Electrical Power and Energy Systems 46 (2013) 115–122

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

A multi-objective optimization problem for allocating parking lots in a distribution network

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ARTICLE INFO

Article history:
Received 1 June 2012
Received in revised form 18 October 2012
Accepted 20 October 2012
Available online 22 November 2012

Keywords:
Electric vehicle
Distribution system
Parking lots allocation
Vehicle to grid

ABSTRACT

This paper presents a multi-objective approach to determine optimal site and size of parking lots, which provide vehicle to grid (V2G) power in distribution system as new type of distributed generations (DGs). In this approach, the reliability of distribution system and power losses along with investment cost are considered in optimization problem. This optimization problem is solved using genetic algorithm (GA) method. Simulation study is carried out on a nine bus test system. The results of simulations show that the economic issue of parking lots installation depends on many factors such as availability of electric vehicles (EVs) as well as the electricity price. Also, it is shown that by taking enough incentive for EVs owners, optimal sitting and sizing of parking lots has economical benefit for distribution system companies. Also, optimal allocation of parking lots can improve the distribution system voltage profile.

1. Introduction

In recent years several problems including environmental issues, decrease in fuel quantity and volatility in its price and the need for decreasing dependency on fossil fuels caused the electric vehicles (EVs) get known as an effective resource in transportation and power system [1–5]. As addressed in [6], the backbone of smart grid emphasis on environmental protection, using variable generation (such as wind and solar), demand response, and distributed generation (DG) including EV technology, driving for better asset utilization, while maintaining reliable system operation, and the need for enhanced customer choice. Fig. 1 depicts these factors in relation to the new emerging smart grid paradigm, and illustrates the role of EV technology in the new era [7]. In [8,9], it is shown that vehicles are parked for about 93–96% time during a day. Therefore, they are available for other purposes such as serving as storage device to the grid. Based on this fact and the increasing need for economical storages in power system, EVs are suggested to be used as limited energy resources in power system [10]. Additionally, EVs can be utilized as controllable loads. In other words, they can be operated as a battery to save energy during off-peak period. Also, these can act as generation units during peak period or high electricity price intervals. Since EVs have limited power output, they can be used in distribution system as a DG resource. For using EV as a DG in distribution system, charging and discharging of batteries should be controlled. Some models for vehicle to grid (V2G) power output are presented in [11–14].

Distribution system planners try to supply economical and reliable electricity to their customers. These companies deploy different technologies such as DGs and capacitors. DG technologies have many economical and technical benefits [15,16]. These benefits cannot be maximized except when optimal sizes and sites of DG units are determined. Therefore, optimal allocation of DG is one of the most important issues, which have to be considered in distribution planning problem. An appropriate decision making can provide benefits to distribution network, suppliers, and customers. Reliability index and loss reduction are two major objectives that have to be considered in sitting and sizing of DGs [17,18]. Using a type of DGs such as renewable DGs has an important role in smart environment.

Optimum allocation of parking lots, as new type of DGs, should be accomplished as well as other type of DGs. High-penetrations of distribution-connected storage devices or plug-in vehicles have adverse impacts on the grid due to their charging loads, randomly-located or unmanaged additions. Contrary, optimal allocation of parking lots can reduce the network loss such as other DGs, enhance reliability, improve voltage profile, and consequently bring economical benefits for distribution system company (DISCO). Many studies have been accomplished regarding associated problems with EVs and their impacts on power system. In many of the studies it is shown that the impact of EVs depends on charging schedule and electricity tariffs [19–21]. Ref. [22] presents a simulator tool in order to evaluate EVs impacts on power system. The proposed simulator in [22] allows estimation of the impacts of charging on each bus of the system.

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http://dx.doi.org/10.1016/j.ijepes.2012.10.041

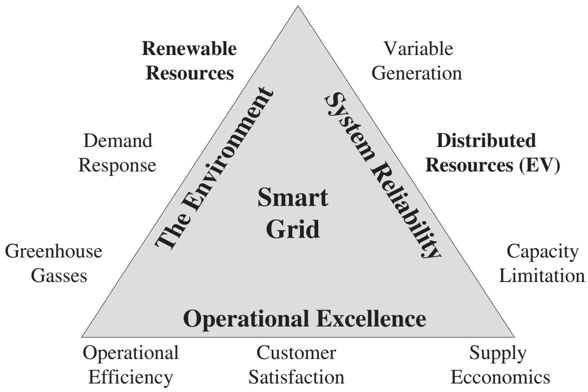

Fig. 1. The role of EV in smart grid [11].

Despite numerous studies about EVs, optimal allocation of parking lots has not been considered until now in the studies. Hence, this paper presents a multi-objective approach to determine optimal site and size of parking lots as DGs. Due to the multi-objective feature of allocation problem, Analytic Hierarchy Process (AHP) is employed in this paper to determine the optimal weighting coefficient for each objective. AHP was proposed in 1970 and since then, it has been progressively become an algorithm with extensive uses in multi-objective comprehensive evaluations [23].

One of the main differences between parking lot and other traditional DGs is that this resource does not have deterministic output. In this paper, a simplified model is used for power output of EV parking lots. In the modeling of parking lots, they act as storage devices and store electrical power in the batteries of vehicles at times with low electricity price and deliver power to distribution system at times with high electricity price. Also, parking lots act as charging stations of EVs for driving purposes. Because of stochastic nature of EV owners' behavior, the parking lots output is stochastic. One approach for decreasing the uncertainty of EV owners' behavior is implementing some incentive mechanisms. Enough incentive mechanism should be considered to promote EV drivers to participate in providing power to the network.

In this study, the allocation optimization problem is solved using genetic algorithm (GA) method. Due to the stochastic nature of the outputs of these resources, reliability is taken into consideration as an important issue. On the other hand, the power loss as well as the investment cost are other objectives have to be paid enough attention. For this reason, a trade-off shall be made between these objectives.

The rest of this paper is organized in the following order. Section 2 describes the proposed model of parking lots allocation framework. In Section 3, the parking lot power generation is discussed. Section 4 presents the problem formulation. In Section 5, the solving method is discussed. The case study and discussion on the results are driven in Section 6. Finally, the last section is devoted to conclusions.

2. Framework of allocation problem

The proposed framework of parking lots allocation is illustrated in Fig. 2, which is structured in 9 blocks. The data required for solving the optimization problem (e.g., data of load, EV data, and electricity price data) is indicated in block one. The output power of EVs depends on drivers' behavior. Thus, the incentive mechanism as illustrated in block 1 can be considered for management of EVs power output and promote the owners of these resources.

Generally, EVs do not have deterministic output therefore, in this paper the simplified model is used for power output of EVs parking lots (block 2). Due to the stochastic output of this resource, reliability is taken into consideration as an important issue. In this study, the energy not supplied (ENS) is proposed as a reliability index (block 3). On the other hand, the power loss as the other objective has to be paid attention (block 4). Another objective, which has important impacts on these resources allocation is the investment cost of parking lots, which is illustrated in block 5. Since optimal allocation of parking lots is a multi-objective optimization problem, a trade-off between these objectives is taken into account in this paper. GA is used for solving optimization problem as indicated in block 6.

Number of EVs in each candidate bus, reliability benefit, and loss benefit are outputs of the simulation, as presented in blocks 7, 8, and 9, respectively.

In order to allocate parking lots, some assumptions are taken into account as follows:

1. In this study it is assumed that, DISCO is responsible for supplying customers demand, parking lots installation, and controlling charging and discharging of EVs batteries. DISCO tries to carry all of these responsibilities based on cost reduction and improving the quality and reliability of customer service.
2. It should be noted that in calculating the profit, it is assumed that the DISCO does not receive compensation from EV owners for battery charging necessary for driving purposes. Also, degradation cost of vehicles due to V2G is paid to EV owners by DISCO. These assumptions are taken to encourage EV owners to park their vehicles in parking lot in the days with high price peak electricity.
3. All vehicles are charged and discharged with maximum charging rate. It should be noted that this assumption has been considered in several EV studies [20,21].
4. In the modeling of parking lots, it is assumed that the initial state of charge (SOC) of EVs has three levels. The proposed model can be used for other SOC levels too. The initial SOC of vehicles can be fitted with suitable distribution function and parking lots can be placed optimally, considering this function. Other assumption used in modeling of parking lots is that all batteries have the same size. Thus, the output power of parking lot is flat in discharging state. This assumption has been taken in many EV studies such as [20–22].

3. Parking lot power generation

The EV battery storage has a low capacity. Thus, in this paper, wide use of aggregated EVs in parking lots is suggested to overcome the small storage capacity of an EV. EV parking lots are considered as new players whose roles are collecting the EVs in order to reach high storage capacity from small battery capacity of EVs, affecting the grid beneficially.

In a restructured power system, DISCO buys electricity from wholesale market to supply the consumers. Purchasing electricity in off-peak hours from the market with low prices, storing it in batteries of vehicles in parking lots, and delivering electricity to consumers in peak time are three major steps that enable DISCOs to save costs through preventing purchasing fraction of required peak power with high price. Usually, peak power is generated by power plants that can be switched on for shorter periods, such as gas turbines at the hours of day when high levels of power consumption are expected (for example, in hot summer afternoons) [24]. The peak power is typically needed only a few 100 h/year. This power is usually provided by generators with low capital cost however high operational cost. Providing peak power by parking lots may be an economic alternative source. For optimal participation of parking lots in providing peak power, they should be allocated optimally.