Chapter 11
Optimal Incentive Plans for Plug-in Electric Vehicles

Mehdi Rahmani-Andebili, Mahmud Fotuhi Firuzabad and Moein Moeini-Aghtaie

Abstract This chapter investigates implementation of some parking lots for a plug-in electric vehicle (PEV) aggregator to participate in energy market. Herein, behaviors of the PEVs' drivers regarding their cooperation with the aggregator with respect to the introduced incentive (value of discount on charging fee of PEVs) are modeled. The considered incentive includes the value of discount on the charging fee of PEVs' batteries. In addition, the capability of parking lots for transacting electrical energy is modeled based on the hourly arrival/departure time of PEVs to/from the parking lots and the hourly state of charge (SOC) of PEVs' batteries. Also, the degradation of PEVs' batteries is modeled based on the effective ampere-hours throughput of the PEVs' batteries due to vehicle-to-grid (V2G). Moreover, the economic factors such as inflation and interest rates and the technical factors including the PEVs' batteries power limit, the depth of discharge (DOD) constraint of PEVs' batteries, the yearly maintenance of parking lot, and the yearly replacement rate of the conventional vehicles with the PEVs are taken into consideration in the problem over the definite planning horizon. Furthermore, due to variability and uncertainties involved with the energy market prices and the PEVs' drivers' behavior, the planning problem is solved stochastically.

Keywords Modeling capability of parking lot for energy transaction
Modeling behavior of PEVs' drivers · Modeling life loss of PEVs' batteries
Optimal incentive plans · Stochastic optimization

M. Rahmani-Andebili (✉) · M. F. Firuzabad
Department of Electrical Engineering, Sharif University of Technology,
Tehran, Iran
e-mail: mehdi.rahmani.andebili@gmail.com

M. F. Firuzabad
e-mail: fotuhi@sharif.edu

M. Moeini-Aghtaie
Sharif Energy Research Institute, Sharif University of Technology,
Tehran, Iran
e-mail: moeini@sharif.edu

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11.1 Introduction

Replacing internal combustion vehicles with plug-in electric vehicles (PEVs) is a promising strategy to calm the energy security and environmental issues, since PEVs can be charged by the electricity generated by renewables or clean energy resources [1]. Nowadays, governments around the world call for the deployment of PEVs and hybrid PEVs [2–5]. 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 [6]. Based on the studies presented in [7, 8], PEVs utilization is being increased rapidly in some developed countries due to the advancement of battery technology. Recently, the role of energy storage has become more important with development of smart grids [9]. An individual PEV has a trifle impact on an electric distribution network; however, aggregation of a large number of PEVs can noticeably affect the network performance [10, 11]. Through effective coordination and communication technologies, the PEVs can be considered as the mobile energy storage and play an important role in the smart grids [12]. Nonetheless, replacing conventional vehicles with electric ones may put the network at risk and bring about new issues such as system overload and spikes in energy market prices due to uncontrolled charging of the PEVs' batteries [13, 14]. Herein, a PEV aggregator can play an effective role to calm the above mentioned issues, since it can motivate the PEVs' drivers (by introducing a variety of incentives to them) to park their vehicles in the specific locations (parking lots) to manage and coordinate the charging time of the PEVs' batteries. By implementing this strategy, the aggregator can take part in different power markets and provide benefit for itself, for the PEVs' drivers, and also for the network.

It has been reported that private vehicles are parked at parking lots in idle state for more than 90% during a day [15]. Therefore, the PEVs as the energy storage units have a huge potential for doing energy transactions in power market. Since every individual PEV's driver is not able to participate in energy market and compete with other powerful market players, due to a low power capacity, a PEV aggregator is introduced to aggregate them [16]. A comprehensive literature overview regarding the economic and technical management of a PEV aggregator has been given in [17]. In [18], the methods for optimal charging management of PEVs have been reviewed. Moreover, advantages and disadvantages, and also economic and technical characteristics of V2G technology have been discussed in [10, 19–21].

In [22], the feasibility of utilizing Ontario's grid for charging PEVs has been analyzed applying a zonal model of Ontario's transmission network and base-load generation capacities for the period of 2009–2025. In [23, 24], real-time load management strategies for coordinating the charging time of PEVs for minimum energy losses and voltage control have been proposed. In [25], reliability assessment of network considering PEVs fleet has been studied. In [26], feeder reconfiguration has been used for coordinating V2G of PEVs in a stochastic framework.

In [27], energy management of one PEV connected to a smart home has been investigated.

Presence of the PEV aggregator in different power markets has been investigated in several studies [28–37]. In [28–30], PEVs have been utilized to support smart grids by offering ancillary service including frequency regulation. In [31, 32], participation of the PEVs in the spinning reserve market has been studied. In [33], the PEV charging scheduling by an aggregator in a day-ahead energy market applying mixed integer linear programming (MILP) has been investigated. In [34], an optimal bidding strategy of a PEV aggregator participating in day-ahead energy and regulation markets using stochastic optimization has been presented. The authors in [35] have presented a method to manage the PEVs charging in real-time for participation of the PEV aggregators in the energy market. In [36], solar parking lots have been sized and allocated in an electrical distribution system based on their optimal power factor applying quantum annealing.

In spite of the numerous studies in the literature about PEVs and their aggregator, the behavior of PEVs' drivers regarding their cooperation level with the aggregator with respect to the incentive plans has not been modeled. In this chapter, in addition to the PEVs' drivers' responsiveness level, capability of parking lots for energy transaction in energy market is modeled. Moreover, model of a battery life loss presented in [37] is applied for the PEVs' batteries in the problem simulation.

11.2 Modeling Capability of the Parking Lots for Energy Transaction

Figure 11.1 illustrates the schematic diagram of a PEV's battery indicating its capacity, state of charge (SOC) level, and the defined depth of discharge (DOD) limit. As can be seen, the value of available grid-to-vehicle (G2V) power can be determined based on the difference between the PEV's battery capacity and its SOC level. Also, the value of available vehicle-to-grid (V2G) power can be calculated based on the difference between the SOC level of the PEV's battery and the given DOD limit for the PEV's battery. Therefore, in a parking lot, at every

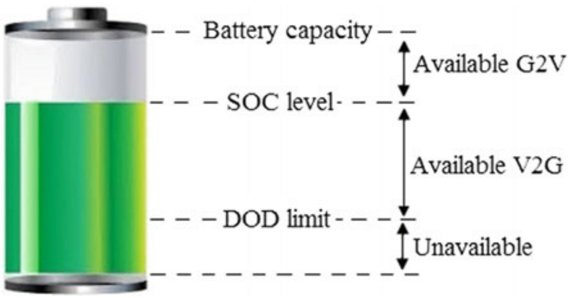

Fig. 11.1 Schematic diagram of a PEV's battery indicating its capacity, SOC level, and the defined DOD limit

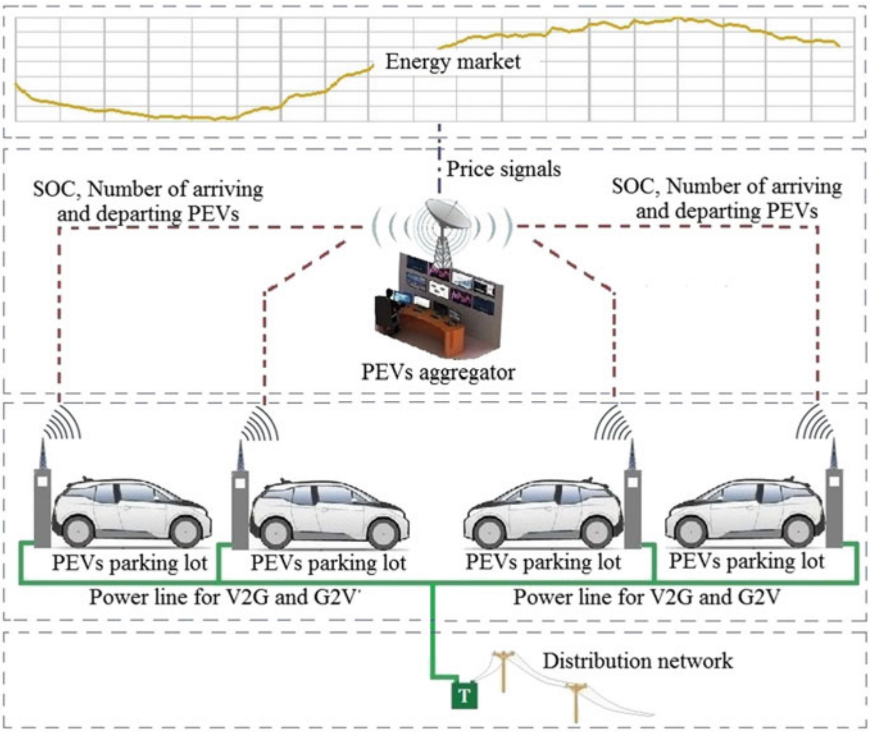

Fig. 11.2 The aggregator as an intermediate agent between the energy market and the PEVs connected to the distribution network

hour, the total value of available V2G and G2V powers can be computed by knowing the values of some parameters concerned with the PEVs' drivers' behavior. These parameters include the number of PEVs arriving to the parking lots, the number of PEVs departing from the parking lots, and the SOC level of the batteries of the PEVs arrived to the parking lots [31]. Figure 11.2 shows the role of aggregator as an intermediate agent between the energy market and the PEVs connected to the distribution system through the parking lots. Based on this, the aggregator can participate in the energy market transactions considering the price signals and the total available V2G and G2V powers of the parking lots.

The PEVs' drivers' behavior and the energy market price are uncertain and they may have a wide range of variability. Nevertheless, the variability range of every uncertain parameter can be estimated based on the hourly historical data gathered by the aggregator. Figure 11.3 shows the upper and lower bands for the possible value of an uncertain parameter at every hour of the day.

Herein, the data gathered for every uncertain parameter and for every hour of a day are fitted on a Gaussian distribution function as the most appropriate distribution function, as can be seen in Fig. 11.4 [31]. Then, in order to address the

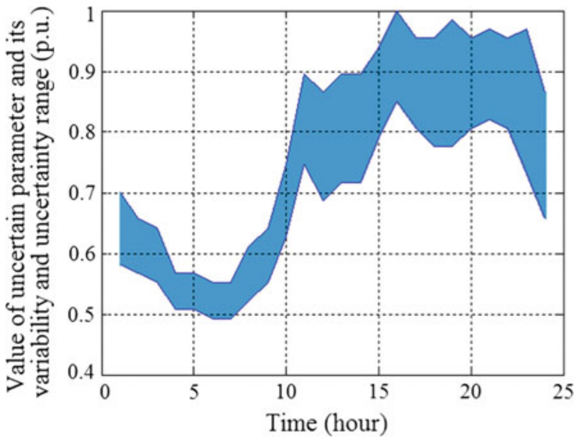

Fig. 11.3 The upper and lower bands for the possible value of an uncertain parameter at every hour of the day

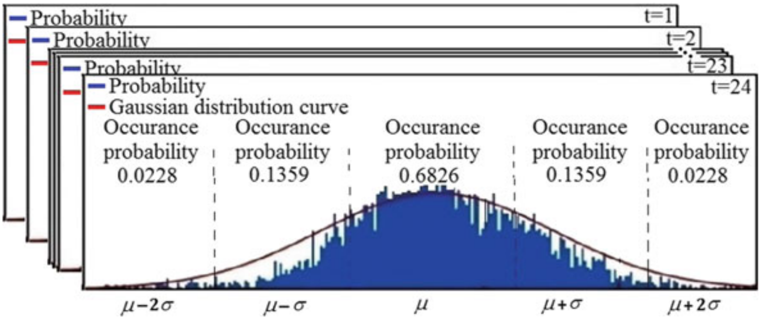

Fig. 11.4 Considering five distinct values for each uncertain parameter at every hour of the day

prediction uncertainty, five distinct values are considered for every uncertain parameter with the probabilities 0.0228, 0.1359, 0.6826, 0.1359, and 0.0228 according to the areas in the related Gaussian distribution function concerned with the $\mu - 2\sigma$, $\mu - \sigma$, μ, $\mu + \sigma$, $\mu + 2\sigma$. Figure 11.4 graphically illustrates the above mentioned approach. After that, in order to investigate the problem stochastically, 15 comprehensive and diverse scenarios are defined for the hourly value of each uncertain parameter throughout the day, as can be seen in Fig. 11.5. These scenarios have been defined arbitrarily; however, it has been tried to design the diverse and comprehensive scenarios to include the most probable scenarios and eliminate the similar ones.

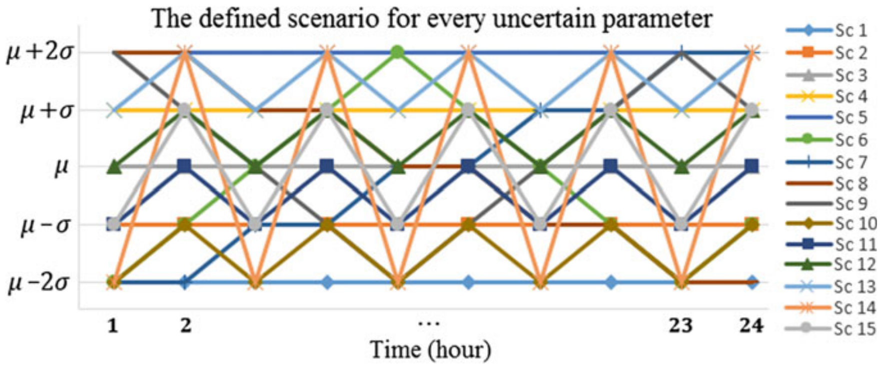

Fig. 11.5 The considered scenarios for the values of each uncertain parameter over the day

11.3 Modeling Cooperation Between PEVs' Drivers and Aggregator

In this part, cooperation between PEVs' drivers (ξ) and the aggregator with respect to the value of discount on charging fee (ψ) is modeled applying linear, power, logarithmic, and exponential functions. As can be seen in (11.1)–(11.4) in Table 11.1, these models have been designed for 100% cooperation of the PEVs' drivers under free charging and no cooperation under zero discount on the charging fee. The cooperation percentage curves related to the linear model, power model with exponents 0.1, 0.3, 1.5, and 3, logarithmic model, and exponential model respect to value of discount on charging fee for the range of (0%, 100%) are illustrated in Fig. 11.6. As can be seen, the considered models are very comprehensive, since they cover all the two dimensional space. Therefore, all the possible linear and nonlinear behaviors of the PEVs' drivers are taken into consideration.

Table 11.1 Models for cooperation percentage of the PEVs' drivers with the aggregator as the function of discount on charging fee

Model	Cooperation percentage of PEVs' drivers (%)	
Linear	$\xi_{Lin} = \psi$	(11.1)
Power	$\xi_{Pow} = 100 \times \left(\frac{\psi}{100}\right)^n, \quad n \in \mathbb{R}$	(11.2)
Exponential	$\xi_{Exp} = 100 \times e^{M \times \left(\frac{\psi}{100} - 1\right)}, \quad M \gg 1$	(11.3)
Logarithmic	$\xi_{Log} = 100 \times ln\left(\frac{\psi}{100} \times (\exp(1) - 1) + 1\right)$	(11.4)

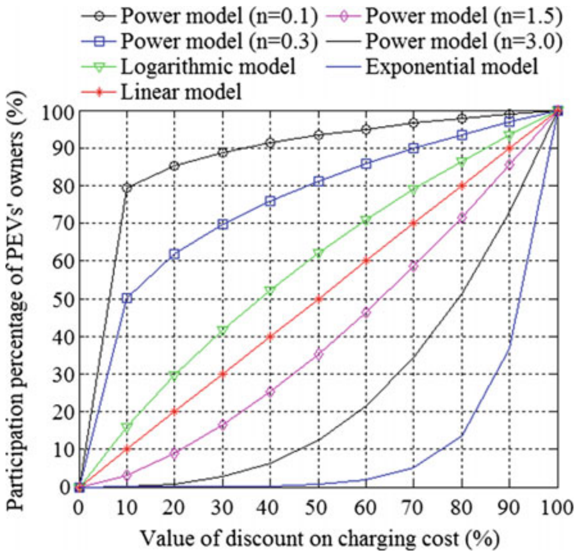

Fig. 11.6 Curves of cooperation percentage of the PEVs' drivers with the aggregator respect to value of the discount on charging fee assuming various linear and nonlinear models

11.4 Modeling PEV's Battery Life Loss Cost Due to V2G

Herein, the value of life loss cost or aging cost of a PEV's battery is modeled based on the effective ampere-hours throughput of the PEV's battery due to the V2G actions [37], as can be seen in (11.5). In (11.5), $Ah_{b,t}$ is the ampere-hours throughput of the PEV's battery due to V2G at hour t, Ah_b^{Tot} is the total cumulative ampere-hours throughput of the PEV's battery in its life cycle, $Price^{Bat}$ is the price of a PEVs' battery, and λ, as the effective weighting factor, is determined using the model introduced in [37]. As can be seen in Fig. 11.7, in the presented model, the value of the effective weighting factor has a nonlinear relationship with the SOC level of the PEV's battery. For instance, at SOC of 50%, removing 1 A h from the PEV's battery is equivalent to removing 1.3 A h from the total cumulative ampere-hours throughput of the PEV's battery. However, at SOC of 100%,

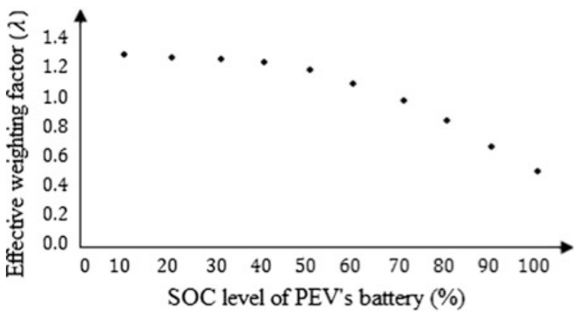

Fig. 11.7 Relationship between effective weighting factor and SOC level of a PEV's battery [37]

removing 1 A h results in only about 0.55 A h reduction. This reality indicates that the PEVs' batteries should be operated at high SOC levels to optimize their lifetime.

$$Cost^{LL}(\mathrm{t}) = \frac{\lambda \times Ah_b(t)}{Ah_b^{Tot}} \times Price^{Bat} \tag{11.5}$$

11.5 Planning Problem Formulation

In this chapter, the PEV aggregator builds and implements some parking lots in a residential area to participate in the energy market transactions to maximize its profit over the given planning horizon.

11.5.1 Objective Function

Different terms of the objective function include the income resulted from transactions in energy market, investment cost for structuring and implementing parking lots and equipping them, yearly maintenance cost of the parking lots, aging cost of the PEVs' batteries due to V2G, and cost of considering discount on the charging fee of the PEVs' batteries. Herein, some economic factors such as inflation and interest rates and several technical factors including the PEVs' batteries' power limit, DOD constraint of the PEVs' batteries, PEVs' batteries aging due to V2G, yearly maintenance of the parking lot, and yearly replacement rate of internal combustion engine based vehicles with electric ones are considered in the problem. Furthermore, due to variability and uncertainties involved with the energy market prices and the PEVs' drivers' behavior, the planning problem is solved stochastically considering several comprehensive scenarios for every uncertain parameter. The uncertain parameters include the energy market price, the number of PEVs arriving to the parking lot, the number of PEVs departing from the parking lot, and the SOC level of the PEVs' batteries arrived to the parking lots. The objective function of the planning problem is presented in (11.6).

$$\begin{aligned} OF_{pp} = Max\{ & -Cost_{Tot}^{Inv} - PWV\left(Cost^{M}\right) + PWV\left(Income^{T}\right) - PWV\left(Cost^{BA}\right) \\ & -PWV\left(Cost^{Inc}\right)\} \end{aligned} \tag{11.6}$$

The first term of the objective function is related to the total investment cost for structuring the parking lots and equipping them and the second term of the objective function is concerned with the present worth value of maintenance cost of the parking lots over the planning period.

Table 11.2 The binary variables used to code the decisions of the aggregator

u^a	u^b	Decision
0	0	Idle
	1	
1	0	G2V
	1	V2G

The third term of the objective function is related to the present worth value of the aggregator's income over the planning period because of optimal transactions in the energy market by doing optimal V2G and G2V actions considering all the defined scenarios for the uncertain parameters. Equation (11.7) presents the deterministic value of aggregator's income per year. As can be seen in Table 11.2, u^a and u^b as the binary numbers are used to code the decision of the aggregator for being in idle state or performing one of the V2G or G2V actions. Equation (11.8) presents the number of PEVs' drivers who are willing to cooperate with the aggregator and connect their PEVs to the parking lots. Herein, Nev_{Tot} indicates the total number of PEVs in the area. Also, ξ_{Model}, as the cooperation percentage of the PEVs' drivers with the aggregator respect to value of the discount on charging fee (ψ), is determined using Table 11.1 or Fig. 11.6. Equations (11.9) and (11.10) present the stochastic value of aggregator's income per year and the present worth value of aggregator's income over the planning period, respectively.

$$Income_y^T = \sum_{d=1}^{365}\sum_{t=1}^{24} u^a(t) \times \left(u^b(t) \times \pi^E(t) \sum_{ev=1}^{Nev} V2G_{ev,y,d}(t) - \left(1 - u^b(t)\right) \times \pi^E(t) \sum_{ev=1}^{Nev} G2V_{ev,y,d}(t) \right) \tag{11.7}$$

$$Nev = Nev_{Tot} \times \xi_{Model} \tag{11.8}$$

$$Stoch\left(Income_y^T\right) = \sum_{i \in S^{\pi}} \sum_{j \in S^{Narr}} \sum_{k \in S^{Ndep}} \sum_{l \in S^{SOC}} \left\{Income_y^T\right\} \times Pr_i^{\pi} \times Pr_j^{Narr} \times Pr_k^{Ndep} \times Pr_l^{SOC} \tag{11.9}$$

$$PWV\left(Stoch\left(Income_y^T\right)\right) = \sum_{y=1}^{pp} Stoch\left(Income_y^T\right) \times \left(\frac{1+IFR}{1+ITR}\right)^y \tag{11.10}$$

The forth term of the objective function is related to the present worth value of aging cost of the PEVs' batteries over the planning period due to V2G actions considering all the defined scenarios for the uncertain parameters. Equations (11.11) and (11.13) give the deterministic value of yearly aging cost of the PEVs' batteries, the stochastic value of yearly aging cost of the PEVs' batteries, and the present worth value of aging cost of the PEVs' batteries over the planning period, respectively.

$$Cost_y^{BA} = \sum_{d=1}^{365}\sum_{t=1}^{24} u^a(t) \times u^b(t) \sum_{ev=1}^{Nev} Cost_{ev,y,d}^{LL}(t) \tag{11.11}$$

$$Stoch\left(Cost_y^{BA}\right) = \sum_{i\in S^{\pi}}\sum_{j\in S^{Narr}}\sum_{k\in S^{Ndep}}\sum_{l\in S^{SOC}} \left\{Cost_y^{BA}\right\} \times Pr_i^{\pi} \times Pr_j^{Narr} \times Pr_k^{Ndep} \times Pr_l^{SOC} \tag{11.12}$$

$$PWV\left(Cost^{BA}\right) = \sum_{y=1}^{pp} Stoch\left(Cost_y^{BA}\right) \times \left(\frac{1+IFR}{1+ITR}\right)^y \tag{11.13}$$

The fifth term of the objective function is related to the present worth value of discount on charging fee over the planning period considering all the scenarios defined for the uncertain parameters. Herein, it is assumed that the cooperative drivers' PEVs' batteries will be charged from the initial SOC level to the full charge considering discount on the charging fee. Equations (11.14) and (11.16) present the deterministic value of yearly incentive paid to the drivers, the stochastic value of yearly incentive paid to the drivers, and the present worth value of incentive paid to the drivers over the planning period, respectively.

$$Cost_y^{Inc} = \sum_{d=1}^{365}\sum_{t=1}^{24}\sum_{ev=1}^{Nev}\left(1 - \frac{SOC_{ev,y,d}^{arr}(t)}{100}\right) \times P_{ev} \times \frac{\psi}{100} \times \pi^{ch} \tag{11.14}$$

$$Stoch\left(Cost_y^{Inc}\right) = \sum_{i\in S^{\pi}}\sum_{j\in S^{Narr}}\sum_{k\in S^{Ndep}}\sum_{l\in S^{SOC}} \left\{Cost_y^{Inc}\right\} \times Pr_i^{\pi} \times Pr_j^{Narr} \times Pr_k^{Ndep} \times Pr_l^{SOC} \tag{11.15}$$

$$PWV\left(Cost^{Inc}\right) = \sum_{y=1}^{pp} Stoch\left(Cost_y^{Inc}\right) \times \left(\frac{1+IFR}{1+ITR}\right)^y \tag{11.16}$$

11.5.2 Constraints

The first constraint of the problem relates to supplying each PEV after daily V2G and G2V actions. As can be seen in (11.7), the daily energy demand of each PEV must be supplied considering the daily cumulative values of G2V and V2G done by the PEV.

$$\sum_{t=1}^{24} u^a(t) \times \left(1 - u^b(t)\right) \times G2V_{ev,y,d}(t) - \sum_{t=1}^{24} u^a(t) \times u^b(t) \times V2G_{ev,y,d}(t) = \sum_{t=1}^{24} \left(1 - \frac{SOC_{ev,y,d}^{arr}(t)}{100}\right) \times P_{ev} \tag{11.17}$$

$\forall i \in S^{\pi}, \forall j \in S^{Narr}, \forall k \in S^{Ndep}, \forall l \in S^{SOC}, \forall ev = 1, \ldots, Nev, \forall y = 1, \ldots, pp, \forall d = 1, \ldots, 365$

The second and third constraints concerned with the allowable injectable power of every PEV's battery into the grid and the allowable injectable power of the grid into every PEV's battery, respectively. These constraints must be regarded at every hour of the planning period and in every scenario.

$$V2G_{ev,y,d}(t) = P_{ev} \tag{11.18}$$

$$G2V_{ev,y,d}(t) = P_{ev} \tag{11.19}$$

$\forall i \in S^{\pi}, \forall j \in S^{Narr}, \forall k \in S^{Ndep}, \forall l \in S^{SOC}, \forall ev = 1, \ldots, Nev, \forall y = 1, \ldots, pp, \forall d = 1, \ldots, 365, \forall t = 1, \ldots, 24$

The forth constraint is related to the obligation of the aggregator respect to the PEVs' drivers. In order to prolong the lifetime of PEVs' batteries, at every hour of the planning period and in every defined scenario, the battery of every PEV must not be discharged more than the defined DOD limit. In addition, the SOC level cannot be considered more than 100%.

$$DOD^{limit} \leq SOC_{ev,y,d}(t) \leq 100 \tag{11.20}$$

$\forall i \in S^{\pi}, \forall j \in S^{Narr}, \forall k \in S^{Ndep}, \forall l \in S^{SOC}, \forall ev = 1, \ldots, Nev, \forall y = 1, \ldots, pp, \forall d = 1, \ldots, 365, \forall t = 1, \ldots, 24$

11.6 Proposed Optimization Technique

In this chapter, the problem is solved by applying genetic algorithm (GA) as the optimization methodology [38]. Other optimization algorithms could be used in this problem, however capability of GA for parallel optimization and its competence in complex and nonlinear environments are the main reasons for utilization of GA in this problem.

Variables of the optimization problem include u^a and u^b (the indicator of the aggregator's decision regarding being in idle state or performing one of the V2G or G2V actions) at every hour of a day. Based on this, every chromosome in the

Fig. 11.8 Structure of the defined chromosome

Transaction matrix

	u^a	u^b
Hour 1	0 or 1	0 or 1
Hour 2	0 or 1	0 or 1
⋮	⋮	⋮
Hour t	0 or 1	0 or 1
⋮	⋮	⋮
Hour 24	0 or 1	0 or 1

population is defined as the transaction matrix with 24×2 as its dimensions. Figure 11.8 illustrates the structure of the defined chromosome. Herein, the value of net profit of the aggregator over the planning period is defined as the value of fitness of the chromosome. Different steps for applying GA in the problem are presented and described below.

Step 1: Obtaining primary data

Parameters for applying GA: These parameters includes mutation probability of the genes $(P^{Mutation})$ and the size of population (N_{ch}).

Parameters of the problem: The values of all the problem parameters and the initial data are obtained. Moreover, the value of discount on charging fee and the cooperation model of the PEVs' drivers with the aggregator are determined.

Initial population: The chromosomes of the population are initialized with random binary values.

Step 2: Updating the population

Applying crossover operator: Two crossover points are randomly selected for every pair chromosomes, and then, crossover operator is applied on every two chromosomes of the population to reproduce two new chromosomes as the off-spring, as can be seen in Fig. 11.9.

Applying mutation operator: This operator is applied on every gene of every chromosome of the population with the definite probability $P^{Mutation}$.

Step 3: Selecting new population

Evaluating fitness of the chromosomes: For every chromosome, the problem is run and if all the constraints are satisfied, the fitness of chromosome is measured.

Applying selection process: As can be seen in (11.21), new chromosomes are selected through the probabilistic fitness-based selection process, where the fitter chromosomes are more likely to be chosen. The value of selection probability of every chromosome is calculated using (11.22) which is proportional to the fitness of chromosome.

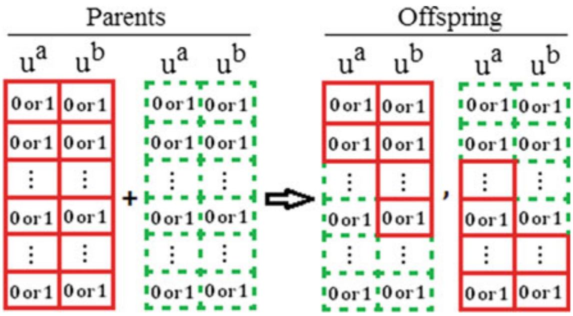

Fig. 11.9 Applying crossover operator on two chromosomes for reproducing new chromosomes

$$a_{ch} = \begin{cases} 1 & P_{ch}^{Selection} > r_{ch} \\ 0 & P_{ch}^{Selection} < r_{ch} \end{cases} \tag{11.21}$$

$$P_{ch}^{Selection} = \frac{f_{ch}}{Max(S^f)}, \quad S^f = \{f_1, \ldots, f_{ch}, \ldots, f_{Nch}\} \tag{11.22}$$

Step 4: Checking termination criterion

Herein, the convergence status of the optimization procedure is checked. Based on this, the values of improvements in fitness of the chromosomes of the old and new populations are measured and if there are no significant improvements (1% of the fitness of chromosome) in them, the optimization process is finished, otherwise, the algorithm is continued form Step 2.

Step 5: Introducing the outcomes

The consequences include the best fitted chromosome as the optimal transaction matrix.

This process is repeated for all possible values of discount on charging fee with a 10% step, and also for every cooperation model of the PEVs' drivers with the aggregator. After that, the optimal incentive, the optimal cooperation percentage of the PEVs' drivers with the aggregator, and the maximum net profit of the aggregator over the given time horizon are determined.

11.7 Numerical Studies

11.7.1 Primary Data

The initial data and the value of problem parameters are presented in Table 11.3. Figures 11.10, 11.11, 11.12 and 11.13 illustrate the variability range of the energy market price and the uncertain parameters of the PEVs' drivers' behavior including the number of PEVs arriving to the parking lot, the number of PEVs departing from the parking lot, and the SOC level of the PEVs' batteries arrived to the parking lots

Table 11.3 The initial data and parameters of the problem

Planning period (y)	20	Total cumulative ampere-hours throughput of a PEV's battery in its life cycle	700,000
Inflation rate (%/y)	10	Power of PEV's battery (kW)[a]	10
Interest rate (%/y)	15	Capacity of PEV's battery (kWh)[a]	50
Investment cost for a parking lot ($)	100,000	Charging/discharging voltage level (volt)[a]	480
Maintenance cost for a parking lot ($/y)	1000	DOD^{limit} based on the contract (%)	20
Size of a parking lot	200	Growth rate of PEVs (%/y)	1
Total number of parking lots	10	Charging fee ($/kWh)	0.043
PEVs' battery price ($)	10,000	Size of population in GA	100
Mutation probability of genes	0.05		

[a]TESLA, level 3 charging

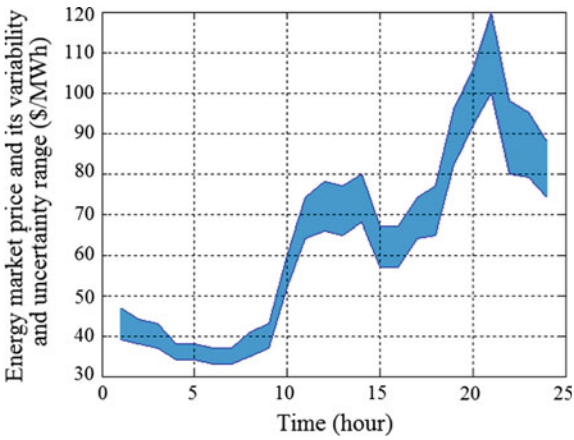

Fig. 11.10 The hourly upper and lower bands for the possible energy market price

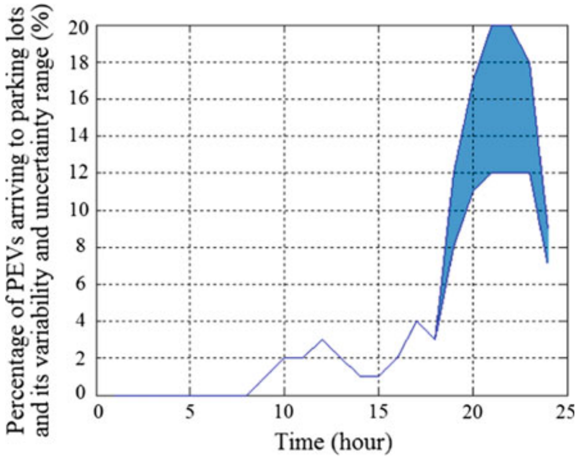

Fig. 11.11 The hourly upper and lower bands for the possible percentage of PEVs arriving to the parking lots

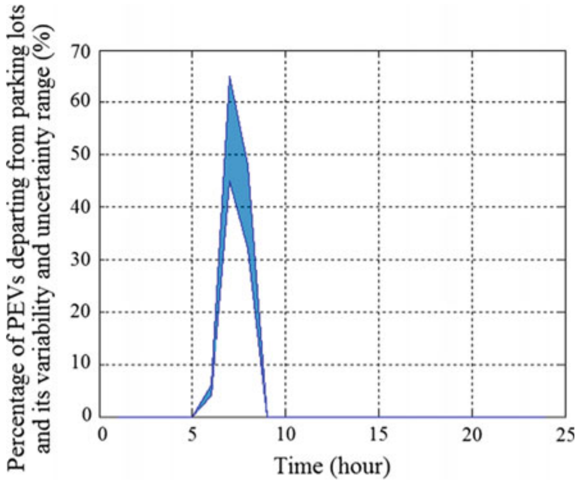

Fig. 11.12 The hourly upper and lower bands for the possible percentage of PEVs departing from the parking lots

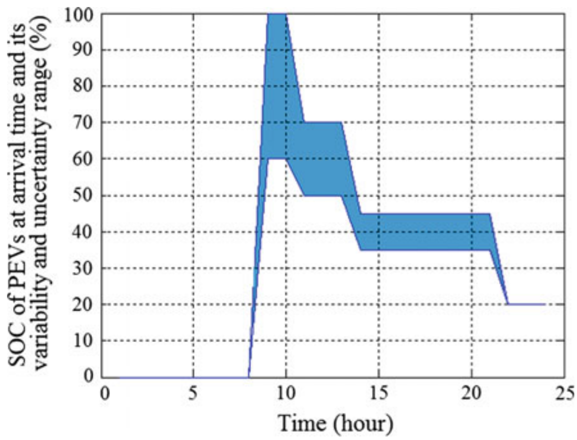

Fig. 11.13 The hourly upper and lower bands for the possible level of SOC of the PEVs batteries

Table 11.4 The average value and the standard deviation of Gaussian distribution functions related to the uncertain parameters

Hour	Arriving PEVs (%)		Departing PEVs (%)		SOC (%)		Energy market price ($/MWh)	
	μ	σ	μ	σ	μ	σ	μ	σ
1	0	0	0	0	0	0	43	4
2	0	0	0	0	0	0	41	3
3	0	0	0	0	0	0	40	3
4	0	0	0	0	0	0	36	2
5	0	0	0	0	0	0	36	2
6	0	0	5	1	0	0	35	2
7	0	0	55	10	0	0	35	2
8	0	0	40	8	0	0	38	3
9	1	0	0	0	80	20	40	3
10	2	0	0	0	80	20	56	4
11	2	0	0	0	60	10	69	5
12	3	0	0	0	60	10	72	6
13	2	0	0	0	60	10	71	6
14	1	0	0	0	40	5	74	6
15	1	0	0	0	40	5	62	5
16	2	0	0	0	40	5	62	5
17	4	0	0	0	40	5	69	5
18	3	0	0	0	40	5	71	6
19	10	2	0	0	40	5	89	7
20	14	3	0	0	40	5	99	7
21	16	4	0	0	40	5	110	10
22	16	4	0	0	20	0	89	9
23	15	3	0	0	20	0	87	8
24	8	1	0	0	20	0	81	7

at every hour of the day. The average value and the standard deviation of the Gaussian distribution functions related to the energy market price and the uncertain parameters of the PEVs' drivers' behavior at every hour of the day are presented in Table 11.4. Also, the scenarios considered in the problem simulation are based on the details presented in Fig. 11.5.

11.7.2 Results

The curves related to the value of aggregator's net benefit over the planning period with respect to the discount value are illustrated in Fig. 11.14 for every cooperation

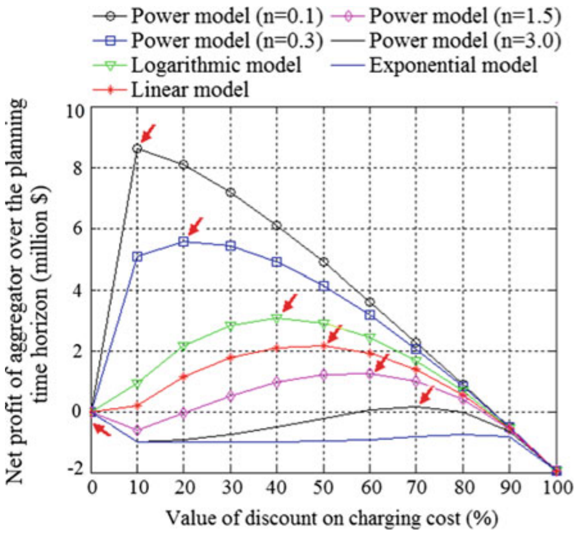

Fig. 11.14 Aggregator's net profit curves versus the value of discount on charging fee considering a variety of cooperation models (the arrows show the peak point of the curves)

model. As can be seen, by changing the value of discount on the charging fee, the profit of aggregator over the planning horizon is changed. However, increasing the value of incentive for raising motivation of the PEVs' drivers is not always effective, since the benefit curves do not have pure ascending trend. In other words, the curves are nonlinear and there is just one optimal value for the incentive in every model. Moreover, the optimal value of the incentive is different in every cooperation model. Thus, it can be concluded that assuming an incidental value of incentive would not lead to the maximum profit of aggregator and even it may result in detriment for the aggregator in some models.

The detailed results of the problem simulation including optimal value of incentive, cooperation percentage of the PEVs' drivers with the aggregator, the values of income and cost terms of the objective function, and the value of maximum benefit of the aggregator over the given horizon for every model are presented in Table 11.5. As can be seen, the cooperation between the aggregator and the PEVs' drivers with power behavioral model (n = 0.1) results in maximum benefit for the aggregator. In addition, no profit is achieved for the aggregator due to cooperation of the aggregator with the PEVs' drivers with exponential behavioral model. Therefore, this cooperation is not practical and beneficial.

Table 11.5 Detailed results of the problem simulation

	Optimal discount (%)	PEVs cooperation percentage (%)	Investment cost ($/pp)	Maintenance cost ($/pp)	Batteries aging cost ($/pp)	Incentive cost ($/pp)	Income of transaction ($/pp)	Net benefit ($/pp)
Power model with n = 0.1	10	79	1,000,000	10,000	7,008,300	1,154,200	17,794,000	8,621,500
Power model with n = 0.3	20	61	1,000,000	10,000	5,444,000	1,793,100	13,823,000	5,575,900
Logarithmic model	40	52	1,000,000	10,000	4,615,600	3,040,500	11,719,000	3,052,900
Linear model	50	50	1,000,000	10,000	4,411,400	3,632,500	11,201,000	2,147,100
Power model with n = 1.5	60	46	1,000,000	10,000	4,100,500	4,051,800	10,411,000	1,248,700
Power model with n = 3	70	34	1,000,000	10,000	3,026,200	3,488,700	7,683,800	158,900
Exponential model	0	0	1,000,000	10,000	0	0	0	0

Appendix

The notation used throughout the chapter is listed below:

Problem parameters and Variables

$Ah_b(.)$	Ampere-hours throughput of the PEV's battery due to V2G
Ah_b^{Tot}	Total cumulative ampere-hours throughput of the PEV's battery in its life cycle
$Cost^{LL}(.)$	Battery life loss cost due to V2G
$Cost_{Tot}^{Inv}$	Total investment cost for structuring the parking lots and equipping them
$Cost^{M}$	Maintenance cost of the parking lots
$Cost^{BA}$	Aging cost of the PEVs' batteries due to V2G
$Cost^{Inc}$	Cost of considering discount on the PEVs' batteries charging fee
$Income^{T}$	Income resulted from transactions in energy market
$G2V(.)$	Grid-to-vehicle
IFR, ITR	Inflation rate and interest rate
OF_{pp}	Objective function of the problem over the given planning period
P_{ev}	Nominal input or output power of the PEV
$Price^{Bat}$	Price of a PEV's battery
Pr_i^{π}	Occurrence probability of the *i*th scenario related to the energy market price
Pr_j^{Narr}	Occurrence probability of the *j*th scenario related to number of arriving PEVs to the parking lot
Pr_k^{Ndep}	Occurrence probability of the *k*th scenario related to number of departing PEVs from the parking lot
Pr_l^{SOC}	Occurrence probability of the *l*th scenario related to SOC level of the PEVs' batteries
$SOC(.)$	State of charge of the PEVs' batteries
$SOC^{arr}(.)$	State of charge of the PEVs' batteries arrived to the parking lots
DOD^{limit}	Depth of discharge limit based on the contract that must be respected by the aggregator
$u^a(.), u^b(.)$	Controlling parameters for indicating decision of the aggregator for being in idle state or doing one of the V2G and G2V actions
$V2G(.)$	Vehicle-to-grid
ψ	Value of discount on charging fee
ξ	Cooperation percentage of the PEVs' drivers with the aggregator
π^{E}	Energy market price
π^{ch}	PEV's battery charging fee
μ, σ	Mean and standard deviation of the uncertain parameter
λ	Effective weighting factor.

GA Parameters

$P^{Mutation}$ Mutation probability of the genes
N_{ch} Size of the population
a_{ch} Binary variable as the indicator for selection of the chromosome for the new population
r_{ch} Random number in the range of $(0, 1)$
$P_{ch}^{Selection}$ Value of selection probability of a chromosome
f_{ch} Value of fitness of a chromosome
S^f Set of chromosomes' fitness.

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