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A significant reduction in the costs of battery energy storage systems by use of smart parking lots in the power fluctuation smoothing process of the wind farms

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ABSTRACT

Wind farm power fluctuations resulted from the wind random nature bring a significant challenge to the wind turbine generators operating in the maximum power point tracking. Furthermore, the smoothing process of a large wind farm in which the Battery Energy Storage System (BESS) is used, needs a considerable initial investment cost. Utilizing Smart Parking Lots (SPLs) can be considered as an applicable solution. In this paper, assuming conventional parking lots in Tehran converted to an SPL set in a near future and thus establishing an enormous charging/discharging capacity, the smoothing process is performed on a 51 MW wind farm. For this purpose, a coordinated control system based on two control algorithms is proposed. The first proposed algorithm chooses eligible SPLs for charging/discharging activity before receiving a new sample of the wind farm output power. Afterwards, the second proposed algorithm determines qualified vehicles in selected SPLs. The main aim is to minimize the number of SPLs (vehicles) taking part in the process. According to the simulation results, the required BESS capacity in the power smoothing process of a typical wind farm decreases considerably when the proposed approach is applied. Thus, the investment cost of BESS is reduced significantly.

1. Introduction

Wind turbine generators need to work at the maximum power point tracking mode because of their high final price compared with other parts of the power generation network. Thus the power output of the wind power plants experiences so much fluctuation which is a serious challenge to the power grid particularly when the contribution of the wind energy to the generation of the electrical energy becomes significant [1]. In this situation, the output power fluctuations of the renewable energy resources influence the system stability considerably. Hence, using energy storage resources like BESSs seems to be an applicable solution for the mitigation of wind power fluctuations [2–4]. As BESSs are expensive, Smart Distribution Grids (SDGs) can be employed as an alternative. As the use of Electric Vehicles (EVs) increased, SDGs have introduced a new technology known as SPL playing a significant part in the Wind Power Fluctuation Smoothing (WPFS) process. Therefore, the accurate modeling of SLPs is the first step in the WPFS process. In some studies, SPL has been modeled as a fixed capacity BESS which is not an acceptable modeling in the WPFS studies [5–7]. A theoretical system of Plug-in Hybrid Electric Vehicles (PHEVs) in a municipal parking lot was studied in Refs. [8–10]. In order to provide communication between the central controller, PHEV chargers, and vehicles, ZigBee protocol was employed in Ref. [10]. A particle swarm optimization based control algorithm was presented in Ref. [11] for allocating power to PHEVs in a municipal parking deck. Researchers in Ref. [12] conducted a statistical analysis of the Plug-in Electric Vehicles (PEVs) in the distribution network. They proposed a coordinated charging method for reducing unfavorable effects on the network load profile. The integration impact of a large number of PHEVs/PEVs on the existing power grid under certain charging scenarios was evaluated in Ref. [13]. The Monte Carlo method was utilized in Ref. [14] for simulating possible real-world scenarios at a municipal parking deck. Ref. [15] presented a new model which can simulate the

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interactions among PHEVs, wind power, and demand response.

However, not all the effective factors on the modeling of SPLs have been considered in most researches. In this paper, a case study in Tehran metropolis is conducted for the modeling of SPLs proposed by the authors. According to the results achieved, by converting the conventional parking lots to the SPLs and making a correct connection among them a significant amount of charge/discharge capacity will be provided. Afterwards, a coordinated control system is presented as a practical solution to the WPFS performed by SPLs. Although different coordinated control methods have been presented for WPFS, they are mainly focused on utilizing BESSs.

Proposed coordinated control mechanism is based on two control algorithms; one for selecting eligible SPLs and another for selecting eligible PEVs in selected SPLs. In addition, the output power tracking method proposed in this paper is an ADAptive Linear NEuron (ADALINE)-based method which is more accurate than the First-order Low-pass Filter (FLF)-based one.

The rest of the paper is structured as follows: First, a case study on converting the conventional parking lots to the SPLs in Tehran metropolis is conducted in Section 2. The basics of WPFS is described in Section 3. In Section 4 the proposed approach for the WPFS is explained in details. Simulation results and related comparisons are given in Section 5. Finally, Section 6 draws the conclusion.

2. SPLs as enormous BESS

SPLs, as a modern technology, can be effective for improvement of integrating renewable energy resources into traditional centralized power systems. However, regarding their randomness and alternative nature, increasing domination of renewable energy resources may bring unreliability and technical challenges for future smart grids. The random alternative property of renewable energy resources contributes in imposing fluctuations in the system voltage and frequency and makes the dynamic behavior of the power system more sophisticated. So, the possible effects of power fluctuations when interacting with renewable power generation must be accurately considered in smart grids. Some equipment existing in these networks like SPLs is very useful for energy saving and has determinant role in power fluctuation smoothing leading to improvement in dynamic behavior of the system.

SPLs are a set of PEVs located in a parking lot. These parking lots are based on communicational infrastructures. In fact, a SPL is a set of hundreds or thousands of PEVs forming a very huge battery with significant capacity. As a PEV enters a SPL, the parking lot system receives all of its data including battery capacity and initial charge by wireless system or any other technology. Thus the charging or discharging capacity of the park changes all the time. Received data is sent to the central control system of SPLs by the related SPL control system. Therefore the charging/discharging capacity of all the system is determined for every moment. These SPLs are scattered all around the city and are joined to each other by a bus as in Fig. 1.

2.1. Converting regular parking lots into SPLs – a case study of Tehran City

Replacement of regular parking lots with SPLs will bring very considerable capabilities for smart distribution grids in not so distant future. In a case study of Tehran City in Iran, and considering the information taken from Tehran municipality [16], near 213 active parking lots are serving customers. Among those 213 parking lots, 48 of them work 24 h a day. Obviously the capacity of these parking lots is different from each other. There are a minimum capacity of 23 vehicles and a maximum capacity of 2600 vehicles among parking lots of Tehran. In this study only 24-h parking lots are taken into account and those with capacities less than 500 vehicles are disregarded. Considering these two assumptions, there will be only 12 parking lots remained, list of which has been given in Table 1 along with their capacities.

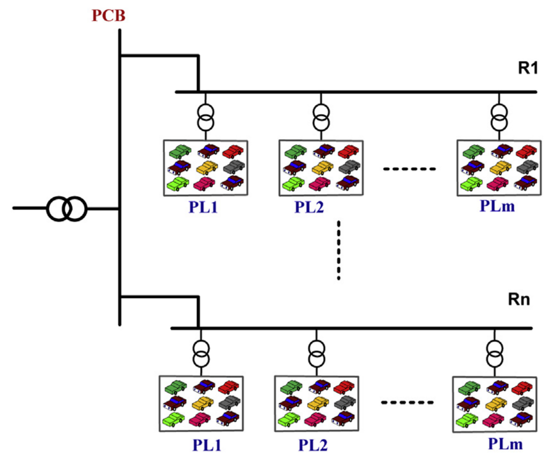

Fig. 1. The configuration of SPLs in city.

Fig. 2 shows the location of mentioned parking lots in the satellite map of Tehran. The connecting links between parking lots are imaginary although they may indicate the connection of parking lots to form SPLs in near future. Therefore, connecting lines will be local buses connected to the common bus and then attached to the distribution network.

2.2. Modeling and simulations

In numerous references, SPLs have been modeled as a single battery with a specified capacity. This type of modeling may be applicable in some studies; however it is not an acceptable precise model in the smoothing of renewable power fluctuations. For example when there is need for energy saving, maybe there is not adequate capacity in vehicles for saving. In other words, the SPL capacity needs to be considered variable in order to take results nearest to practical ones.

The instantaneous capacity of a SPL depends on the number of parked PEVs and their initial State Of Charging (SOC). Assuming that the initial SOC of PEVs is equal to 50% (it is a comparatively reasonable assumption for avoiding the complexity) and the average nominal battery capacity of each vehicle is 15 kWh, the instantaneous capacity of SPLs will depend on the number of parked PEVs merely. The number of parked PEVs is affected by some factors such as daily working hours, week days, and the location of SPLs (categorized as airport, terminal or city center locations). These factors are discussed in the next section.

2.2.1. Daily working hours effect

The histogram of the number of parked vehicles in a regular parking lot (PL-2) in Tehran during 24 h of a day has been shown in Fig. 3. It is clear that the number of parked vehicles in PL-2 grows from 6 A.M to 12 noon. The entire capacity of PL-2 is occupied at noon (according to data provided by the municipality, the parking lot capacity is full before 11 A.M during the days after holidays). As the office hours finishes, the number of vehicles in parking lot begins to decrease from 2:00 P.M. This decrease continues from 6:00 P.M to 10 P.M as the working hours of other careers finishes. The capacity of parking lot doesn't have tangible changes from 10