



A Novel Charging Plan for PEVs Aggregator Based on Combined Market and Network Driven Approach

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Abstract

With the large-scale production of plug-in electric vehicles (PEVs), a new entity, the PEV fleet aggregator manages charging and discharging processes of the vehicles. The main objective of an individual aggregator in interaction with electricity markets is maximizing its profit. In this paper, the performance of this aggregator in day-ahead and real-time electricity markets, considering (a) customers' satisfaction constraints, (b) the effects of driving patterns and real-time energy market prices uncertainties and (c) resulted effects on the network operation, is studied. Then, the capability of a bilateral contract between the aggregator and distribution system operator as a regulation for satisfying the network's limitations is investigated. The proposed model is formulated as a two-stage stochastic programming problem and implemented in GAMS software. The findings of the study reveal the effectiveness of the proposed algorithm on maximizing the aggregator's profit-making as well as both customers' and Distribution System Operator's financial and technical satisfaction.

Keywords: Aggregator; Electricity market; Plug-in electric vehicle; Stochastic programming.

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1. Introduction

High penetration of plug-in electric vehicles (PEVs) may impose undesirable effects on the operation of the power systems, especially distribution networks. The charging load of a large number of PEVs increases the peak demand load of the distribution feeder, the power losses of the network, and the maximum voltage deviation of the nodes [1]. Hence, the integration of PEVs by individual aggregators and utilizing them as flexible loads or distributed generation units under the concept of vehicle-to-grid (V2G) technology, have led to a new line of research regarding optimal charging and discharging problems of these vehicles [2], [3], [4]. Accordingly, in the literature PEVs have served various services to mitigate the operational challenges of the grid through economic and technical objectives, e.g. PEV aggregator's profit maximization in [5], peak shaving and load shifting in [6], power losses reduction in [7], reliability improvement in [8], and smoothing the voltage profile in [9]. This has led to many optimization problems from various players'

perspectives in the literature, e.g. aggregator of individual PEVs, owner of parking lots, integration of PEVs and renewable-based generators, and distribution system or micro-grid operator. Although there are lots of studies that investigate each of PEV's facilities individually, considering both financial and technical aspects of an aggregator's performance on customers and also distribution system operator (DSO) has not been studied properly yet. Moreover, considering the effects of a bilateral contract to improve power quality of the network is another contribution of the paper which is reasonable and beneficial for the aggregator and DSO at the same time.

In this paper, the self-scheduling problem of a PEV fleet aggregator in a residential network is presented. It provides the forecasted demand by optimal participation in day-ahead energy market, as well as ancillary service market and real-time energy market. Regarding the fact that the network operation condition is out of responsibility of an individual aggregator, the performance of the

aggregator is guaranteed through a bilateral contract with DSO as a regulation for improving the power quality of the network. In this paper, the main objective is maximizing the aggregator's daily profit, considering constraints related to customers' satisfaction and various sources of uncertainty. Connection of vehicles into the grid is considered only via domestic chargers and once a day. Moreover, stochastic behavior of PEV owners and real-time energy market clearing prices (EMCPs) are modeled using scenarios based on historical/statistical data. In order to study the problem more accurately, different kinds of PEV technologies and different penetration levels are considered in this paper.

In the following, modeling of uncertainties is presented in Section 2. Section 3 discusses system model and problem formulation. Numerical studies and analysis are conducted in Section 4. Finally, Section 5 is assigned to the conclusion.

2. Uncertainty Consideration

Considering uncertainties in computational methods will result in optimal solutions with less sensitivity to environmental effects [10]. This paper considers two sources of uncertainty including PEV owners' behavior and real-time EMCPs.

A) Driving Pattern

National Household Travel Survey (NHTS) 2009 is one of the most comprehensive transportation reports in the U.S. [11]. According to this report, 'the arrival time' and 'the departure time' are defined as 'the final trip end time' and 'the first trip start time', respectively. The daily mileage driven is also defined as 'the sum of the trip mileages per day'. Based on NHTS data, probability density functions (Pdfs) of these three variables are extracted. So that, the departure time, the arrival time and the daily mileage can be formulated as normal, normal and lognormal Pdfs, respectively, and expressed as follows [12]:

$$F_{dep}(t), F_{arr}(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(t-\mu)^2}{2\sigma^2}}, \quad 0 < t < 24 \quad (1)$$

$$F_d(d) = \frac{1}{d\sigma\sqrt{2\pi}} e^{-\frac{(\ln d - \mu)^2}{2\sigma^2}}, \quad d > 0 \quad (2)$$

where F_{dep} , F_{arr} and F_d are Pdfs of the departure time, the arrival time and the daily mileage, respectively. Associated parameters are indicated in Table 1. Also, the arrival and departure times are two independent variables but daily mileage depends on both of them. Hence, in order to realize the correlation between variables, a fuzzy logic based stochastic model is used. Fig. 1 shows this model. Symmetric five-segment triangular Membership Functions are used to map the random

variables between crisp and linguistic values and the output is obtained based on a Mamdani fuzzy inference system which has been proposed in [12].

The battery state of charge (SOC) is defined as 'the percentage of energy remained in the battery'. The initial battery SOC at the arrival time of a PEV is calculated based on its daily mileage as formulated in (3) and (4). In order to preserve the battery against degradation, it is usually refused to discharge it at a SOC lower than 20%.

$$SOC_{d,\omega}^{initial} = \begin{cases} (1 - \frac{DM_{d,\omega}}{AER_d}) \times 100, & 0 < DM_{d,\omega} < 0.8AER_d \\ 20\%, & DM_{d,\omega} > 0.8AER_d \end{cases}; \quad (3)$$

$$\forall d \in D, \omega \in \Omega$$

$$AER_d = Cap_d^{batt} / Cons_d; \forall d \in D \quad (4)$$

where AER is PEV all electric range and defined as the maximum distance that the vehicle can travel only on its battery. DM , Cap^{batt} and $Cons$ are also the electric mode traveling distance in mile, battery capacity in kWh and the vehicle's driving consumption in kWh/mile, respectively. The subscripts d and ω denote PEV and scenario numbers.

Table.1.
Parameters of Pdfs Related to Driving Pattern Variables [12]

	Arrival Time (h)	Departure Time (h)	Daily Mileage (mile)
Mean	17.01	9.97	3.2
Standard Deviation	3.2	2.2	0.9

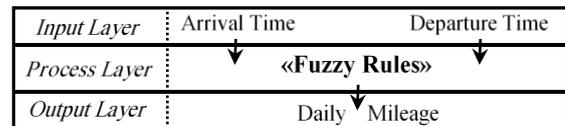


Fig. 1. Implemented stochastic fuzzy model.

B) Real-time Prices for Energy Market

Market clearing prices are one of the sources of uncertainty encountered in electricity markets originating from various market players' unpredicted behaviors. This paper assumes that market clearing prices are not influenced by the aggregator's requests because of its small size in comparison with other players. Considering the nature of this problem as a day-ahead scheduling, it is assumed that day-ahead EMCPs can be predicted with a high accuracy because of proximity to the clearing process. Day-ahead ancillary service market is usually cleared soon after energy market. Hence, here we only model the uncertainty of real-time EMCPs. For simplicity, it is assumed that the real-time market clears only one time at the

beginning of the day and for all the 24 hours ahead. Price intervals are considered 1 hour for all markets. In order to model real-time EMCPs, ARMA method is utilized which has a structure as follows [10]:

$$y_t = \sum_{j=1}^p \phi_j y_{t-j} + \varepsilon_t - \sum_{j=1}^q \theta_j \varepsilon_{t-j} \quad (5)$$

where y_t is stochastic variable, ϕ_j autoregressive parameters and p its degree, θ_j moving average parameters and q its degree, and ε_t white noise or error term. White noise is a variable obtained from a normal stochastic process with the mean of zero and the standard deviation of σ . The 3 months' data related to New York Independent System Operator (NYISO) are extracted and processed to obtain required parameters using data-mining and related MATLAB Toolbox [13]. These parameters are illustrated in Table 2.

Table.2.
Parameters of ARMA Method for Real-Time EMCPs

ARMA (1,2)	$p=1$	$\phi_1=1$
	$q=1$	$\theta_1=-0.0851$
	$q=2$	$\theta_2=-0.07714$

3. Problem Modeling

In this paper, a two-stage stochastic programming approach is utilized for problem modeling. In the *here-and-now* stage (as the first stage), the aggregator sells and purchases the required amount of energy in day-ahead energy market and offers capacity for frequency regulation services in day-ahead ancillary service market. In the *wait-and-see* stage (as the second stage), the aggregator will decide on the status of each PEV which is connected to the network considering the purchases/sales in day-ahead markets and utilize real-time energy market for additional purchases/sales after the realization of the scenarios. Fig. 2 shows the schematic of the proposed method.

In the proposed algorithm, the daily time horizon of the study can be represented as the vector $[1, \dots, t, \dots, T]$ including 24 one-hour time slots. The vector of PEVs under the control of the aggregator can also be indicated by $[1, \dots, d, \dots, D]$. For d^{th} PEV, the arrival and departure times are defined by t_d^{in} and t_d^{out} , respectively. The aggregator can charge or discharge PEVs. Also, if PEVs are connected to the grid but not being controlled by the aggregator, they are in idle mode. Considering high controllability and quick response of batteries, as well as their capability to change their states - if necessary - via suitable signals while they are in idle mode, the aggregator can

offer capacity services to frequency regulation service market and benefit from the resulted profits. Also, regarding the nature of the frequency regulation signals, the SOC variations of a PEV battery caused by being called for exchanging energy can be ignored during connection to the grid [12]. Control vectors of PEV d in scenario ω including charge, discharge and idle states are as follows:

$$I_{ch_{d,\omega}} = [I_{d,t,\omega}^{G2V}, \dots, I_{d,t,\omega}^{G2V}, \dots, I_{d,t,\omega}^{G2V}]; \forall d \in D, \omega \in \Omega \quad (6)$$

$$I_{dch_{d,\omega}} = [I_{d,t,\omega}^{V2G}, \dots, I_{d,t,\omega}^{V2G}, \dots, I_{d,t,\omega}^{V2G}]; \forall d \in D, \omega \in \Omega \quad (7)$$

$$I_{idle_{d,\omega}} = [I_{d,t,\omega}^{idle}, \dots, I_{d,t,\omega}^{idle}, \dots, I_{d,t,\omega}^{idle}]; \forall d \in D, \omega \in \Omega \quad (8)$$

where I^{G2V} , I^{V2G} and I^{idle} are binary variables and denote charging, discharging and idle modes of every PEV in every time slot and scenario, respectively. So that, the activeness of a mode is defined by 1.

A) Objective Function

The objective function of the problem is maximizing the daily profit of the individual PEV fleet aggregator who manages vehicles in a residential network. The proposed two-stage stochastic programming problem is reformulated as a deterministic equivalent problem, considering constraints of PEV owners' satisfaction. The objective function can be described as follows:

$$\text{Obj. Fun.} = \text{Max} \left[\begin{array}{l} (Rev^{DA,Reg} - Cost^{DA,En}) + \\ \sum_{\omega \in \Omega} \pi_{\omega} \times \left[-Cost_{\omega}^{RT,En} - Cost_{\omega}^{Reg} + \right. \\ \left. Rev_{\omega}^{cust} - \sum_{d \in D} Cost_{d,\omega}^{batt} \right] \end{array} \right] \quad (9)$$

$$Rev^{DA,Reg} = \sum_{t=1}^T (\lambda_t^{DA,Reg} \times Offer_t^{DA,Reg}); \quad (10)$$

$$Cost^{DA,En} = \sum_{t=1}^T (\lambda_t^{DA,En} \times Req_t^{DA,En}); \quad (11)$$

$$Cost_{\omega}^{RT,En} = \sum_{t=1}^T (\lambda_{t,\omega}^{RT,En} \times Req_{t,\omega}^{RT,En}); \forall \omega \in \Omega \quad (12)$$

$$Cost_{\omega}^{Reg} = \sum_{t=1}^T \left[X \% \times \lambda_t^{DA,Reg} \times \left(Offer_t^{DA,Reg} - \sum_{d=1}^D P_{d,t,\omega}^{Reg} \right) \right]; \forall \omega \in \Omega \quad (13)$$

$$Rev_{\omega}^{cust} = \left(\sum_{d=1}^D \sum_{t=1}^T (\lambda_{d,\omega}^{Ave} \times (P_{d,t,\omega}^{G2V} - P_{d,t,\omega}^{V2G})) \right) - Cost_{\omega}^{cust}; \quad (14)$$

$$\forall \omega \in \Omega$$

$$Cost_{\omega}^{cust} = Y \% \times \left[Rev^{DA,Reg} - Cost^{DA,En} - \left(Cost_{\omega}^{RT,En} - Cost_{\omega}^{DA,Reg} \right) \right]; \forall \omega \in \Omega \quad (15)$$

$$Cost_{d,\omega}^{batt} = \frac{c^b Cap_d^{batt} + c^L}{L^c Cap_d^{batt} DOD} \times \sum_{t=1}^T (P_{d,t,\omega}^{V2G}); \forall d \in D, \omega \in \Omega \quad (16)$$

As can be seen in (9), the objective function of the problem contains two main parts. The first part includes profits obtained from participating in day-ahead markets in the first stage, and the second

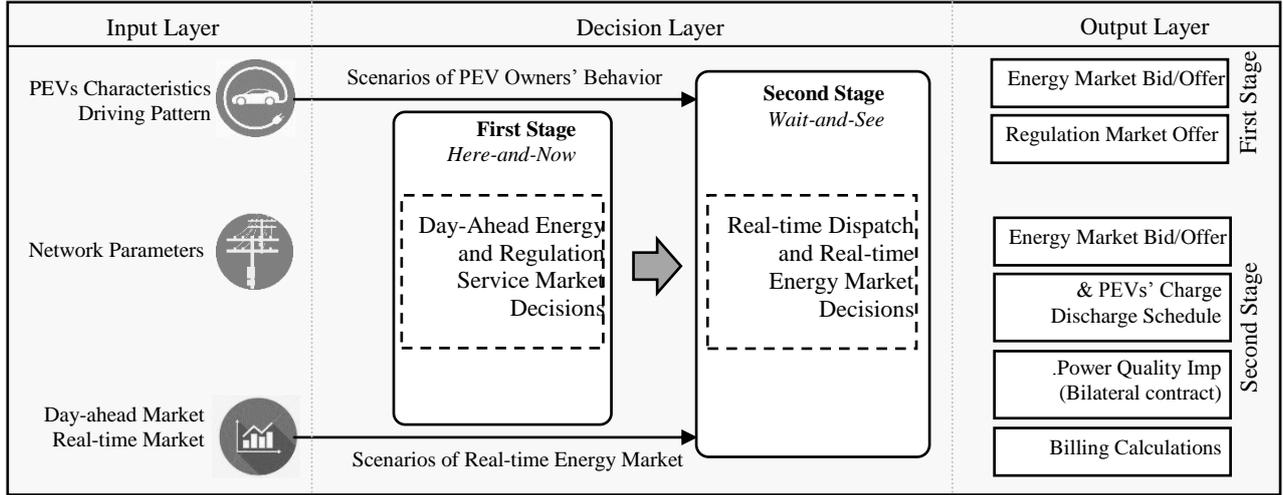


Fig. 2. Schematic of the proposed two-stage stochastic model from the aggregator's perspective.

part consists of the aggregator's costs and revenues resulted from realization of scenarios in the second stage. These two parts are calculated in (10) to (16). π_{ω} denotes the scenarios' probability of occurrence. Equation (10) describes the revenue obtained from capacity offers in day-ahead regulation service market. $\lambda^{DA,Reg}$ and $Offer^{DA,Reg}$ are the market price and the offered capacity, respectively. The cost of the purchased energy from day-ahead energy market is also calculated in (11) which may have a negative value if energy is sold to the market. $\lambda^{DA,En}$ denotes day-ahead EMCPs and $Req^{DA,En}$ is the energy purchased/sold from/to the market.

Equations (12) to (16) calculate costs and revenues associated with every scenario. The energy cost purchased from real-time energy market and the penalty cost due to the violations of the accepted offers in regulation service market is calculated in (12) and (13), respectively. $\lambda^{RT,En}$ denotes real-time EMCPs and $Req^{RT,En}$ is the energy purchased/sold from/to the market. The penalty cost rate ($X\%$) is also considered as a percentage of the capacity price in regulation service market. The revenue obtained from the customers' bills is described in (14) and (15). This revenue contains an earnings due to charging PEVs which is paid by each customer and a cost term which is devoted to the customers' share ($Y\%$) in the total resulted profit. λ^{Ave} is the average of day-ahead EMCPs during connection of a vehicle into the grid. P^{G2V} and P^{V2G} are charging and discharging powers of every vehicle in every time slot, respectively. The degradation cost of a battery due to V2G is formulated in (16) [12].

B) Problem Constraints

The constraints considered in this problem are as follows:

$$I_{d,t,\omega}^{G2V} + I_{d,t,\omega}^{V2G} + I_{d,t,\omega}^{idle} = 1; \forall d \in D, t \in T, \omega \in \Omega \quad (17)$$

$$P_{d,t,\omega}^{G2V} = I_{d,t,\omega}^{G2V} \times P_d^{charger}; \forall d \in D, t \in T, \omega \in \Omega \quad (18)$$

$$P_{d,t,\omega}^{V2G} = I_{d,t,\omega}^{V2G} \times P_d^{charger}; \forall d \in D, t \in T, \omega \in \Omega \quad (19)$$

$$P_{d,t,\omega}^{Reg} = I_{d,t,\omega}^{idle} \times P_d^{charger}; \forall d \in D, t \in T, \omega \in \Omega \quad (20)$$

$$Req_t^{DA,En} + Req_{t,\omega}^{RT,En} = \sum_{d=1}^D (P_{d,t,\omega}^{G2V} - P_{d,t,\omega}^{V2G}); \quad (21)$$

$$\forall t \in T, \omega \in \Omega$$

$$SOC_{d,t,\omega} = SOC_{d,t-1,\omega} + \left[\frac{P_{d,t,\omega}^{G2V} \times \eta_d^{ch} - P_{d,t,\omega}^{V2G} / \eta_d^{dch}}{Cap_d^{batt}} \right] \times 100; \quad (22)$$

$$\forall d \in D, t \in T, \omega \in \Omega$$

$$SOC_d^{\min} \leq SOC_{d,t,\omega} \leq SOC_d^{\max}; \quad (23)$$

$$\forall d \in D, t \in T, \omega \in \Omega$$

$$SOC_{d,0,\omega} = SOC_{d,24,\omega}; \forall d \in D, \omega \in \Omega \quad (24)$$

$$SOC_{d,\omega}^{initial} + \left(\sum_{t=1}^T \left[\frac{P_{d,t,\omega}^{G2V} \times \eta_d^{ch} - P_{d,t,\omega}^{V2G} / \eta_d^{dch}}{Cap_d^{batt}} \right] \right) \times 100 \geq 80; \quad (25)$$

$$\forall d \in D, \omega \in \Omega$$

$$Bill_{d,\omega} = Rev_{d,\omega}^{cust} - Cost_{d,\omega}^{batt} - \frac{F_{d,\omega}^{participation}}{\sum_{d=1}^D F_{d,\omega}^{participation}} \times Cost_{\omega}^{cust}; \quad (26)$$

$$\forall d \in D, \omega \in \Omega$$

$$F_{d,\omega}^{participation} = F_{d,\omega}^{ConnectionTime} \times F_{d,\omega}^{InitialSOC} \times F_{d,\omega}^{BatteryCap}; \quad (27)$$

$$\forall d \in D, \omega \in \Omega$$

Equation (17) indicates the fact that charge, discharge and idle modes are not applicable simultaneously. According to (18) to (20), It is assumed that charging and discharging of PEVs are carried out in nominal exchange rate of employed chargers ($P^{charger}$). The power balance constraint is also described by (21) where the total power

purchased/sold from/to the markets at every time slot should be equal to the sum of the charging and discharging powers of all PEVs at that time slot. Equations (22) and (23) represent the relationship between the battery SOC of every vehicle and the energy received from or injected into the grid in every time slot. Charging and discharging efficiencies (η^{ch} and η^{dch}) are assumed here to be 100%. Minimum and maximum allowed SOC constraints are defined by (24). The battery SOC at departure time and commencing a new travel represents an index of customer's satisfaction. Hence, in (25) the minimum allowed battery SOC at departure time of each vehicle is considered as 80%.

In order to calculate the bill paid by each PEV owner, a system based on *Partnership Percentage* is utilized which makes enough financial incentives for PEV owners to participate in these services. Schematic of the system is illustrated in Fig. 3. So that each customer's benefit resulted from offering the capacity of his/her PEV battery to the aggregator is calculated based on three factors including (i) connection hours into the grid ($F^{ConnectionTime}$) (ii) initial battery SOC ($F^{InitialSOC}$) and (iii) battery capacity ($F^{BatteryCap}$). This value is considered as a percentage of the aggregator's daily profit through participating in electricity markets and will cause a reduction in PEV owners' bills. Equations (26) and (27) refer to the related calculations.

High penetration of PEVs affects distribution networks intensively due to operational challenges. Not only when there is no control scheme on PEVs' charging, but also when they are managed by aggregators, these challenges may appear. Hence, considering the network operation condition in an individual aggregator's self-scheduling problem is important through choosing feasible optimal strategies. In this paper, a bilateral contract (as a regulation) between DSO and the aggregator is proposed in terms of the voltage deviations of the nodes which is a main challenge in high penetrations of PEVs. This can be achieved by adding power flow equations to the aggregator's decision making framework and considering the voltage boundaries as (28).

$$V_{i,t,\omega}^{Min} \leq V_{i,t,\omega} \leq V_{i,t,\omega}^{Max}; \forall i \in N, t \in T, \omega \in \Omega \quad (28)$$

where $V_{i,t,\omega}$ is the voltage magnitude of node i in time t and scenario ω .

Moreover, the optimal incentive for securing the aggregator's performance and considering the network's constraints is calculated while ensuring the economic viability of the aggregator. Linearized AC power flow equations are used to have a linear mathematical model of the problem. The equations are presented in [14].

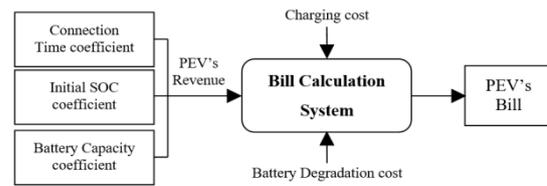


Fig. 3. Billing system based on partnership percentage.

4. Case Studies and Discussion

The residential distribution grid studied here is a 12.4 kV network based on the topology of an IEEE 34-node test feeder [15], as shown in Fig. 4. The PEVs in this grid are assumed to be controlled by an aggregator. 8 best-selling electric vehicles of U.S. transportation market in 2016 are selected [16] and their features are illustrated in Table 3. The penetration level of PEVs is defined as the ratio of available electric cars to total number of houses connected to the mentioned feeder. So, this parameter is assumed 10, 30 and 50% and consequently the total numbers of available PEVs are 83, 250 and 417 vehicles, respectively. In order to model the uncertainties, 2 scenarios for driving patterns and 3 scenarios for real-time EMCPs were selected out of 1000 generated scenarios by using Probability Distance based scenario reduction method. The 6 final scenarios are formed by combining the mentioned scenarios. The clearing prices of day-ahead energy market and regulation service market are extracted from NYISO [13]. The expected values of the predicted real-time EMCPs together with day-ahead prices are indicated in Fig. 5.

The Roulette Wheel Mechanism (RWM) is also used to allocate PEVs in different nodes of the grid randomly. Because of the position stability of the houses in the grid, it is assumed that the connection positions of PEVs into the grid are also fixed. Finally, the problem is formulated as a Mixed-Integer Linear Programming approach and implemented in GAMS software [17]. CPLEX solver is also used to solve the problem. The following three case studies are considered:

Case 1: Uncoordinated charging of PEVs.

Case 2: Coordinated charging, just economic objective (the aggregator's profit maximizing).

Case 3: Coordinated charging, both economic and technical objectives (the aggregator's profit maximizing together with the network limitations).

By implementing the mentioned approach, the daily feeder load demand curves in different penetration levels are calculated for cases 1 and 2 and are shown in Fig. 6 and Fig. 7, respectively. As can be seen, high penetration of PEVs in case 1, causes demand increases at evening hours; while in case 2, these increases are shifted to the first hours of the day with shorter duration because of lower

energy prices in these hours. Fig. 8 and Fig. 9 show the daily voltage curves of the load point 34 of the system for case 1 and case 2 with different penetration levels. The results show that even in case 2, high penetration level of PEVs causes voltage deviations from standard limitations. But the duration of these deviations are relatively lower than case 1. Table 4. also shows different financial terms of the proposed problem from the aggregator's, DSO's and PEV owners' perspectives for both cases.

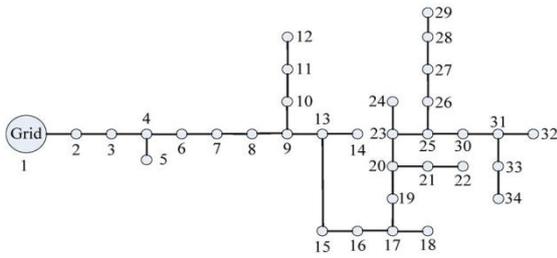


Fig. 4. Topology of the test system [15].

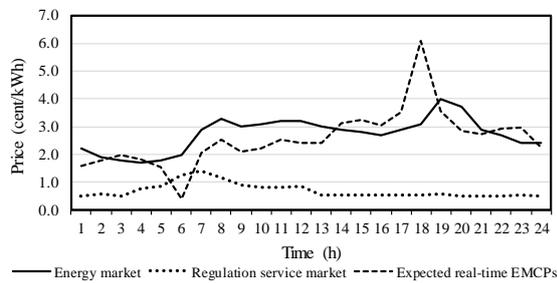


Fig. 5. Electricity market prices.

Table.3.
PEVs Characteristics [16]

PEV Type Number	1	2	3	4	5	6	7	8
Battery Capacity (kWh)	72	24.6	33	8.2	18	12.4	20.6	27
All Electric Range (mile)	212	90	112	21	56	44	73	93
Market Share (%)	20.5	20.5	18	16	9	6	4.5	5.5
Charger Rate (kW)	7.2	6.6	6.6	3.3	3.6	3.3	3.3	7.2

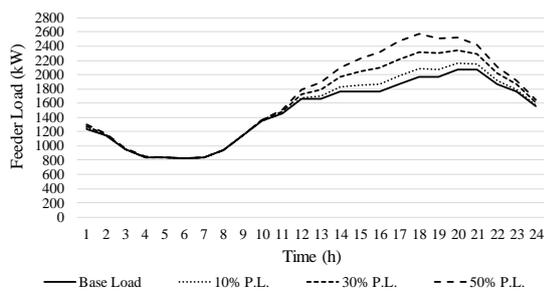


Fig. 6. Feeder load demand in case 1.

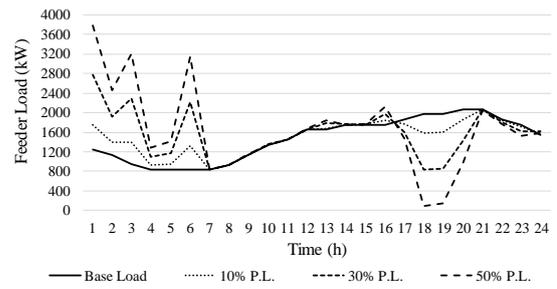


Fig. 7. Feeder load demand in case 2.

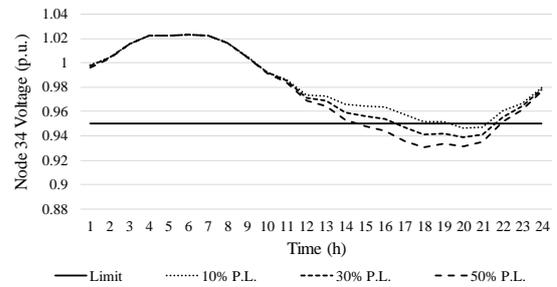


Fig. 8. Daily voltage curve of node 34 in case 1.

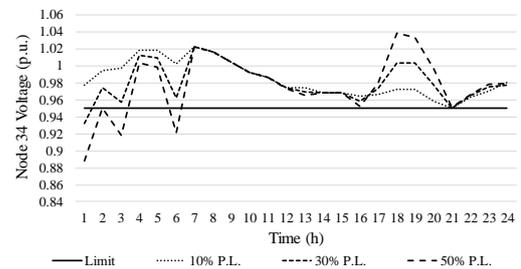


Fig. 9. Daily voltage curve of node 34 in case 2.

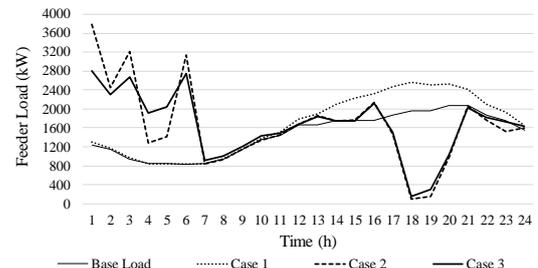


Fig. 10. Feeder load demand for 50% penetration level.

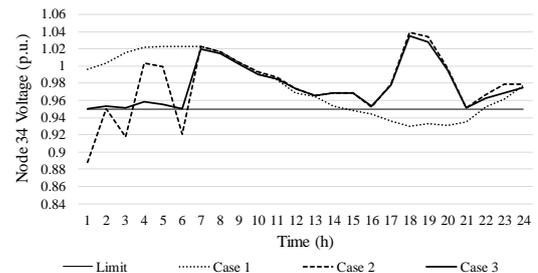


Fig. 11. Daily voltage curve of node 34 for 50% Penetration Level.

Considering the fact that an individual aggregator doesn't have any responsibility for the proper operation of the network, It can be seen that high penetration level of PEVs (i.e. 50%) not only makes voltage deviations in uncoordinated charging mode, but also such a challenge exists when vehicles are controlled by the aggregator. Thus, it is reasonable to solve this problem using a bilateral contract between the aggregator and DSO. But it is important to investigate the effects of such a contract on the aggregator's daily profit and try to make enough incentives for this entity to admit this kind of contracts. In this step, by adding power flow equations to the proposed problem, we investigate the third case study. The results are shown in Fig. 10, Fig. 11 and Table 5. The results show that there is no voltage deviation lower than 0.95 p.u. during the day and a reduction in first hours' load peaks has occurred. Also, implementing the mentioned contract has little impact on the aggregator's daily profit which can be compensated by DSO through offering a fixed amount of payment. Also, this leads to an increase in the total PEV charging cost and the power losses cost which are not considerable.

Table.4.
Resulted Values of Financial Terms in Case 1&2

Penetration level of PEVs (%)		10	30	50
Case 1	Expected value of total PEV charging costs (\$)	33.9	99	165.3
	Expected power losses cost (\$)	107.4	112.6	117.8
Case 2	Objective function (\$)	63.4	188.3	312.7
	Revenue resulted by participating in regulation service market (\$)	36.4	105.4	172.7
	Expected value of total PEV charging costs (\$)	8.9	26.8	46.1
Expected power losses cost (\$)		105	105.3	105.7

Table.5.
Resulted Values of Financial Terms in Case 3

Penetration level of PEVs (%)		50
Case 3	Objective function (\$)	308.1
	Objective function reduction compared to case 2 (\$)	4.6
	Expected value of total PEV charging costs (\$)	49.2
	Expected power losses cost (\$)	105.9

5. Conclusion

This paper has introduced an algorithm for day-ahead stochastic programming of a PEV fleet aggregator considering two sources of uncertainty. The proposed algorithm aimed at maximizing the aggregator's daily profit. As the results show, the control of charging and discharging processes of PEVs by an aggregator, not only benefits this entity but also causes customers' and DSO's satisfaction by reducing the cost of distribution company due to network power losses and decreasing the customers' charging costs. Also, it can be seen that

adding power flow equations to the problem and defining a limitation through a contract between the aggregator and DSO can alleviate probable network challenges in terms of the voltage deviations of the nodes and benefit the aggregator at the same time.

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