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Planning and Operation of Parking Lots Considering System, Traffic, and Drivers Behavioral Model

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***Abstract*—The planning and operation problems of parking lots of plug-in electric vehicles (PEVs) are studied in this paper. Herein, each distribution company (DISCO) allocates the parking lots to the electrical feeders to minimize the power loss and expected energy not supplied of the system, and consequently minimize the total cost of the planning problem over the given time horizon. In addition, the generation company (GENCO) manages the charging time of PEVs parked in the parking lots to defer the more expensive and pollutant generation units, and as a result maximize its daily profit. In both planning and operation problems, the behavioral model of PEVs' drivers are modeled with respect to the value of incentive and their distance from the parking lots. To achieve the realistic results in the planning problem of each DISCO, several economic and technical factors including yearly inflation and interest rates, hourly and daily variations of the load demand, yearly load growth of the system, and yearly growth rate of PEVs' application are considered. The optimization problems of each DISCO and GENCO are solved applying quantum-inspired simulated annealing algorithm and genetic algorithm, respectively. It is demonstrated that the behavioral model of drivers, their driving patterns, and even the type of PEVs can remarkably affect the outcomes of planning and operation problems. It is shown that the optimal allocation of parking lots can minimize every DISCO's planning cost and optimal charging management of PEVs can increase the GENCO's daily profit.**

***Index Terms*—Charging management, drivers' behavioral model, driving patterns, plug-in electric vehicle (PEV), traffic and system-based parking lot allocation.**

I. Introduction

NOWADAYS, the conventional power systems are being restructured and changed into the smart grids to improve the reliability and efficiency of the power systems that results in social, economic, and environmental benefits. In this regard, energy scheduling, energy management, parking lot allocation, and charging management of plug-in electric vehicles (PEVs) are some of the important subjects considered in a smart grid environment. A smart grid is an electricity network that uses advanced technologies to monitor and manage the electricity transmission from all generation sources to meet the varying electricity demands of end users [1]. Smart grids coordinate the needs and capabilities of all generators, grid operators, end users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimizing costs and environmental impacts while maximizing system reliability, resilience, and stability [1].

A recent study demonstrates that almost 27% of total energy consumption and 33% of greenhouse gas emissions in the world are related to the transportation sector [2]. Replacing internal combustion-based vehicles with PEVs is a promising strategy to mitigate the energy security and environmental issues, since PEVs can be charged by the electricity generated by renewables as the free and clean resources of energy [3]. Based on the study presented in [4] and [5], PEVs utilization is being increased rapidly in some developed countries because of the advancement in the battery technology. In this regard, fast charging is one of the most important characteristics of EV in future smart grid and smart city [6], [7].

However, replacing conventional vehicles with PEVs might create new issues for every power system such as causing congestion in the feeders, resulting in overload in the power distribution, transmission, and generation systems, and even making spikes in electricity market price due to uncontrolled charging of PEVs [8], [9]. Therefore, the above-mentioned issues must be mitigated by proper coordination of PEVs fleet. Moreover, optimal parking placement in the distribution network and optimal charging management of PEVs can result in benefits for the distribution company (DISCO) and generation company (GENCO).

In this paper, the problem of parking lot placement and charging management of PEVs is investigated from the DISCOs and a GENCO viewpoints in two different problems including planning and operation problems. Herein, the DISCOs solve the planning problem and allocate the parking lots in the optimal locations of every feeder of the electrical distribution network to achieve the minimum overall cost over the planning horizon (30 years). The cost terms of the objective function of DISCO include the total investment for purchasing and installing parking lots in the optimal locations, the present

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worth value of maintenance cost of the installed parking lots over the operation period, the present worth value of incentive (discount on charging fee) considered for the PEVs' drivers over the operation period, the present worth value of energy loss cost over the operation period, and the present worth value of expected energy not supplied (EENS) cost over the operation period. In addition, to achieve the realistic results, several economic and technical factors such as yearly inflation and interest rates, yearly growth rate for application of PEVs, yearly load growth rate, and daily and hourly variations of the load demand are taken into consideration in the planning problem. Moreover, the security constraints of the grid including the loading limit of branches and the voltage magnitude limits of the buses are considered over the operation period.

On the other hand, the GENCO manages the charging time of PEVs parked in the parking lots (allocated by DISCO) to maximize its daily profit by deferring the most expensive and pollutant generation units while satisfying the same daily charging demand of PEVs. In both problems (planning problem solved by every DISCO and operation problem solved by the GENCO), the driving patterns of the PEVs' owners and their reaction with respect to the value of incentive and their average daily distance from the parking lots are modeled. The value of incentive (the percentage of discount on charging fee of the PEVs) is considered by a DISCO to motivate the drivers to charge their vehicles through the parking lots. In addition, the value of incentive (the extra credit, which is equal to the percentage of charging fee) is considered by the GENCO to encourage the drivers to let the GENCO decide on the charging time of their PEVs. Furthermore, genetic algorithm (GA) and quantum-inspired simulated annealing (QSA) algorithm are applied to solve the operation problem of GENCO and planning problem of each DISCO, respectively.

II. Literature Review and Related Works

The economic and technical features of PEVs have been discussed in [10] and [11]. Ferreira *et al.* [10] presented a mobile information system to give relevant information to the PEV drivers by allowing them to access the data sources. In [11], the operation costs of PEVs in a future power system and the benefits of smart charging and discharging of PEVs have been estimated.

In [12]–[15], the parking lot allocation problem has been studied on the real power systems. In [12], the charging demand of PEVs in Beijing has been estimated and a model for charging stations has been presented. This paper concludes that the service radius of fast charging stations affects the distribution pattern of charging stations and it has less disturbance on the power system. In [13], parking lot information from 30 000 records of personal trips in the Puget Sound, Seattle, Regional Council's 2006 Household Activity Survey has been used to determine the public parking locations and durations. In this paper, the presented algorithm minimizes the PEV drivers' costs for station access while penalizing unmet demand. In [14], a study on the location of PEVs charging stations for an area of Lisbon, has been conducted considering the population and employment in the area. In [15], a dynamic model of development of a charging station for PEVs in the German metropolitan region of Stuttgart has been presented. The presented model consists of simulating development of PEVs ownership, determining the demand of charging stations, calculating profitability of the infrastructure, and simulating the mobility of PEVs throughout the region. However, in these studies, the reaction of PEVs' drivers with respect to the value of incentive and distance from parking lots has not been modeled. In addition, the parking lot placement problem for minimizing power loss and EENS of system, as well as, charging management of PEVs for generation scheduling problem of a GENCO has not been investigated.

In [16]–[20], parking lot allocation problem and PEVs charging management problem have been investigated considering minimum energy and power losses of the system. In [16], in addition to charging-recharging of PEVs, capacitor is installed in the electrical distribution system to supply the reactive power of distribution network. In [17], optimal charging stations of PEVs are determined based on the minimum total cost associated with the charging stations considering the environmental factors and service radius of charging stations. In [18], PEVs are charged in a coordinated way to find its positive effects on the feeder losses, load factor, and load variance of the system. In [19] and [20], charging stations, renewable energy resources (solar power), and distributed generation have been allocated simultaneously to minimize power loss of the system. Nonetheless, in these studies, the behavior of PEVs' drivers has not been modeled and the problem has not been investigated from a GENCO's point of view.

In [21]–[25], the PEVs charging management and parking lot placement have been investigated for improving the system reliability and performance. In [21], parking lot allocation has been conducted to improve the reliability of distribution system and to incorporate the PEVs fleet in the energy market transactions. However, in this paper, the behavior of drivers has been modeled just with respect to the value of incentive, while the geography of area, the driving pattern, and the traffic of PEVs have not been modeled. In [22], the effects of large-scale application of PEVs on the power systems of five Northern European countries (Denmark, Finland, Germany, Norway, and Sweden) have been investigated. In [23], the environmental and social criteria have been considered in the life cycle of charging stations of PEVs to minimize the total cost of the micro grid. In [24] and [25], the behavior of PEVs for being in the parking lots and the available energy of PEVs have been modeled based on the arrival time, departure time, and state of charge (SOC) of batteries of the PEVs. However, in [24] and [25], the reaction of PEVs' drivers with respect to the value of incentive has been neglected and the optimal charging management of PEVs has not been considered. In addition, in [21], [22], and [25], the PEVs charging management problem has not been investigated from a GENCO's point of view.

In [26], to minimize the drivers' trip duration, the charging location and charging time of PEVs are managed. In [27], to find the optimal parking trajectory, a trajectory planning method that links the actual parking trajectories and the steering actions has been presented. In [28], parking lot sizing and placement problem has been studied considering the drivers'

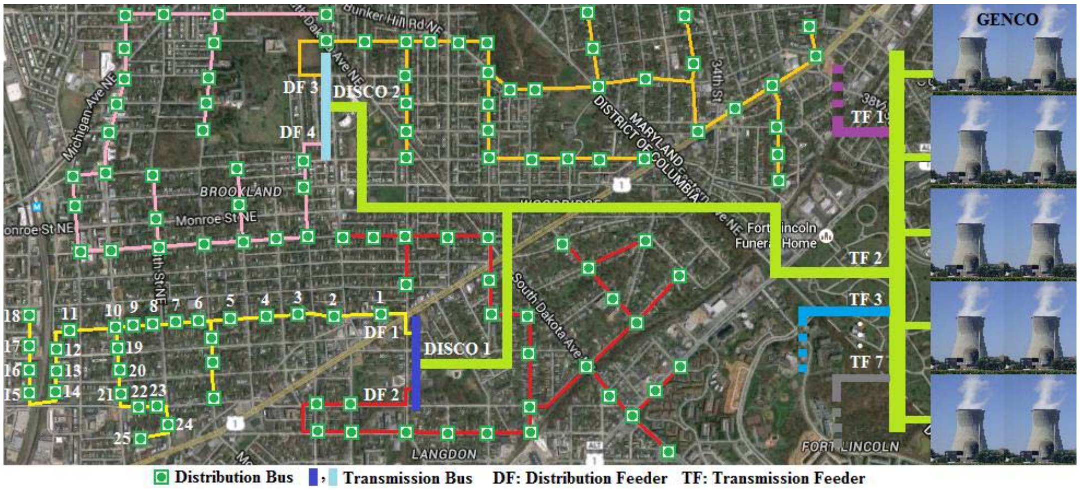

Fig. 1. Power system under study.

welfare. Also, a K-means clustering approach has been applied to estimate the number of drivers approaching to a parking lot. In the above-mentioned studies, the economic behavior of drivers, the driving pattern of PEVs' owners, and the traffic and geography of the area have not been modeled.

Compared to the previous works, the presented study in this paper is the first study that investigates the optimal parking lot placement problem (from every DISCO's view point) and the problem of optimal charging management of PEVs (from a GENCO's point of view) considering the driving pattern of PEVs and the behavior of drivers with respect to value of introduced incentive and their daily average distance from the suggested parking lots.

III. Proposed Technique

A. Modeling Driving Patterns of the PEVs Fleet

Fig. 1 illustrates a power system that includes a GENCO, some transmission feeders (TFs), DISCOs, and distribution feeders (DFs). Herein, the GENCO includes ten generation units, every TF supplies two DISCOs, and each DISCO has two DFs. DF 1 has 28 distribution buses (substations) and each of them has real latitude and longitude with real geographic data of Washington, DC, USA.

To determine the daily driving pattern (i.e., route) of a PEV, the hourly position data (latitude and longitude) of the PEV can be specified using global positioning system. Herein, to simulate the problem, the hourly position and speed of vehicles are randomly generated by the computer considering the real geographic borders of each DF (based on the real latitude and longitude of points in Washington using Google Map) and the minimum and maximum traffic velocity limits in the residential area in Washington (32–80 km/h [29]). The defined area for each DF covers a square zone based on the nearest and farthest buses of the feeder.

Fig. 2 illustrates the hourly position of six PEVs (as the six driving patterns) around the buses of DF 1, which is randomly generated by the computer considering the geographic borders of feeder and the minimum and maximum velocity limits of

Fig. 2. Hourly position data (longitude and latitude) of PEVs fleet (patterns 1–6) around DF 1.

vehicles in the residential area in Washington. In this paper, every PEV is considered as the representative of 100 PEVs. In other words, 600 PEVs are moving around DF 1.

Fig. 3 shows the hourly space-time driving patterns of the PEVs around DF 1 (patterns 1–6) in a day. As can be seen, at some hours of the day (hours 1–7 and 23–24), the PEVs do not move in the space as time goes on, since the PEVs have been parked. Moreover, every driving pattern has different average daily distance from each bus of the electrical distribution system. In other words, two PEVs with different driving patterns will not have identical reaction to the value of incentive due to their different average daily distances from a candidate parking lot.

Using the above-mentioned approach for other feeders of the power system, the total number of vehicles in the whole territory of power system is calculated about 16 800, as can be seen at the following equation:

$$\begin{aligned}&100(\text{Number of PEVs per driving pattern})\\&\quad\times 4(\text{Number of DFs of a TF})\times 6(\text{Driving patterns})\\&\quad\times 7(\text{Number of TFs in system}) = 16800.\end{aligned}$$

Now, by knowing the driving pattern of the eth PEV, the amount of average daily distance of the PEV from the bth bus of the feeder $(\overline{\beta_{e,b}})$ can be calculated using the hourly position data of the PEV $(x_{e,t}^{\mathrm{PEV}}, y_{e,t}^{\mathrm{PEV}})$ and the bus (x_b^B, y_b^B), as can be

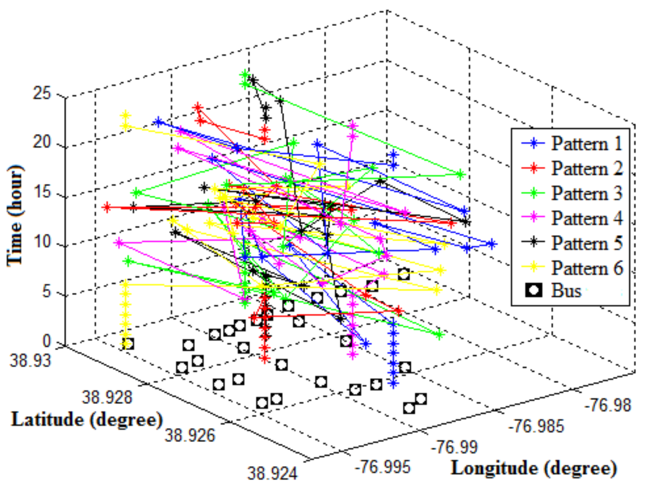

Fig. 3. Hourly space-time driving patterns of the PEVs fleet around DF 1 (patterns 1–6).

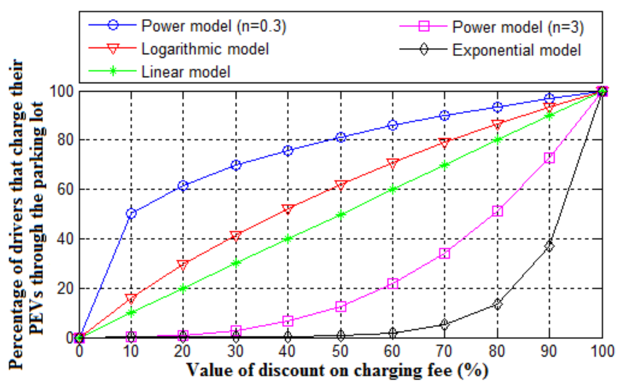

Fig. 4. Percentage of drivers that charge their PEVs through the parking lot as the mathematical functions of discount on charging fee (%) [21].

seen in (1). Herein, every bus of the feeder ($\forall b \in \{1, \ldots, Nb\}$) is considered as a candidate for installing a parking lot. The value of $\overline{\beta_{e,b}}$ (along with the value of incentive) will be applied for determining the percentage of drivers that charge their PEVs through the parking lot (ξ) installed in the bth bus of the feeder

$$\overline{\beta_{e,b}} = \frac{1}{24} \times \sum_{t=1}^{24} \sqrt{\left(x_{e,t}^{\mathrm{PEV}} - x_b^B\right)^2 + \left(y_{e,t}^{\mathrm{PEV}} - y_b^B\right)^2}\ \forall e \in \left\{1, \ldots, N_{\mathrm{Tot}}^{\mathrm{PEVs}}\right\}\ \ \forall b \in \{1, \ldots, Nb\}. \quad (1)$$

Herein, $N_{\mathrm{Tot}}^{\mathrm{PEVs}}$ (600 PEVs) is the total number of PEVs exist around the feeder and Nb is the total number of buses of the feeder.

By knowing the driving pattern of the PEV, the SOC of the PEV can be approximated, since the SOC of a PEV has a direct relation with the amount of distance that it travels in a day. The value of SOC of the PEV is used to determine the amount of power and energy demands of the parking lot. The value of SOC of a PEV at every hour of a day (t) can be determined using (2). Herein, $\mathrm{kWh_{km}}$ is the amount of energy (kWh) that the PEV needs to travel about 1 km and C_e^{PEV} is the capacity

TABLE I
PERCENTAGE OF DRIVERS THAT CHARGE THEIR PEVS THROUGH THE PARKING LOT AS THE MATHEMATICAL FUNCTIONS OF DISCOUNT ON CHARGING FEE (%) [21]

Mathematical model	Percentage of drivers that charge their PEVs through the parking lot
Power model	$\xi_{Pow} = 100 \times \left(\frac{\gamma}{100}\right)^n, n\epsilon\{0.3,3\}$
Linear model	$\xi_{Lin} = \gamma$
Logarithmic model	$\xi_{Log} = 100 \times ln\left(\frac{\gamma}{100} \times (exp(1) - 1) + 1\right)$
Exponential model	$\xi_{Exp} = 100 \times exp\left(M \times \left(\frac{\gamma}{100} - 1\right)\right), M \gg 1$

of battery of the PEV

$$\mathrm{SOC}_{e,t}^{\mathrm{PEV}} = 100 \times \left(1 - \frac{\mathrm{kWh_{km}}}{C_e^{\mathrm{PEV}}} \times \sum_{t=1}^{t} \sqrt{\left(x_{e,t}^{\mathrm{PEV}} - x_{e,t-1}^{\mathrm{PEV}}\right)^2 + \left(y_{e,t}^{\mathrm{PEV}} - y_{e,t-1}^{\mathrm{PEV}}\right)^2}\right)$$
$$\forall e \in \left\{1, \ldots, N_{\mathrm{Tot}}^{\mathrm{PEVs}}\right\} \forall t \in \{1, \ldots, 24\}. \quad (2)$$

B. Modeling Behavior of Drivers As Function of Incentive and Distance

The percentage of drivers that charge their PEVs through the suggested parking lot as the function of discount on charging fee (γ in percent) for power function with exponent 0.3 and 3, logarithmic function, linear function, and exponential function are presented in Table I and Fig. 4 [21]. As can be seen, almost all the surface of figure is covered with the presented functions. In other words, approximately all the possibilities for the reaction of drivers with respect to the value of incentive are considered. As can be seen, the drivers do not charge their vehicles through the parking lot if there is no incentive, and also considering 100% discount on the charging fee of PEVs motivate all the drivers to charge their vehicles through the parking lot.

In this paper, the behavior of PEVs' drivers is modeled based on two parameters ($\overline{\beta}, \gamma$). In fact, in addition to the value of discount on charging fee (γ), the average daily distance of the PEVs from the location of parking lot ($\overline{\beta}$) is considered. Herein, a linear function is assumed between ξ (percentage of drivers that charge their PEVs through the parking lot) and $\overline{\beta}$, as can be seen in Table II. The a_1 and a_2 are the constant values needed for modeling linear reaction of drivers with respect to their average daily distance from the parking lot.

By considering both $\overline{\beta}$ and γ, the two-dimensional (2-D) plots presented in Fig. 4 are changed into three-dimensional spatial surfaces, as can be seen in Figs. 5 and 6 (for $a_1 = -1/1200, a_2 = 1$). These figures illustrate the percentage of drivers that charge their PEVs through the parking lot. In all of these figures, the behavioral model of drivers has linear relation with the amount of average daily distance of the drivers from the parking lot (meter), and power (with exponent 0.3), logarithmic, linear, power (with exponent 3), and exponential relations with the value of discount on charging fee (%), respectively.

TABLE II
PERCENTAGE OF DRIVERS THAT CHARGE THEIR PEVS THROUGH THE PARKING LOT AS THE MATHEMATICAL FUNCTIONS OF DISCOUNT ON CHARGING FEE (%) AND DISTANCE FROM THE PARKING LOT (METER)

Mathematical model	Percentage of drivers that charge their PEVs through the parking lot
Power model	$\xi_{Pow} = (a_1 \times \overline{\beta} + a_2) \times 100 \times \left(\frac{\gamma}{100}\right)^n, n\epsilon\{0.3, 3\}$
Linear model	$\xi_{Lin} = (a_1 \times \overline{\beta} + a_2) \times \gamma$
Logarithmic model	$\xi_{Log} = (a_1 \times \overline{\beta} + a_2) \times 100 \times ln\left(\frac{\gamma}{100} \times (exp(1) - 1) + 1\right)$
Exponential model	$\xi_{Exp} = (a_1 \times \overline{\beta} + a_2) \times 100 \times exp\left(M \times \left(\frac{\gamma}{100} - 1\right)\right), M \gg 1$

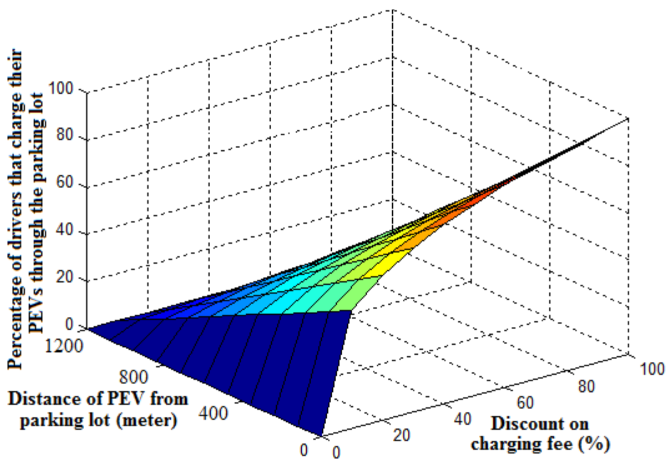

Fig. 5. Percentage of drivers that charge their PEVs through the parking lot as power function (exponent is 0.3) of discount on charging fee (%) and linear function of average daily distance from the parking lot (meter).

The number of PEVs that charge their vehicles through the parking lot ($N_{\text{Model}}^{\text{PEVs}}$), as the size of the parking lot, is determined using (3) that depends on the value of incentive (γ), the average daily distance of PEVs from the location of parking lot ($\overline{\beta}$), and the total number of PEVs around the feeder ($N_{\text{Tot}}^{\text{PEVs}}$). Moreover, the hourly demand of parking lot (D_t^{PL}) in MW is approximated applying the following equation:

$$N_{\text{Model}}^{\text{PEVs}} = \xi_{\text{Model}} \times N_{\text{Tot}}^{\text{PEVs}} \tag{3}$$

$$D_t^{\text{PL}} = \sum_{e=1}^{N_{\text{Model}}^{\text{PEVs}}} \left(1 - \frac{\text{SOC}_{e,t}^{\text{PEV}}}{100}\right) \times \frac{C_e^{\text{PEV}}}{1000}. \tag{4}$$

C. Optimization Technique

In this section, the optimization techniques for solving the planning problem of a DISCO and the operation problem of the GENCO are presented.

1) Optimization Technique for Solving the Planning Problem of DISCO: In this paper, quantum computation concept is applied in the simulated annealing (SA) to design the QSA algorithm and solve the optimization problem [30], which is a mixed-integer nonlinear programming problem. Other optimization algorithms could be used for this problem; however, quantum parallelism, as the superiority of the quantum computation, which originates from the uncertainty of quantum states, is the advantage compared to the other algorithms [31].

A classical bit can be either 0 or 1, while in quantum computation, a quantum bit (Q-bit) is a linear superposition of both states (0 and 1), which simultaneously lies in both states [32], as can be seen in (5). However, when a Q-bit is observed, it collapses to one determined state (0 or 1) with a certain probability. The superposition of the states is also presented in other forms such as $\alpha\begin{pmatrix}1\\0\end{pmatrix} + \beta\begin{pmatrix}0\\1\end{pmatrix}$ and $\alpha|\uparrow\rangle + \beta|\downarrow\rangle$

$$|\psi\rangle = \alpha|0\rangle + \beta|1\rangle. \tag{5}$$

Herein, $|0\rangle$ and $|1\rangle$ represent the state "0" and "1," respectively, and α and β are generally complex numbers where $|\alpha|^2$ and $|\beta|^2$ represent the probability amplitudes (http://en.wikipedia.org/wiki/Probability_amplitude) that the Q-bit will be observed in the 0 and 1 states, respectively, with respect to (6). In this paper, applying 2-D quantum computation in the SA algorithm is enough, thus (6) can be simplified as $(\alpha)^2 + (\beta)^2 = 1$

$$|\alpha|^2 + |\beta|^2 = 1. \tag{6}$$

The Q-bit matrix of the problem variables ($\mathbb{Q}$ matrix) includes the Q-bits related to the location of parking lots and the value of incentive (discount on charging fee of the PEVs), as can be seen in (7). Herein, the number of drivers that charge their PEVs through the parking lot and the demand of parking lot are determined based on the value of incentive and the average daily distance of PEVs from the parking lot using (3) and (4), respectively. As can be seen in (7), every bus of the feeder ($\forall b \in \{1, \ldots, Nb\}$) is considered as a candidate to install a parking lot. In other words, every bus of the feeder can have a parking lot. Therefore, the bth bus has a parking lot with the probability amplitude about $(\beta_b^{\text{PL}})^2$ or this bus does not have a parking lot with the probability amplitude about $(\alpha_b^{\text{PL}})^2$

$$\mathbb{Q} = \left[\begin{pmatrix}\alpha_1^{\text{PL}}\\ \beta_1^{\text{PL}}\end{pmatrix} \cdots \begin{pmatrix}\alpha_b^{\text{PL}}\\ \beta_b^{\text{PL}}\end{pmatrix} \cdots \begin{pmatrix}\alpha_{Nb}^{\text{PL}}\\ \beta_{Nb}^{\text{PL}}\end{pmatrix} \middle| \begin{pmatrix}\alpha_1^{\text{INC}}\\ \beta_1^{\text{INC}}\end{pmatrix} \cdots \begin{pmatrix}\alpha_4^{\text{INC}}\\ \beta_4^{\text{INC}}\end{pmatrix}\right]. \tag{7}$$

In addition, the value of incentive is changed from 0% (or 0) to 100% (or 10) with the 10% (or 1) steps. Thus, the minimum number of Q-bits needed to indicate the value of incentive is 4, since $2^3 < 10 < 2^4$. In other words, for indicating the numbers $0, 1, \ldots,$ and 10 (proportional to $0\%, 10\%, \ldots,$ and 100%), at least four binary variables are needed. It is noteworthy to mention that $(\alpha_1^{\text{INC}})^2$ and $(\beta_1^{\text{INC}})^2$ are the probability amplitudes (http://en.wikipedia.org/wiki/Probability_amplitude) that the binary variable is 0 and 1, respectively. Based on this, 0% discount and 100% discount can be indicated by the states $|0000\rangle$ and $|1010\rangle$ that have probability amplitude about $(\alpha_1^{\text{INC}})^2 \times (\alpha_2^{\text{INC}})^2 \times (\alpha_3^{\text{INC}})^2 \times (\alpha_4^{\text{INC}})^2$ and $(\beta_1^{\text{INC}})^2 \times (\alpha_2^{\text{INC}})^2 \times (\beta_3^{\text{INC}})^2 \times (\alpha_4^{\text{INC}})^2$, respectively.

Herein, the value of objective function of problem is defined as the value of internal energy of the molten metal (ε) and then

Algorithm 1 Pseudocode for Finding the Optimal Scheme of Charging Management by a GENCO

1: Set $\gamma = 0$. *// The value of credit which is equal to the percentage of charging fee.*
2: Solve the optimization problem to maximize the daily profit of GENCO.
  Use GA to determine the status of generation units. *//Presented in Section III-C.2.*
  Use Lambda-Iteration method to determine generation level of units [33].
    Calculate the daily profit of GENCO.
3: $\gamma = \gamma + 10$.
4: Determine the number of drivers that let the GENCO to decide about the charging time of their PEVs (parked in the parking lots allocated by the DISCOs) based on TABLE II and (3).
5: Go to Step 2, if $\gamma \leq 100$.
6: Determine the optimal value of γ based on the maximum daily profit of GENCO.

it is tried to minimize the amount of this energy. Based on the concept of SA, in the cooling process of molten metal, the temperature of molten metal is gradually decreased to minimize the internal energy of molten metal [30]. The different steps for applying QSA algorithm in a problem have been presented and described in [25].

2) Optimization Technique for Solving the Operation Problem of GENCO: Herein, GA is applied to solve the optimization problem of GENCO. The value of objective function [the total profit of GENCO over the operation period (one day)] is defined as the fitness of a chromosome, and then the GA tries to maximize the fitness of chromosomes. A chromosome (shown in Fig. 7) represents the status of all the generation units at every hour of a day. This problem is optimized for every possible value of incentive (credit which is equal to the percentage of charging fee of PEVs) with a 10% step increase, that is, 0%, 10%, ..., 100%. Then, the optimal value of incentive is determined based on the maximum value of GENCO's profit over the operation period (one day). Algorithm 1 presents the pseudocode for finding the optimal scheme of charging management of PEVs (optimal value of credit for drivers) parked in the parking lots in the operation problem of GENCO.

In the following, the steps for applying the GA in the optimization problem of GENCO are presented and described.

Step 1 Obtaining the Primary Data:

1) *Parameters for Applying GA:* These parameters include the mutation probability of the genes (θ^{Mut}) and the size of population (n_c) as the number of the chromosomes.
2) *Parameters of the System Under Study:* The values of all the parameters of the system and problem are obtained. Also, the value of incentive (γ as value of credit which is equal to the percentage of charging fee) is chosen.
3) *Updating Participation Percentage of PEVs' Drivers:* The participation percentage of drivers (and consequently the number of drivers) that let the GENCO to decide on the charging time of their PEVs are determined using Table II and (3). Then the revised demand of the system is identified.
4) *Initial Population:* The chromosomes of population (Fig. 7) are initialized with random binary values (0 or 1).

Step 2 Updating the Population:

1) *Applying Crossover Operator:* The crossover operator is applied on every two chromosomes to reproduce two new chromosomes as the offspring.
2) *Applying Mutation Operator:* The mutation is applied on every gene of every chromosome of the population with the definite probability θ^{Mut}.

Step 3 Selecting New Population:

1) *Evaluating Fitness of Every Chromosome:* For every chromosome, the optimal generation scheduling problem of GENCO is solved using the lambda-iteration economic dispatch method [33] and if all the constraints are satisfied, the fitness (fit_c) of chromosome is calculated.
2) *Applying Selection Process:* The new chromosomes are selected using the probabilistic fitness-based selection (PFBS) technique, where the fitter chromosomes are more likely to be chosen. Herein, r_c is a random number between [0, 100] generated for the chromosome (c)

$$a_c = \begin{cases} 1 & \theta_c^{\mathrm{PFBS}} > r_c \\ 0 & \theta_c^{\mathrm{PFBS}} < r_c. \end{cases} \tag{8}$$

The value of selection probability of every chromosome (θ_c^{PFBS}) is determined using (9), which is proportional to the fitness of the chromosome. Herein, n_c is the number of chromosomes in the population and a_c is the acceptance indicator of a chromosome for the new population

$$\theta_c^{\mathrm{PFBS}} = \frac{\mathrm{fit}_c}{\mathrm{Max}\{\mathrm{fit}_1, \ldots, \mathrm{fit}_{nc}\}} \times 100. \tag{9}$$

Step 4 (Checking Termination Criterion): In this step, the convergence status of the optimization procedure is checked. Based on this, the values of improvements in the fitness of the chromosomes of the old and new populations are computed and if there are no significant improvements in them, the optimization process is finished, otherwise, the algorithm is continued from step 2.

Step 5 (Introducing the Outcome): The consequences include the maximum value of GENCO's profit over the operation period (one day), the generation level of units, and the revised demand of system.

IV. Mathematical Formulation

In this section, the mathematical formulations for the planning problem of a DISCO (Section IV-A) and operation problem of a GENCO (Section IV-B) are presented, respectively. The goal of a DISCO is minimizing total cost of the planning problem over the planning time horizon (30 years). Herein, the inputs of planning problem of a DISCO include all the technical and economic parameters of the problem and all the technical data of the electrical distribution network. Also, the outputs of problem include the optimal location of parking lots and the optimal value of incentive.

The aim of the GENCO is maximizing its profit over the operation period (one day). Herein, the inputs of problem include the demand level of system and all the technical data of

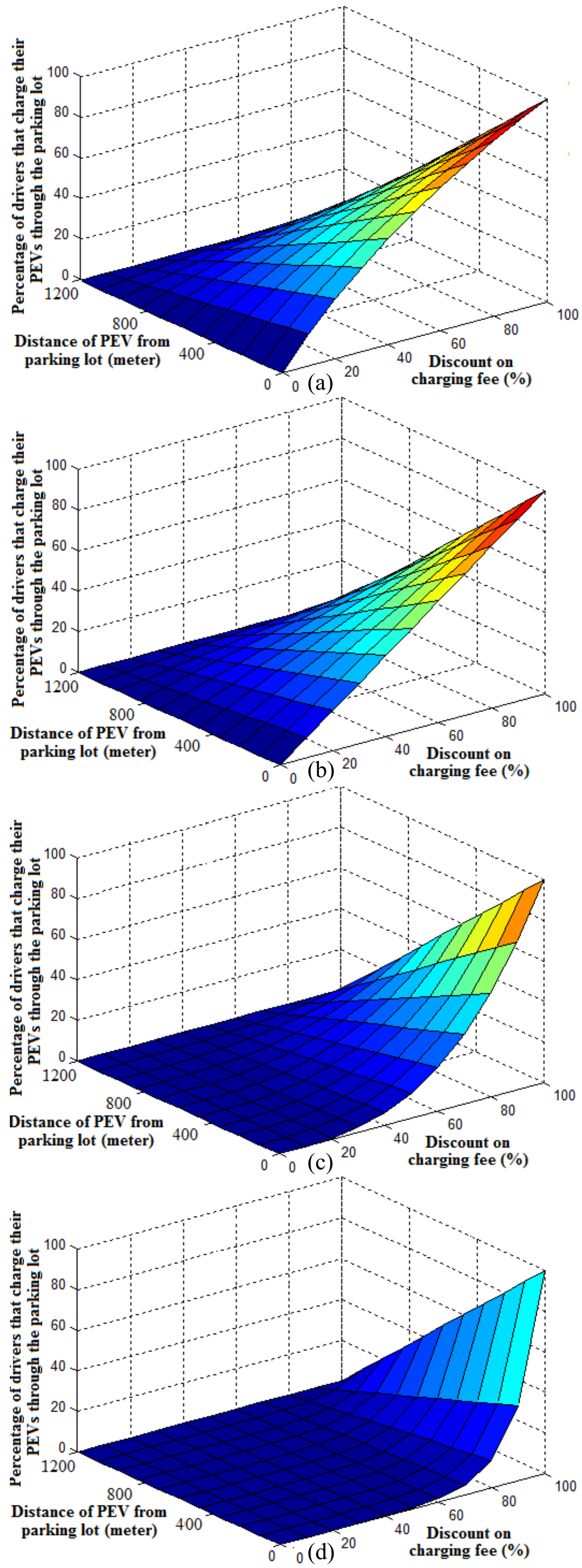

Fig. 6. Percentage of drivers that charge their PEVs through the parking lot as (a) logarithmic, (b) linear, (c) power (with exponent 3), and (d) exponential functions of discount on charging fee (%) and linear function of average daily distance from the parking lot (meter).

generation units. Also, the outputs include the optimal status and generation level of each generation unit and the optimal value of incentive.

	G1	G2	...	G10
1	0/1	0/1	0/1	0/1
2	0/1	0/1	0/1	0/1
⋮	⋮	⋮	⋮	⋮
24	0/1	0/1	0/1	0/1

Fig. 7. Structure of a chromosome in the applied GA.

A. Formulating the Planning Problem of DISCO

1) Objective Function of DISCO: The objective function of planning problem of each DISCO is minimizing total cost of the problem over the planning period (Ny) by installing the parking lots in the optimal locations of the feeders. Herein, the driving patterns of PEVs' drivers and their behavioral model are considered in the planning problem. In addition, several economic and technical factors including yearly inflation and interest rates, hourly and daily variations of the load demand, yearly load growth rate of the system, and yearly growth rate of the PEVs' application are taken into consideration. The cost terms of objective function include total investment cost for installing the parking lots in the optimal locations (Cost^{INV}), present worth value of maintenance cost of the installed parking lots over the operation period ($\widetilde{\text{Cost}}^{\text{MAINT}}_{Ny}$), present worth value of cost of discount on charging fee of the PEVs over the operation period ($\widetilde{\text{Cost}}^{\text{INC}}_{Ny}$), present worth value of energy loss cost of the feeder over the operation period ($\widetilde{\text{Cost}}^{\text{EL}}_{Ny}$), and present worth value of EENS cost of the feeder over the operation period ($\widetilde{\text{Cost}}^{\text{EENS}}_{Ny}$), as can be seen in the following equation:

$$\text{OF}^{\text{DISCO}}_{Ny} = \min\Big\{\text{Cost}^{\text{INV}} + \widetilde{\text{Cost}}^{\text{MAINT}}_{Ny} + \widetilde{\text{Cost}}^{\text{INC}}_{Ny} + \widetilde{\text{Cost}}^{\text{EL}}_{Ny} + \widetilde{\text{Cost}}^{\text{EENS}}_{Ny}\Big\}. \tag{10}$$

2) Cost Terms of the Planning Problem:

a) Investment cost: The total investment cost for purchasing and installing the equipment of parking lots (Cost^{INV}) in the optimal locations of the feeder is presented in (11). Herein, C^{INV} is the amount of investment to equip the parking lot for one PEV

$$\text{Cost}^{\text{INV}} = C^{\text{INV}} \times N^{\text{PEVs}}_{\text{Model}}. \tag{11}$$

b) Maintenance cost: The value of maintenance cost of the installed parking lot in the yth year ($\text{Cost}^{\text{MAINT}}_{y}$) and its present worth value for the whole operation period ($\widetilde{\text{Cost}}^{\text{MAINT}}_{Ny}$) are given in (12) and (13), respectively. Herein, C^{MAINT} is the amount of yearly maintenance cost of the parking lot for one PEV and IFR and ITR are inflation and interest rates, respectively. Also, Ny is the length of the planning period in year (30 years)

$$\text{Cost}^{\text{MAINT}}_{y} = C^{\text{MAINT}} \times N^{\text{PEVs}}_{\text{Model}} \tag{12}$$

$$\widetilde{\text{Cost}}^{\text{MAINT}}_{Ny} = \sum_{y=1}^{Ny} \text{Cost}^{\text{MAINT}}_{y} \times \left(\frac{1+\frac{\text{IFR}}{100}}{1+\frac{\text{ITR}}{100}}\right)^{y}. \tag{13}$$

c) Incentive cost: The value of cost of discount on charging fee of the PEVs in the yth year ($\mathrm{Cost}_y^{\mathrm{INC}}$) and its present worth value for the whole operation period ($\widetilde{\mathrm{Cost}}_{Ny}^{\mathrm{INC}}$) are presented in (14) and (15), respectively. Herein, γ and π^E are the percentage of discount on charging fee and the price of electricity in Cents per kWh, respectively. Also, the value of D^{PL} has been presented in (4). Herein, t, d, and π^E are index of time in hour, index of day, and the value of charging price

$$\mathrm{Cost}_y^{\mathrm{INC}} = \sum_{d=1}^{365}\sum_{t=1}^{24} D_t^{\mathrm{PL}} \times \frac{\gamma}{100} \times \pi^E \times 10 \tag{14}$$

$$\widetilde{\mathrm{Cost}}_{Ny}^{\mathrm{INC}} = \sum_{y=1}^{Ny} \mathrm{Cost}_y^{\mathrm{INC}} \times \left(\frac{1+\frac{\mathrm{IFR}}{100}}{1+\frac{\mathrm{ITR}}{100}}\right)^y. \tag{15}$$

d) Energy loss cost: The value of energy loss of feeder over the planning horizon (EL_{Ny}) is presented in (16). Moreover, the energy loss cost of the feeder in the yth year ($\mathrm{Cost}_y^{\mathrm{EL}}$) and its present worth value for the whole operation period ($\widetilde{\mathrm{Cost}}_{Ny}^{\mathrm{EL}}$) are given in (17) and (18), respectively. Herein, R is the value of resistance of the branch of feeder, $|I|$ is the magnitude of current flowing through the branch, and $\mathrm{MVA}^{\mathrm{BASE}}$ is the value of base power in per unit system (p.u.). Also, Nbr is the total number of branches of feeder

$$EL_{Ny} = \sum_{y=1}^{Ny}\sum_{d=1}^{365}\sum_{t=1}^{24}\sum_{\mathrm{br}=1}^{Nbr} R_{\mathrm{br}} \times \left|I_{y,d,t,\mathrm{br}}\right|^2 \times \mathrm{MVA}^{\mathrm{BASE}} \tag{16}$$

$$\mathrm{Cost}_y^{\mathrm{EL}} = \sum_{d=1}^{365}\sum_{t=1}^{24}\sum_{\mathrm{br}=1}^{Nbr} R_{\mathrm{br}} \times \left|I_{y,d,t,\mathrm{br}}\right|^2 \times \mathrm{MVA}^{\mathrm{BASE}} \times \pi^E \times 10 \tag{17}$$

$$\widetilde{\mathrm{Cost}}_{Ny}^{\mathrm{EL}} = \sum_{y=1}^{Ny} \mathrm{Cost}_y^{\mathrm{EL}} \times \left(\frac{1+\frac{\mathrm{IFR}}{100}}{1+\frac{\mathrm{ITR}}{100}}\right)^y. \tag{18}$$

e) Expected energy not supplied cost: The value of EENS of the feeder over the operation period (EENS_{Ny}) is determined using (19) [34]–[35]. As can be seen, this value, as the reliability index or risk level of the system, depends on the failure rate of the branches of the feeder (λ), failure locating duration (τ^{FL}), and failure repairing duration (τ^{FR}). Herein, $\mathrm{LNS}^{\mathrm{FL}}$ is the value of load not supplied during locating the fault and $\mathrm{LNS}^{\mathrm{FR}}$ is the value of load not supplied during repairing the fault.

The EENS cost in the yth year ($\mathrm{Cost}_y^{\mathrm{EENS}}$) and its present worth value for the whole operation period ($\widetilde{\mathrm{Cost}}_{Ny}^{\mathrm{EENS}}$) are presented in (20) and (21), respectively. Herein, π^{ENS} is the value of cost of energy not supplied of the customers in Cents per kWh. Also, b and Nb are the index of the bus and the total number of buses of the feeder, respectively

$$\mathrm{EENS}_{Ny} = \sum_{y=1}^{Ny}\sum_{\mathrm{br}=1}^{Nbr}\lambda_{\mathrm{br}} \times \left(\tau^{\mathrm{FL}}\sum_{b=1}^{Nb}\mathrm{LNS}_y^{\mathrm{FL}} + \tau^{\mathrm{FR}}\sum_{b=1}^{Nb}\mathrm{LNS}_y^{\mathrm{FR}}\right) \tag{19}$$

$$\mathrm{Cost}_y^{\mathrm{EENS}} = \sum_{\mathrm{br}=1}^{Nbr}\lambda_{\mathrm{br}} \times \left(\tau^{\mathrm{FL}}\sum_{b=1}^{Nb}\mathrm{LNS}_{y,b}^{\mathrm{FL}} + \tau^{\mathrm{FR}}\sum_{b=1}^{Nb}\mathrm{LNS}_{y,b}^{\mathrm{FR}}\right) \times \pi^{\mathrm{ENS}} \times 10 \tag{20}$$

$$\widetilde{\mathrm{Cost}}_{Ny}^{\mathrm{EENS}} = \sum_{y=1}^{Ny} \mathrm{Cost}_y^{\mathrm{EENS}} \times \left(\frac{1+\mathrm{IFR}}{1+\mathrm{ITR}}\right)^y. \tag{21}$$

3) Security Constraints of the System in the Planning Problem:

a) Loading limit of the branches: The loading constraint of each branch, as its thermal limit, is presented in (22). As can be seen, the magnitude of apparent power flowing through the branch ($|\mathrm{MVA}_{\mathrm{br}}|$) must be less than the allowable magnitude of the apparent power of the branch ($|\overline{\mathrm{MVA}}_{\mathrm{br}}|$)

$$|\mathrm{MVA}_{\mathrm{br}}| \le \left|\overline{\mathrm{MVA}}_{\mathrm{br}}\right| \;\; \forall \mathrm{br} \in \{1,\ldots,Nbr\}. \tag{22}$$

b) Voltage magnitude limits of the buses: The magnitude of voltage of each bus ($|V_b|$) must be within the allowable minimum and maximum limits. Herein, σ^V is the value of acceptable tolerance of voltage magnitude. Also, $|\bar{V}_b|$ is the magnitude of rated voltage of the bus

$$\left(1-\sigma^V/100\right) \times \left|\bar{V}_b\right| \le |V_b| \le \left(1+\sigma^V/100\right) \times \left|\bar{V}_b\right| \;\; \forall b \in \{1,\ldots,Nb\}. \tag{23}$$

B. Formulating the Operation Problem of the GENCO

1) Objective Function of the GENCO: The objective function of the operation problem of GENCO over the operation period (one day) is presented in (24). As can be seen, it includes income term due to selling electricity to the end user customers and PEVs' drivers ($\mathrm{Income}_t^{\mathrm{SELL}}$), cost of discount on charging fee of the PEVs ($\mathrm{Cost}_t^{\mathrm{INC}}$), fuel cost of the generation units ($\mathrm{Cost}_{g,t}^F$), greenhouse gas emissions cost of the generation units ($\mathrm{Cost}_{g,t}^E$), the start-up cost of de-committed units ($\mathrm{Cost}_{g,t}^{\mathrm{STU}}$), and the shutdown cost of committed units ($\mathrm{Cost}_{g,t}^{\mathrm{SHD}}$). Herein, g and Ng are the index of generation unit and total number of generation units, respectively

$$\mathrm{OF}^{\mathrm{GENCO}} = \max \sum_{t=1}^{24}\left[\begin{array}{c}\mathrm{Income}_t^{\mathrm{SELL}} - \mathrm{Cost}_t^{\mathrm{INC}} \\ -\sum_{g=1}^{Ng}\left[\mathrm{Cost}_{g,t}^F + \mathrm{Cost}_{g,t}^E + \mathrm{Cost}_{g,t}^{\mathrm{STU}} + \mathrm{Cost}_{g,t}^{\mathrm{SHD}}\right]\end{array}\right]. \tag{24}$$

2) Income and Cost Terms of the Operation Problem: In the following, the income and cost terms of the objective function are described. As can be seen in (25), income term of GENCO ($\mathrm{Income}_t^{\mathrm{SELL}}$) includes the value of earning from electricity selling to the end user customers (D^{EU}) and PEVs (D^{PL}). Herein, π^E indicates the electricity price

$$\mathrm{Income}_t^{\mathrm{SELL}} = \sum_{t=1}^{24}\left[D_t^{\mathrm{EU}} + D_t^{\mathrm{PL}}\right] \times \pi^E. \tag{25}$$

a) Incentive cost: The incentive cost ($\mathrm{Cost}^{\mathrm{INC}}$) imposed to the GENCO includes the value of credit (γ) offered to PEVs which is equal to the percentage of charging fee of the PEVs in all the parking lots. Herein, PL and NPL are the indices of parking lot and total number of installed parking lots in the whole power system

$$\text{Cost}_t^{\text{INC}} = \sum_{\text{PL}=1}^{\text{NPL}} D_t^{\text{PL}} \times \frac{\gamma}{100} \times \pi^E \times 10. \tag{26}$$

b) Fuel cost of generation units: The fuel cost of every generation unit (Cost^F) is a quadratic polynomial of power (P) [33]. The α_1^F, α_2^F, and α_3^F are the fuel cost coefficients of the generation unit and g is the index of a generation unit

$$\text{Cost}_{g,t}^F = \alpha_{1,g}^F \times \left(P_{g,t}\right)^2 + \alpha_{2,g}^F \times \left(P_{g,t}\right) + \alpha_{3,g}^F. \tag{27}$$

c) Greenhouse gas emissions cost of generation units: The greenhouse gas emissions cost of every generation unit is a quadratic polynomial of power (P) [33]. The α_1^E, α_2^E, and α_3^E are the emission coefficients of the generation unit and β^E is the emission cost factor

$$\text{Cost}_{g,t}^E = \beta^E \times \left(\alpha_{1,g}^E \times \left(P_{g,t}\right)^2 + \alpha_{2,g}^E \times \left(P_{g,t}\right) + \alpha_{3,g}^E\right). \tag{28}$$

d) Start-up cost and shut down cost of generation units: The start-up cost of a de-committed unit (Cost^{STU}) and shut-down cost of a committed unit (Cost^{SHD}) at every hour of the operation period are presented in (29) and (30), respectively. Herein, x^G indicates the status of generation unit, where 1 and 0 mean "on" and "off," respectively

$$\text{Cost}_{g,t}^{\text{STU}} = C_g^{\text{STU}} \times \left(1 - x_{g,t-1}^G\right) \times x_{g,t}^G \tag{29}$$

$$\text{Cost}_{g,t}^{\text{SHD}} = C_g^{\text{SHD}} \times x_{g,t-1}^G \times \left(1 - x_{g,t}^G\right). \tag{30}$$

3) Constraints of the System in the Operation Problem:

a) System power balance constraint: The power-demand balance constraint of the system that must be held in every time step of the operation period is presented in (31). Herein, D_t^{EU} and D_t^{PL} are the hourly demands of end users and PEVs fleet, respectively

$$\sum_{g=1}^{Ng} P_{g,t} \times x_{g,t}^G = D_t^{\text{EU}} + D_t^{\text{PL}}. \tag{31}$$

b) System minimum generation constraint: The constraint of minimum power of the system generated by *on* units for every hour of the operation period is presented in (32). In other words, the units, which are *on*, must be able to supply the minimum demand level of the system

$$\sum_{g=1}^{Ng} P_g^{\min} \times x_{g,t}^G \leq D_t^{\text{EU}} + D_t^{\text{PL}}. \tag{32}$$

c) System maximum generation constraint considering spinning reserve: The maximum generation of the power system considering spinning reserve (SR) level provided by the *on* units for every hour of the operation period is presented in (33). In other words, the units, which are *on*, must be able to supply the maximum demand level of the system considering the required SR of the system

$$\sum_{g=1}^{Ng} P_g^{\max} \times x_{g,t}^G \geq D_t^{\text{EU}} + D_t^{\text{PL}} + \text{SR}_t. \tag{33}$$

d) Generation units' power constraint: The maximum and minimum power constraints of every generation unit at every hour of the operation period is presented in

$$P_g^{\min} \leq P_{g,t} \leq P_g^{\max}. \tag{34}$$

e) Generation units' ramp-up rate and ramp-down rate constraints: The ramp-up rate (RUR) and ramp-down rate (RDR) constraints of every generation unit at every hour of the operation period are presented in (35) and (36), respectively

$$\left(P_{g,t+1} - P_{g,t}\right) \leq \text{RUR}_g \tag{35}$$

$$\left(P_{g,t} - P_{g,t+1}\right) \leq \text{RDR}_g. \tag{36}$$

f) Generation units' minimum "off time" and minimum "on time" constraints: The minimum off time (MDT) and minimum on time (MUT) constraints of every generation unit at every hour of the operation period are presented in (37) and (38), respectively

$$\text{OFFT}_{g,t} \geq \text{MDT}_g \tag{37}$$

$$\text{ONT}_{g,t} \geq \text{MUT}_g. \tag{38}$$

TABLE III
TECHNICAL DATA OF DIFFERENT TYPES OF PEVS [36]

-	Nissan Leaf BEV	Chevy Volt 2012 PHV	Toyota Prius 2012 PHV
Performance (kWh/km)	0.21	0.17	0.18
Battery capacity (kWh)	24	16	4.5
Charging voltage (V)	240	240	240

TABLE IV
VALUE OF PARAMETERS OF THE PLANNING PROBLEM

Parameter	Value	Unit	Symbol
Operation period	30	Year	Ny
Load growth rate	0.6	%/year	-
PEV application growth rate	5	%/year	-
Inflation rate	10	%/year	IFR
Interest rate	5	%/year	ITR
Investment cost for parking lot [36]	2200	$/PEV	C^{INV}
Maintenance cost for parking lot	1	%/year	C^{MAINT}
Electricity price [37]	10	Cent/kWh	π^E
Energy not supplied cost	50	Cent/kWh	π^{ENS}
Failure rate of a branch	3	Fault/year	λ
Locating duration of a fault place	1	Hour	τ^{FL}
Repairing duration of a defective branch	3	Hour	τ^{FR}
Acceptable voltage tolerance	5	%	σ^V
Base power in per unit system	10	MVA	MVA^{BASE}

V. SIMULATION AND RESULTS

The simulations are done in MATLAB environment using the Intel Xeon Sever with 64-GB RAM. The number of chromosomes in the population (n_c) and the value of mutation probability of the genes (θ^{Mut}) in the applied GA are considered about 100% and 10%, respectively.

TABLE V
VALUE OF TECHNICAL PARAMETERS OF DF 1. THE DEMAND LEVEL OF END USERS IS RELATED TO MARCH 1ST AT 5 P.M.

First bus	End bus	Latitude of end bus	Longitude of end bus	Active demand (MW)	Reactive demand (MVAR)	Resistance (p.u.)	Reactance (p.u.)	Loading limit of branch (MVA)
1	1	38.9290	-76.9776	0.2	0.1	-	-	-
1	2	38.9289	-76.9799	0.2	0.1	0.0040	0.0020	41
2	3	38.9290	-76.9817	0.5	0.2	0.0075	0.0109	39
3	4	38.9290	-76.9832	0.5	0.2	0.0089	0.0081	36
4	5	38.9290	-76.9851	0.6	0.2	0.0096	0.0084	34
5	6	38.9289	-76.9867	0.6	0.2	0.0078	0.0098	28
6	7	38.9288	-76.9877	0.6	0.2	0.0081	0.0130	26
7	8	38.9288	-76.9888	0.6	0.2	0.0100	0.0102	24
8	9	38.9287	-76.9898	0.6	0.2	0.0099	0.0112	21
9	10	38.9287	-76.9907	0.7	0.3	0.0105	0.0112	19
10	11	38.9286	-76.9927	0.7	0.3	0.0085	0.0028	9
11	12	38.9280	-76.9937	0.7	0.3	0.0093	0.0054	8
12	13	38.9270	-76.9937	0.7	0.3	0.0080	0.0083	7
13	14	38.9260	-76.9939	0.5	0.2	0.0096	0.0100	6
14	15	38.9260	-76.9949	0.9	0.4	0.0118	0.0089	5
15	16	38.9270	-76.9950	0.9	0.4	0.0115	0.0097	4
16	17	38.9279	-76.9950	0.9	0.4	0.0071	0.0050	3
17	18	38.9292	-76.9950	0.9	0.4	0.0071	0.0050	2
10	19	38.9280	-76.9907	0.9	0.4	0.0070	0.0026	9
19	20	38.9271	-76.9906	0.9	0.4	0.0095	0.0031	8
20	21	38.9262	-76.9905	0.9	0.4	0.0109	0.0068	7
21	22	38.9256	-76.9899	1.0	0.4	0.0099	0.0058	5
22	23	38.9256	-76.9885	1.0	0.4	0.0126	0.0064	4
23	24	38.9247	-76.9880	1.0	0.4	0.0111	0.0029	3
24	25	38.9245	-76.9893	1.0	0.4	0.0110	0.0025	2
5	26	38.9284	-76.9860	0.9	0.4	0.0126	0.0064	4
26	27	38.9273	-76.9859	0.9	0.4	0.0111	0.0029	3
27	28	38.9259	-76.9858	0.9	0.4	0.0110	0.0025	2

A. Simulating the Planning Problem of DISCO

1) Primary Data of the System and Problem: In this part, the optimal parking allocation problem is investigated on DF 1 (the first feeder of DISCO 1 as shown in Fig. 1) that includes 28 buses. The total number of PEVs around DF 1 is 600. The technical data of different types of PEVs including Nissan Leaf BEV, Chevy Volt 2012 PHV, and Toyota Prius 2012 PHV are presented in Table III [36]. In the simulation of planning problem of a DISCO, the type of PEVs is considered to be Nissan Leaf BEV. Table IV presents the value of parameters of the planning problem. In addition, Figs. 8 and 9 illustrate the hourly power demand of DF 1 throughout a day (p.u.) and the daily power demand of DF 1 throughout a year (p.u.), respectively.

Moreover, the value of parameters of DF 1 and demand of DF 1 related to March 1st at 5 P.M. are given in Table V. The position of each bus of DF 1 (latitude and longitude) can be seen in Table V.

2) Results: Before allocating the parking lots to DF 1, the value of energy loss and energy not supplied of DF 1 over the planning period are about 2.9173 and 0.1349 million MWh, respectively. Without installing parking lots, PEVs are charged by their nearest buses between 10 A.M. and 11 P.M.

After solving the problem of traffic and grid-based parking lot allocation, it is observed that just one parking lot is allocated to DF 1 considering each of the PEVs behavioral model (power, logarithmic, linear, and exponential models). Table VI presents the detailed results of the planning problem simulation. As can be seen, power model with exponent 0.3 and exponential model (and power model with exponent 3, as well) are the most and the least desirable behavioral models of the PEVs fleet, since the total profit (the difference between the costs before and after the parking lot allocation) of the DISCO 1 are the most and the least, respectively. Regarding the Power model (with exponent 0.3), by installing a parking lot with the size of 756 PEVs in bus 26 and considering 30% discount on the charging fee of PEVs, the energy loss and EENS of DF 1 are decreased about 142 800 and 700 MWh over the operation period, respectively.

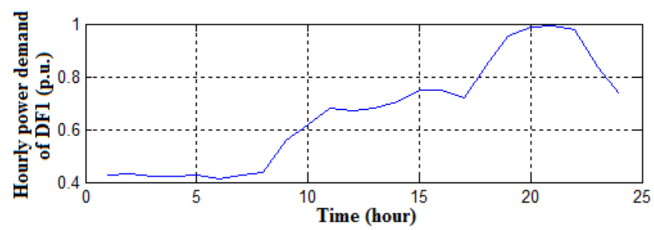

Fig. 8. Hourly power demand of DF 1 (first feeder of DISCO 1) throughout a day (p.u.).

It should be noticed that although the exponential model (and power model with exponent 3, as well) has the least value of energy loss and EENS (and accordingly the least value of cost of energy loss and cost of EENS), these models are not the most favorable model because minimizing the total cost of the local DISCO is the objective function of the planning problem.

This article has been accepted for inclusion in a future issue of this journal. Content is final as presented, with the exception of pagination.

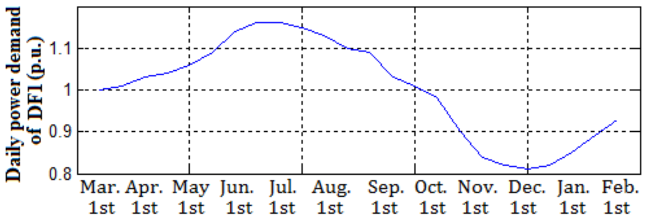

Fig. 9. Daily power demand of DF 1 (first feeder of DISCO 1) throughout a year (p.u.).

TABLE VI
DETAILED RESULTS OF OPTIMAL PARKING LOT ALLOCATION ON DF 1 (FIRST FEEDER OF DISCO 1) CONSIDERING DIFFERENT BEHAVIORAL MODELS FOR THE PEVS' DRIVERS

-	Without parking lot	Pow. (exponent is 0.3)	Log.	Lin.	Exp. or Pow. (exponent is 3)
Optimal discount (%)	0	30	70	90	100
Optimal bus for parking lot	-	26	3	3	2
Optimal size of parking lot (No. of PEVs)	0	756	542	617	686
Energy loss (Million MWh)	2.9173	2.7745	2.7772	2.7592	2.7432
Risk level (Million MWh)	0.1349	0.1342	0.1344	0.1343	0.1342
Investment cost (Million \$)	0	1.6636	1.1928	1.3593	1.5104
Maintenance cost (Million \$)	0	1.0612	0.7608	0.8670	0.9634
Cost of discount (Million \$)	0	6.346	10.617	15.557	19.206
Energy loss cost (Million \$)	620.26	589.91	590.48	586.66	583.26
Risk cost (Million \$)	143.41	142.73	142.87	142.80	142.73
Maximum profit (Million \$)	-	21.963	17.755	16.433	16.002

By investigating the results presented in Table VI, it is observed that the optimal value of discount on charging fee, the optimal location of parking lot, and the optimal size of parking lot are not the same for every behavioral model of the PEVs fleet. In other words, a predetermined value of incentive and default size and location of the parking lot will not result in minimum cost for the local DISCO.

B. Simulating the Operation Problem of GENCO

1) Characteristics of the Generation System: The technical characteristics of generation units including the fuel cost coefficient of generation units, the emission coefficient of generation units, the power limits of the units, the minimum up/down time of units, the RUR and RDR of units, the start-up cost and shut down cost of units, and the initial status of units are presented in Table VII. Positive and negative numbers for the status of units mean the time interval in hour that the unit is in *on* and *off* statuses, respectively.

The hourly demand pattern of the whole power system (shown in Fig. 1) throughout a day (p.u.) and the daily demand pattern of the power system throughout a year (p.u.) are the same as presented in Figs. 8 and 9, respectively. Moreover, the minimum value of SR at every hour of a day is assumed to be about 10% of demand at the same hour. Furthermore, the value of penalty for greenhouse gas emissions is assumed about \$10 per ton based on the California Air Resources Board auction of greenhouse gas emissions [38]. Fig. 10 illustrates the hourly demand of end users, the hourly demand of PEVs fleet, and the hourly demand of power system (shown in Fig. 1). Total number of PEVs in the whole area (supplied by the GENCO) is 16 800 PEVs. The driving patterns of PEVs around every DF are the same as presented in Figs. 2 and 3. Regarding the operation problem of GENCO, the type of PEVs is considered Nissan Leaf BEV. Herein, the value of electricity price for the end users' consumption or charging the PEVs is considered about \$30.35/MWh, which is 10% more than the marginal cost of the generation system (\$27.59/MWh). In other words, the GENCO profits about \$2.76/MWh.

TABLE VII
TECHNICAL CHARACTERISTICS OF GENERATION UNITS

Generation unit	G1	G2	G3	G4	G5
α_1^F (\$/MWh2)	0.00048	0.00031	0.00200	0.00211	0.00398
α_2^F (\$/MWh)	16.19	17.26	16.60	16.50	19.70
α_3^F (\$)	1000	970	700	680	450
α_1^E (Ton/MWh2)	0.0005	0.0005	0.0005	0.0005	0.0010
α_2^E (Ton/MWh)	0.4050	0.4320	0.4150	0.4120	0.4930
α_3^E (Ton)	0.3000	0.4250	0.4500	0.7000	0.7250
P^{min} (MW)	75	75	15	15	15
P^{max} (MW)	200	200	120	100	100
MUT (h)	5	5	5	5	5
MDT (h)	-5	-5	-5	-5	-5
RUR (MW/h)	110	110	80	80	80
RDR (MW/h)	110	110	80	80	80
C^{STU} (\$)	4500	5000	550	560	900
C^{SHD} (\$)	4500	5000	550	560	900
Initial status	+24	+24	+24	+24	+24
Gen. unit	G6	G7	G8	G9	G10
α_1^F (\$/MWh2)	0.00712	0.00790	0.00813	0.00822	0.00873
α_2^F (\$/MWh)	22.26	27.74	25.92	27.27	27.79
α_3^F (\$)	370	480	660	665	670
α_1^E (Ton/MWh2)	0.0020	0.0020	0.0024	0.0025	0.0025
α_2^E (Ton/MWh)	0.5560	1.0940	1.6480	1.6820	1.6950
α_3^E (Ton)	0.9250	1.2000	1.6500	1.6625	1.7750
P^{min} (MW)	10	10	10	10	10
P^{max} (MW)	80	50	25	20	20
MUT (h)	3	1	1	1	1
MDT (h)	-3	-1	-1	-1	-1
RUR (MW/h)	60	20	10	10	10
RDR (MW/h)	60	20	10	10	10
C^{STU} (\$)	170	30	30	30	30
C^{SHD} (\$)	170	30	30	30	30
Initial status	-1	-2	-2	-2	-2

2) Results: The detailed simulation results of the GENCO's operation problem are presented in Table VIII that includes the total daily profit of GENCO without charging management and with optimal charging management of the PEVs fleet considering different behavioral model for the drivers. As can be seen, the GENCO has \$38,101/day profit without charging management of the PEVs fleet. In addition, the charging management of PEVs parked in the parking lots with any behavioral model result in more profit for the GENCO, while the power model with exponent 0.3 leads to the most benefit for it. The results

TABLE VIII
DETAILED RESULTS OF OPTIMAL CHARGING OF PEVS FLEET CONSIDERING DIFFERENT BEHAVIORAL MODELS FOR THEM

-	Without charging management	With optimal charging management of PEVs fleet				
		Pow. (exponent is 0.3)	Log.	Lin.	Pow. (exponent is 3)	Exp.
Optimal discount (%)	0	10	20	30	50	50
Cost of discount ($/day)	0	3096	3649	5559	3860	208
Cost of UC ($/day)	381010	366340	369340	369210	372090	380050
Income of selling electricity ($/day)	419110	419110	419110	419110	419110	419110
Total profit ($/day)	38101	49679	46124	44343	39914	38851

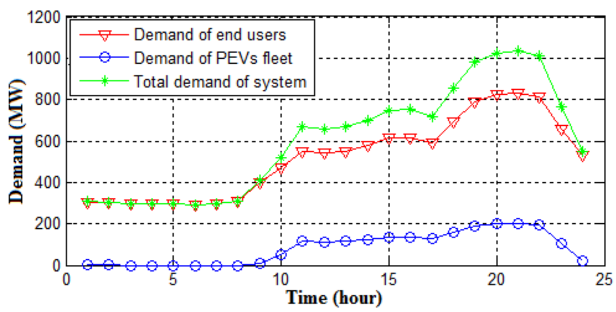

Fig. 10. Hourly demand (MW) of end users, PEVs fleet, and system before charging management.

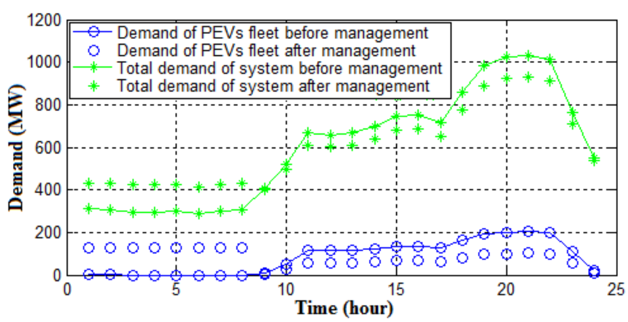

Fig. 11. Hourly demand (MW) of the PEVs and system before and after charging management considering optimal incentive (10% discount on charging fee) and power model (exponent is 0.3) for the drivers' behavior.

TABLE IX
POWER LEVEL OF GENERATION UNITS (MW) AFTER OPTIMAL CHARGING MANAGEMENT OF PEVS FLEET WITH POWER BEHAVIORAL MODEL (EXPONENT IS 0.3)

Hour	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
1	183	75	70	87	15	0	0	0	0	0
2	183	75	70	88	15	0	0	0	0	0
3	180	75	68	86	15	0	0	0	0	0
4	180	75	68	86	15	0	0	0	0	0
5	181	75	69	87	15	0	0	0	0	0
6	178	75	66	83	15	0	0	0	0	0
7	181	75	69	87	15	0	0	0	0	0
8	184	75	72	89	15	0	0	0	0	0
9	169	75	59	77	15	0	0	0	0	0
10	188	75	75	92	15	0	0	0	0	0
11	200	75	105	100	15	0	0	0	0	0
12	200	75	99	100	15	0	0	0	0	0
13	200	75	105	100	15	0	0	0	0	0
14	200	81	120	100	15	0	0	0	0	0
15	200	112	120	100	15	0	0	0	0	0
16	200	114	120	100	15	0	0	0	0	0
17	200	91	120	100	15	0	0	0	0	0
18	200	181	120	100	15	0	0	0	0	0
19	200	200	120	100	68	10	0	0	0	0
20	200	200	120	100	94	10	0	0	0	0
21	200	200	120	100	90	10	10	0	0	0
22	200	200	120	100	87	10	0	0	0	0
23	200	169	120	100	15	0	0	0	0	0
24	200	86	120	100	15	0	0	0	0	0

show the effectiveness of considering incentive (extra credit) for the PEVs' owners in the generation scheduling and unit commitment (UC) problems. Although considering incentive for the drivers imposes extra cost to the GENCO, its overall profit increases because of optimal charging management of PEVs due to deferring the most expensive generation units in the generation scheduling and UC problems. Moreover, as can be seen in Table VIII, the value of incentive is not the same for every model. In other words, knowing the behavioral model of drivers is an important factor.

Fig. 11 illustrates the hourly demand (MW) of PEVs and system before and after charging management considering optimal incentive (10% discount on charging fee) and power model (exponent is 0.3) for the drivers' behavior. As can be seen, one part of PEVs' demand is shifted from the peak period to the valley period that affects the demand of system in the similar pattern.

The hourly generation level of units after optimal charging management of the PEVs (parked in parking lots) considering power model (with exponent of 0.3) are presented in Table IX. As can be seen, due to optimal charging management of the PEVs, some of the most expensive units (G7–G10) are shut down, operation of one of them (G6) is decreased, and operation of the less expensive generation units (G1–G5) are increased in the valley period.

VI. CONCLUSION

In this paper, traffic and grid-based parking lot allocation and charging management of PEVs fleet were investigated in the planning problem of DISCOs and operation problem of a GENCO, respectively. Herein, the driving pattern and behavioral model of drivers were considered in both planning and operation problems.

In the planning problem, each DISCO allocated parking lots to the optimal location of the electrical feeders to minimize the total cost of planning problem over the given planning time horizon by minimizing the power loss and EENS of the feeders. In addition, in the operation problem, the GENCO optimally managed the charging time of PEVs parked in the parking lots to maximize its daily profit by deferring the more expensive and pollutant generation units.

Among different behavioral models of the drivers, the power model (with exponent 0.3) and exponential model, as the interested and reluctant behavior model with respect to the value of incentive, resulted in the most and the least favorable outcomes for every DISCO and GENCO.

It was proven that the drivers' behavioral model, their driving patterns, and even the type of PEVs can remarkably affect the outcomes of both planning and operation problems. In other words, these factors affected the optimal sizes and locations of the parking lots in the planning problem of DISCO, optimal value of incentive in both planning and operation problems of DISCO and GENCO, and minimum cost of DISCO and maximum profit of GENCO. Therefore, these factors must be modeled precisely in the traffic and grid-based parking lot allocation and charging management problems.

For the future studies, it is suggested to consider energy management of the end users (along with charging management of PEVs) in the operation problem of the GENCO and load model of the end users (residential, commercial, and industrial customers) in the planning problem of the DISCO.

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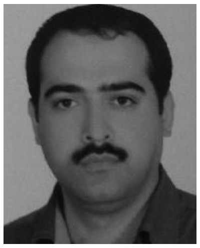

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