solution for reducing required charging time concerns the increasing of energy power transferred to EV in appropriate charging stations by increasing charging voltage and current [16–18].

On the other hand, the approach of constant current/constant voltage (CC/CV) follows a charging algorithm applied to obtain fast charging [19–21]. In this approach, the entire charging process is divided into two modes. The first concerns constant current mode and the second is constant voltage mode. A fast charging station with an energy storage system (ultracapacitors) is proposed in [16]. The proposed solution in this work can decrease charging time duration and reduce the stress on the grid at the same time.

In [22], the authors have proposed a genetic algorithm to achieve the best allocation of EVs' parking lots considering distribution reliability. The proposed approach is implemented and obtained results demonstrate that parking lots location is dramatically sensitive to total number of EVs and charging method. Moreover, these results prove that unscheduled allocation of parking lots may lead to an ineligible reliability of distribution system. In order to limit problems of unscheduled high penetration of EVs that may result in the distribution network detrimental effects, the same authors have proposed in [23] a probabilistic model for EVs charging which based on historical driving data and technical specifications of different EV classes. Through, the proposed model and obtained results, it is shown that increasing in charging rate and parking lot capacity leads to charging demand increment. These efforts have been continued by proposing in [24] an autoregressive integrated moving average method for charging demand of EV parking lots based on ARIMA model. In order to determine the expected charging load profiles, the proposed prediction model takes daily driving patterns and distance as an input. Moreover, a chance-constrained scheduling problem is formulated using the output of the forecaster approach. The authors have concluded that this approach might help achieving significant cost savings in power system operations.

Moreover, managing EVs charging in real time is one of the challenges in this domain. In [25], the authors propose a holistic methodology aiming to manage EV charging in quasi-real-time by considering the participation of aggregation in the markets and the grid technical restrictions. The final objective is double: minimizing of the deviation between the energy bought in the market and the energy consumed by EVs, and managing of the grid and solving operational problems that may appear by controlling EV charging. The proposed approach used a synthetic EV dataset created using a Markov chain algorithm to simulate the EV movement and their power needs.