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Optimal fast charging station placing and sizing

Payam Sadeghi-Barzani [a,*], Abbas Rajabi-Ghahnavieh [b], Hosein Kazemi-Karegar [c]

[a] Department of Energy Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran
[b] Department of Energy Engineering, Sharif University of Technology, Tehran, Iran
[c] Faculty of Electrical and Computer Engineering, Shahid Beheshti University, Evin Street, Tehran, Iran

HIGHLIGHTS

- Considers EV loss and electric grid loss simultaneously.
- Considers urban roads in determining optimal location of charging station.
- Evaluates various policy scenarios in developing EV charging station.
- Evaluates electric grid reliability impact on charging station place and size.

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ABSTRACT

Fast charging stations are vital components for public acceptance of electric vehicle (EV). The stations are connected to the electric grid and can recharge an electric vehicle in less than 20 min. Charging station development is highly influenced by the government policy in allocating station development costs. This paper presents a Mixed-Integer Non-Linear (MINLP) optimization approach for optimal placing and sizing of the fast charging stations. The station development cost, EV energy loss, electric gird loss as well as the location of electric substations and urban roads are among the factors included in the proposed approach. Geographic information has been used to determine EV energy loss and station electrification cost. The optimization problem is solved using genetic algorithm technique. Application of the proposed approach to analyze the impact of different station development policies has been discussed. The impact of electric grid reliability on charging station place and size has been evaluated using a proposed index to evaluate loss of charging cost. Results showed the robustness and efficacy of the proposed method to determine optimal place and size of the charging stations.

1. Introduction

Electric vehicle (EV) has received increasing attention during the recent years. Economic affordability and environmental concerns are among the factors that have contributed to enhancement in EV development and deployment [1,2]. In Tehran, insupportable air pollution and traffic noise have made various health and social problems and the government in under pressure to solve or alleviate the pollution. Road electric mobility is seemed as an interesting option and has received increasing support from legislative and executive bodies in the country. Both government and Tehran Municipality are supporting research works on various aspects of EV application to provide deep insight for policy-making on electro-mobility.

EV needs charging station to supply its electric need. EV battery capacity varies from 20 to 60 kW h. Various technologies are available for EV charging and 3 standard charging levels have been developed. Charging level (1) is referred to use of single-phase AC system with up to 3 kW charging power. It means that charging level (1) takes about 7 h to charge a 20 kW h EV battery. Charging level (2) uses 3-phase AC with up to 24 kW charging power, needing about 1 h for charging 20 kW h EV battery. Charging level (3) is alternatively called fast charging level and provides power to fully charge an EV battery in 30–20 min [3].

Fast charging is a technology that is of utmost important for public acceptance of EV [4]. Fast charging stations are directly connected to the electric grid. A set of equipments, such as transformer and rectifier, are installed in the station to produce DC voltage. Charge connectors are installed in the station to use DC voltage for charging EV batteries in less than 20 min. In such a manner, fast charging station can also be considered as electric fuel station which serves to supply EV energy need in a short period of time.

* Corresponding author. Tel.: +98 9123214608.
E-mail addresses: payam.sdgh@yahoo.com (P. Sadeghi-Barzani), rajabi@sharif.ir (A. Rajabi-Ghahnavieh), h_kazemi@sbu.ac.ir (H. Kazemi-Karegar).

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Widespread use of EVs depends mainly on availability of public fast charging stations [5]. Advantages and disadvantages of fast charging technology have been widely discussed. Charging time [3], access to public charging stations upon EV low remained charge [6], battery life, electric grid and renewable energy integration [7,6] are among the issues which have been widely discussed in fast charging station development. Studies has shown that significant effort is being made in Japan and U.S. to develop fast charging station [8,9], receiving financial support from the public sector [10]. A method has been presented in [11] to coordinate charging of EV with wind farm production.

For an EV with battery capacity of 36 kW h, a fast charging station should supply more than 100 kW for fully charging the vehicle in 20 min. A station that can charge 10 vehicles simultaneously will impose 1000 kW extra demand on the electric grid, leading to increase in energy loss in the grid [12]. A Spatial–Temporal model has been proposed in [13] to analyze the impact of EV charging on electric grid considering the origin–destination of vehicles in the transport system and different EV charging strategies. To reduce the electric loss due to EV charging, the stations should be situated near electric substations. However, a station near an electric substation can be far from the main urban roads or vehicle position and results to increase EV energy loss in travel to the station. So, both grid and EV loss are critical in determining charging station location. The station capacity determines the station surface and increases the station development cost due to the land price. It also affects the number of EV that should be charged in the station to make it economically feasible. These issues show that charging station placing and sizing is a complex problem that needs to fully address the issues in both electric grid and EV sides [14].

Few research works are available on charging station placing and sizing. A partitioning-based technique has been presented in [15] to find optimal station location by minimizing traffic loss. Ref. [16] has found optimal station placement for Lisbon to maximize the availability of stations to EV owners. Optimal station location was derived in [17] to minimize station development cost. An analytical method has been proposed in [18] to find optimal station location considering driving patterns. Graph theory has been used in [19] to find optimal size and location of charging stations. A two step technique was proposed in [20] to determine optimal location and size of the charging stations. Particle swarm optimization technique was used in [21] for optimal charging station planning. A traffic constrained optimization framework has been presented in [22] determine optimal charging station planning. While the development of charging station is highly affected by the policy of the public sector, little works are reported on analyzing the policy impact on charging station development.

This paper proposes a new approach for optimal placing and sizing of EV charging stations. The proposed approach minimizes the total cost including station development and electrification costs as well as EV and electric grid energy loss cost due charging EV. It also considers urban roads to find candidate station points and calculate EV energy loss. The problem is formulated as Mixed-Integer Non-Linear (MINLP) problem which is finally solved by genetic algorithm (GA). The proposed approach has been applied to Tehran North-West district and the impact of different charging station policies has been discussed. Fig. 1 shows the flowchart of the proposed method to determine optimal size and place of charging stations.

The paper is arranged as follows: Section 2 describes the problem and elementary models. Optimization model and solution methodology is discussed in Section 3. Application study results are given in Section 4. Electric grid reliability impact on charging station location and size is analyzed in Section 5. Concluding remarks are summarized in Section 6.

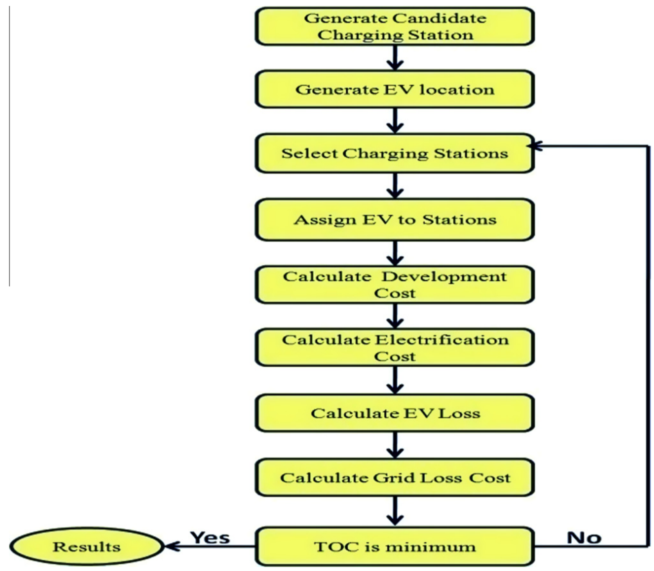

Fig. 1. Flowchart of the proposed method.

2. Components and models

The basic structure of the fast charging station and its use for EV charging is shown in Fig. 2 in which the charging station is connected to the electric substation via a dedicated overhead line.

Electric single line diagram of charging station (i) connected to substation (y) via feeder (Fi) is depicted in Fig. 3.

B6y and B4y represent, respectively, high-voltage and low-voltage bus bars of the substation. Two parallel transformers have been assumed in the substation. B4i represents incoming bus bar of the charging station.

2.1. Station development

Station development cost consists of station equipment cost and land cost. The equipment cost is assumed to vary linearly with the station capacity which is itself a function of the number and capacity of the connectors installed in the station.

Fig. 4 shows the per connector layout of a typical fast EV charging station [23].

As shown in Fig. 4, a minimum width of 9 feet and length of 18 feet is required per connector. If more than one connector is needed, a minimum clearance of 3 feet between the connectors is also required. In this paper, an area requirement of 25 m^2 per connector is assumed and the land cost of the station is considered as 5-year rental cost of the land.

For station (i), the development cost (DC_i) is then calculated as:

$$\mathrm{DC}_i = C_{\mathrm{init}} + 25 \times C_{\mathrm{lan}} \times S_i + \mathrm{PC} \times C_{\mathrm{con}} \times (S_i - 1) \quad [\,] \tag{1}$$

In which PC is the connector rated power, kW; C_{con} is connector development cost, \$/kW; C_{init} is station fixed-cost, \$; C_{lan} is land rental cost for 5 years, \$/m^2; and S_i is the number of connectors in station (i).

The capacity of station (i), SC_i, is then calculated as:

$$SC_i = \mathrm{PC} \times S_i \quad [\mathrm{kW}] \tag{2}$$

Station fixed cost, C_{init}, represents the cost associated with basic equipments and facilities used to establish a charging station. The cost is more or less similar in different countries and market as it is associated with technical equipments.

The land rental cost highly depends on the land quality and varies in the markets and even in different locations of a city.