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CHARGE AND DISCHARGE TEST AND POWER NETWORK QUALITY ANALYSIS OF ELECTRIC VEHICLE ENERGY STORAGE DEVICE BASED ON STACKELBERG GAME

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ABSTRACT

Electric vehicles (EVs) have been widely developed for their advantages of energy saving and environmental protection. However, the disorderly charging of large-scale EVs will bring challenges to the security and stability of the power grid due to the randomness and uncertainty of charging behavior. In this paper, the charging and discharging management system of Electric vehicle (EV) is added between the two-way interactive service system of smart grid and EV to realize the information interaction between EV and grid. Further, the charging and discharging operation of EV is optimized and controlled according to the needs of its both sides. To maximize the revenue of the grid company, the EV charging price is optimized and the EV charging load is transferred through the behavior characteristics prediction of EV users. Then, the EV is charged and discharged in an orderly manner. Besides, the grid load characteristics, voltage quality and frequency quality are improved on the grid side.

Keywords: Game Theory, Electric Vehicles, Discharge Testing, Power Grid Quality

NONMENCLATURE

Electric vehicle	EV
Electric vehicles	EVs
Hybrid Electric vehicles	HEV
Alternating current	AC
Direct current	DC

1. INTRODUCTION

Compared with the traditional fuel vehicles, EVs have the advantages of low noise, high energy efficiency and low environmental pollution [1]. However, large-scale EV charging behavior will result in the great power consumption of power grid, and its irregularity will have an adverse effect on the power grid [2]. In recent years, more and more researchers paid attention to this field. The non-cooperative optimization of EV charging under the demand uncertainty had been proposed by relevant scholars [3]. The ever-opening electricity market environment provided a new stage for the game theory. Game theory provided a powerful tool for power market participants to make decisions about maximizing personal income [4]. EV accessing to the grid was a key step in the development of smart grid [5]. As a distributed energy storage device, EVs can also be used to rotate standby, adjust grid frequency and balance grid voltage, which enrich the means of regulation and control of grid operation [6-7]. During the peak load period of grid, the electric energy is transmitted to the grid. During the grid trough, the electric is charged by grid to the battery of EV, which can reduce the peak-to-valley difference of grid, and play a role of "filling the valley" [8]. The EV can interact positively with the power grid, and it also can regulate the orderly charging and discharging of EVs through reasonable measures. Besides, it can alleviate the pressure of EVs to enter the network [9]. This paper applies the fixed points theorem and successfully proves the existence of Nash equilibrium. It can be learned that the game ideas can be effectively used in power system control and scheduling. Differential game theory provides an effective mean to solve related problems, such as uncertainty interference and frequency modulation control. In summary, the contributions are as follows:

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1.Beetle Antennae Search Algorithm is improved in this paper to test the charge and discharge of EVs energy storage device and analyze power grid quality. This algorithm is a new efficient intelligent optimization algorithm which is first proposed in 2017.

2. Beetle Antennae Search Algorithm is used in the Stackelberg game environment to enhance applicability.

3.The Stackelberg game method is more identifiable, visualized and reliable for optimizing the charging and discharging operation of EV.

Game theory as a basic tool in this paper is used to establish the theoretical system and model of regional power grid dispatching. This model includes photovoltaic power plants and EVs. The scheduling of large-scale EVs satisfies the connotation of Stackelberg game model. This Stackelberg game model, which is different from previous scheduling ideas, aims at dealing with inconsistency between the time-sharing electricity price and the random status of EVs in the scheduling process. This paper studies the charge and discharge test and grid quality analysis of EV energy storage devices based on the game theory.

2. MATERIALS AND METHODS

2.1 Multi-objective Game

With the uncertain and the large-scale network access of new energy sources, the output of photovoltaic power generation is basically not controlled by power system dispatching personnel. The charging and discharging management system of EVs can not only uniformly manage AC charging and discharging piles in the same parking area, but also uniformly manage DC charging and discharging motors in a centralized charging and discharging power station. The HEV mode logic is shown in Fig. 1, while the HEV- mean-motor image is shown in Fig. 2. According to the behavior characteristics prediction of EVs and the basic information of power grid, Monte Carlo simulation method is adopted in this paper. According to the charging strategy of EV users, the conventional load curve of EV charging load grid under each electricity price curve is shown in Fig. 3. Some scheduling strategies are based on the existing time-sharing electricity price, and the scheduling algorithm is used to control the charging behavior of EVs directly according to the charging load. Other scheduling strategies give the time-sharing optimal electricity price according to the relationship and constraints between grid supply and grid demand.

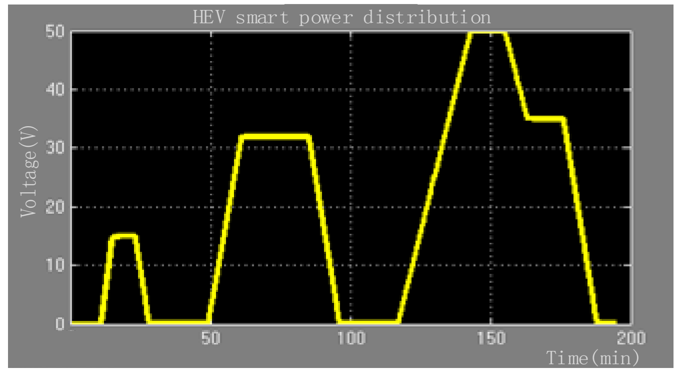

Fig 1 HEV schema logic

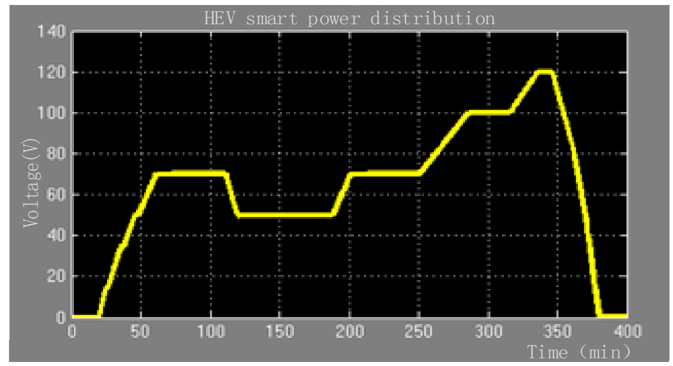

Fig 2 HEV mean value motor

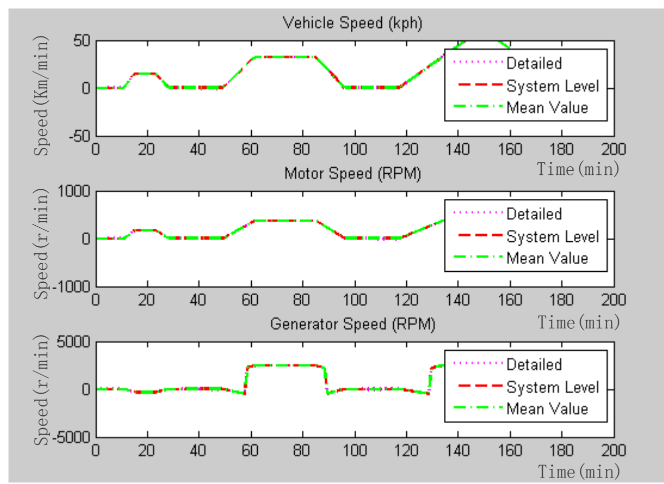

Fig 3 Routine load curve of power grid

Tab 1 Relevant parameters of EVs

Charging scenario	Proportion/%	Arrival time	Departure time	Initial state of charge
Workspace Charging	28.3	N(9,0,32)	N(18,0,32)	U(0.3)
Residential Charging	71.17	N(19,1,32)	N(7,0,32)	U(0.2)

2.2 Strategic Game for Power System Dispatching

The basic idea of interactive control is that EVs can change their charging curves according to the price signals given by EV charging station agents until the equilibrium is reached. Compared with price control, the information interaction between the EV and power grid is different. Interactive control needs to obtain a clear response from each EV. However, if the strategy set of game is continuous, the solution will be transformed from game equilibrium problem to optimization problem. At this time, the description method in Tab. 1 and the result matrix are not very suitable. Besides, all the information required by the game can be listed in the form of this strategy.

The interaction between EVs and residential areas is an important component of V2G, which can make the EVs park in residential areas more convenient. Thus, long-line power transmission and large-scale communication interaction can be avoided. Power balance is the first problem need to be solved in the optimal dispatch of traditional power system. This can guarantee the stability of system frequency and voltage. Similarly, power balance as an autonomous system can operate on isolated islands, which are the same as micro-networks. The charging time of EV can be adjusted flexibly, so EV can be classified as adjustable load under the residential power system.

The charging power of EV is large and the charging time is long, so the charging of EV should be reasonably scheduled. With the rapid development of EVs, the impact of the cluster effect on the power grid cannot be ignored because the number of EVs results in the overall size of load. The grid balance is achieved by adjusting the charging behavior of EV. And the first step is to calculate the charging load of EV. The EV charging station agents is an intermediate bridge between the dispatching organization and the EV users. On the one hand, the EV dealers have to interact with the dispatching organization for billing services, and power supply and demand. On the other hand, they can control each EV in the group in an orderly manner, which can effectively reduce the size of algorithm.

Tab 2 Effect of different charging and discharging modes on daily load rate of residential area

Permeability /%	Load mean square deviation/Kw		
	Disorder impulse/Kw	Orderly charging/Kw	Charge and discharge dispatch/Kw
20	152.35	112.5	109.5
30	156.82	105.3	95.4
50	163.34	10.5	75.3

The daily load curve of residential area is under the 50% of EV permeability, and the daily load rate is under the different charging and discharging modes. These two curves are superimposed on the conventional predicted load of residential area under the various charging and discharging modes. The influence of different charging and discharging modes on the daily load rate of residential area is shown in Tab. 2, while the load of power grid is shown in Fig. 4.

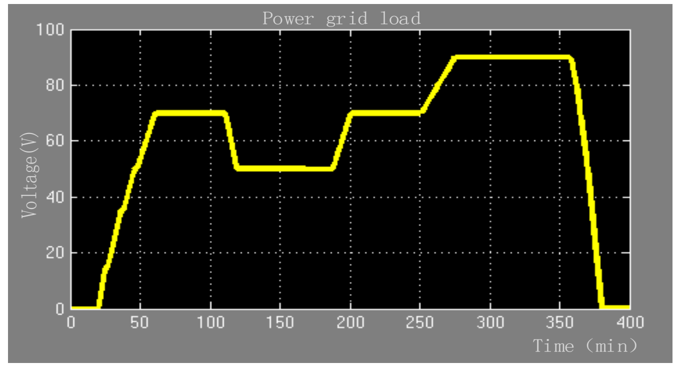

Fig 4 Power grid load

For EV charging station agents, the travel habits and charging demand of EV users are unpredictable. The charging and discharging management system of EV not only communicates with EV through corresponding equipment, but also communicates with the system, which is related to smart grid. The real-time state parameters of EV and grid are collected comprehensively, and the charging and discharging of EV by these random factors are analyzed reasonably. Thus, the influence of Time-sharing tariff strategy is very important. Besides, Nash equilibrium method solves the energy consumption optimization problem of users, who use the game theory in a uniform energy system. Finally, the optimal solution is obtained.

Under the premise of meeting the safe operation of this system, large-scale power grid dispatching attempts to develop scheduling strategies, such as generator set output plans. Then, the most economical operation of the grid can be achieved. Under the equilibrium conditions of the game strategy established by each participant, it can be guaranteed that every participant will not deviate from the agreement, which refers to pursue its own maximum interests. Therefore, it is necessary to automatically promote the performance of system in practice when all participants set a good strategy. The result is equilibrium.

For the choice of EV charging scheme, there are regular charging, fast charging and the quick replacement of battery pack. In the normal and fast charging modes, their rated voltage and rated current are shown in Tab. 3.

Tab 3 Rated voltage and current of each charging mode

Charging mode	Rated voltage/V	Rated current/A
AC conventional charging	380	15
DC fast charging mode	600	150-400

3. STRATEGY AND CALCULATION

3.1 Optimizing Scheduling Strategy

The dispatching optimization mode is established based on the game theory, in which the time-sharing price of power grid is the game subject (leader). On the premise of guaranteeing the profit of electricity sales, the aim of this strategy is to suppress the variances and fluctuations of equivalent load, and give full play to the guiding role of electricity price in EV dispatching. Then, the EVs, which can be accessible to network, are regarded as the game subject (follower). And the optimization goal is minimizing the cost of EVs based on their reasonable charging and discharging. The users of EVs can minimize charging cost according to the charging demand and time-of-use tariff. Further, considering the power supply situation of EVs, the adjustable load is adjusted to the lowest price in the adjustable period using the energy storage characteristics of EV and the flexibility of battery's charging and discharging time. During the peak load period, EVs have no adjustable load. And the electricity can be used during this period.

Tab 4 Comparison between uncertainty method and certainty method of different EV scales

Number		10	20	30
Load rate	Certainty	0.75	0.82	0.88
	Uncertainty	0.76	0.85	0.91
Minimum Load Coefficient	Certainty	0.63	0.72	0.82
	Uncertainty	0.64	0873	0.85

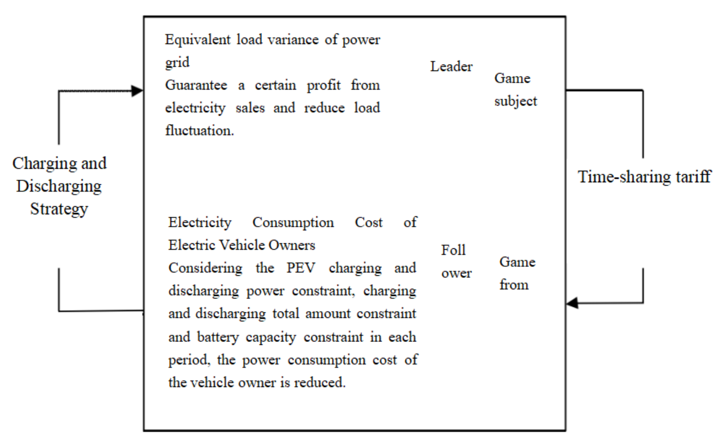

Fig 5 Structure of the leader-follower game

Tab. 4 compares the uncertain characteristics with deterministic load characteristics of various EV scales. It can be seen that both methods can make the load curve fluctuate with the increasing scale of EV, and the total revenue of EV users increases with the number of vehicles. In order to balance the interests between the grid and EV users, The Stackelberg game model takes the grid load and the cost of EV users in to consideration. The Stackelberg game structure is shown in Fig. 5.

3.2 calculation

In order to effectively control the global search and local search, the Beetle Antennae Search Algorithm is improved. The basic idea of Beetle Antennae Search Algorithm is that the step size decreases with the increase of iteration times $T_{yi\text{-}y}$. And the step size d_i strategy is controlled by original attenuation coefficient. The open downward parabolic step size attenuation x strategy is considered based on this algorithm, and the formula is:

$$\rho_i = d_i - \frac{T_{xi} - x}{d_i}\Delta x - \frac{T_{yi} - y}{d_i}\Delta y - \frac{T_{zi} - z}{d_i}\Delta z + c\Delta \qquad (1)$$

The initial descent speed of Beetle Antennae Search Algorithm is less than the step-length decay *A,t*. And the descent speed of *t*-subtraction strategy is gradually accelerated with the increase of iteration times *T*, where *x=Th* is the convex function. The formulas are:

$$\hat{x} = T_h(A,t) = \begin{cases} A & |A| \ge t \\ 0 & |A| \prec t \end{cases} \qquad (2)$$

$$\hat{x} = T_s(A,t) = \begin{cases} A - t & |A| \ge t \\ 0 & |A| \prec t \end{cases} \qquad (3)$$

T(*s,J*) shows that the electricity of EV belongs to the system computer depression combination optimization problem. When calculating *T*(*s,J*), it can be extended on the basis of the traditional unit combination model, that is, the objective function is the minimum sum of unit operation cost and start-up cost, as shown in formula N:

$$N = \left\{\arg\min\left[T(s,J)\right]\right\} - 2 \qquad (4)$$

Considering the power system unit commitment optimization *MN* problem of EVs, the following constraints (*m*, *n*) need satisfy:

$$K_{s,d} = \frac{1}{MN}\sum_{m=1}^{M}\sum_{n=1}^{N}\frac{\left\|W_{s,d}(m,n)\right| - \mu_{s,d}\right|^4}{\sigma_{s,d}^{\;4}} \qquad (5)$$

The total output K_n of all starting thermal power units shall be equal to the total load demand V_t:

$$\mathbf{V}_t = [\sigma_1, K_1, \sigma_2, K_2, \cdots \sigma_n, K_n] \qquad (6)$$

Assuming that the unit cost of the power system without EVs is V_{ti}, and i-1 meets the charging power demand of EVs, the unit cost of whole system is changed from V_t. The increase is the charging cost C of EVs:

$$D(\mathbf{V}_t, \mathbf{V}_t') = \sqrt{\sum_{i=1}^{c} \left(\frac{V_{ti} - V_{ti}'}{|V_{ti}| + |V_{ti}'|} \right)^2} \quad (7)$$

In order to simplify the problem, the current electricity cost of power grid is approximately expressed as the unit combination cost. Considering the interest x of power grid, the implementation of dynamic electricity price y will not result in any loss to the interest of power grid. Therefore, k-1 in the dispatching also aims at maximizing the income of power grid company, and the objective function of economic dispatching is as follows:

$$p(x;\alpha,\beta) = \frac{\beta\eta(\alpha,\beta)}{2\Gamma(1/\beta)} \exp\{-[\eta(\alpha,\beta)|x|]^{\beta}\} \quad (8)$$

$$\log\Gamma(x) = -\gamma x - \log(x) + \sum_{k=1}^{\infty}[\frac{x}{k} - \log(1+\frac{x}{k})] \quad (9)$$

By optimizing the charging price R of EV, users of the EV are guided to charge the EVs when the electricity price is lower, so as to transfer the charging load c of EVs. Under the price curve when i=1, the charging income of EVs is as follows:

$$R = \sum_{i=1}^{N} r_i \cdot c_i \quad (10)$$

According to the requirements of demand-side management, interests of the user side shall not be damaged after the implementation of dynamic electricity price Y, i.e. the average electricity price X on the user side shall not rise. Therefore, the price level constraint condition C is as follows:

$$C_{q\times p} = X_{q\times n} Y_{p\times n}^{T} \quad (11)$$

$$C = \sum_{i=1}^{m} \sigma_i l_i r_i \quad (12)$$

4. RESULT ANALYSIS AND DISCUSSION

4.1 *Results*

Time-sharing tariff can indirectly guide the orderly charging of EVs. Thus, the negative impact of EV's disorderly charging behavior on the existing distribution system can be avoided. Then, the operation status of power grid and the energy storage situation of EV can be got hold of in real time. And the intelligent control of EVs on-board charging and discharging device can timely operate. EVs on-board power batteries are charging in the low period of the power grid or when EVs have rigid charging demand. In the grid-connected operation mode, energy storage and other micro-sources participate in the optimal scheduling. When the wind power generation and photovoltaic power generation exceed the load, that is, net load inside the microgrid is less than zero, the energy storage is first taken into consideration. Then, the electricity is transmitted to a large grid. Intelligent meters are used to provide users with reference data of electricity price. Besides, the non-adjustable load of EV in the idle peak period is charged by using its energy storage characteristics. The EV charging station agents and EV users, who pursue maximizing interests, are mainly modeled by the game method. EV charging station agents control the EV by guiding the charging price of each period rather than directly controlling the EV. Then, the EV is guided to be charged.

High-standard urban residential areas show the cyclical changes of electrical load, which not only in one day but also within one year. These urban residential areas have star-connected high-voltage windings and circulating currents. The voltage of city cycle is shown in Fig. 6. The current circulating in the city is shown in Fig.7.

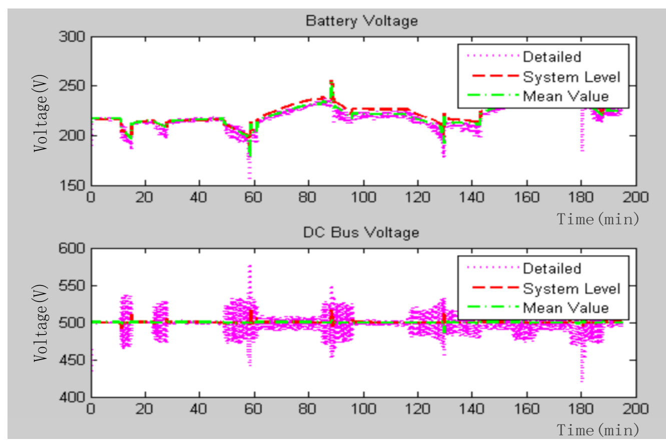

Fig 6 Urban cycle voltage

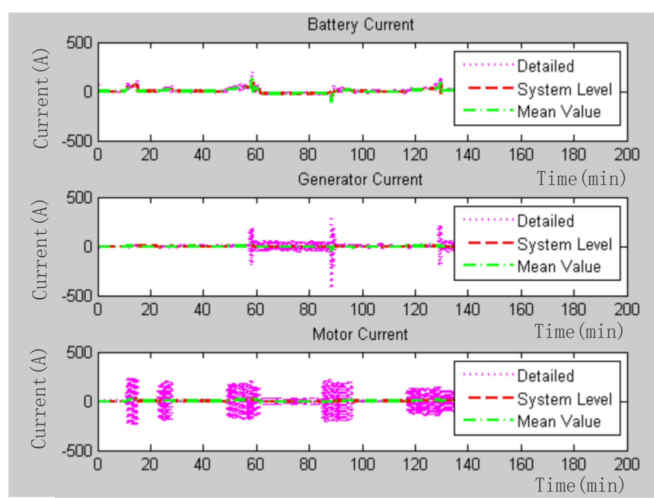

Fig 7 Current of urban cycle

4.2 Discussion

The economic dispatching model of EV based on demand response reduces the peak-valley difference rate and unit commitment cost of this system by optimizing charging price and transferring charging load. It is suitable for economic dispatching of large-scale EV to connect to power grid. The game theory model is also applicable to power system stability control, such as active frequency control. Combining the feedback mechanism with the robust optimization problem can reduce conservativeness of the optimization strategy, and improve the robust feasibility. What needs to be explained is that the access of large-scale new energy brings more problems to the power grid than the EVs and photovoltaic power. There are many new problems worthy of studying.

5. CONCLUSIONS

In this paper, it is a challenge for power system dispatching to take the reasonable and effective use of EV's charging and discharging functions in order to reduce the cost of household electricity. At the same time, the service life of EVs battery should be extended as far as possible. As an advanced mathematical tool, the game theory is expected to analyze the optimal dispatch of power grid, which contains EVs, through systematic modeling method. This method can provide theoretical support for large-scale EVs entering the network. The stochasticity of EV operation is regarded as the prediction error, which is based on the long-term statistical law. The prediction error is fully considered when the charging and discharging strategy has been established. Opportunity constrained programming can be used to optimize the prediction error when the grid constraints, battery constraints and the EV users use constraints are considered comprehensively. Compared with disorderly charging, the dynamic electricity price optimized by the established pricing strategy can significantly improve the dynamic probability characteristics of node voltage amplitude under the different EV scales. Then, the dynamic electricity price will meet the expected value constraint of voltage qualification rate, and ensure the total revenue of agents can increase steadily with the number increase of EVs connected to grid. Therefore, the trading mode between the power grid and EVs will change from simple one-way to complex two-way. And it will require more advanced and more intelligent power market trading technology to support.

REFERENCE

[1] Bahrami S, Parniani M. Game Theoretic Based Charging Strategy for Plug-in Hybrid Electric Vehicles. IEEE Transactions on Smart Grid 2014;5:2368-2375.

[2] Ma Z, Ran L. Game-Based Valley-Fill Charging Coordination for Large-Population Plug-in Electric Vehicles. Asian Journal of Control 2015;17:2010-2018.

[3] Yang H, Xie X, Vasilakos A V. Noncooperative and Cooperative Optimization of Electric Vehicle Charging Under Demand Uncertainty: A Robust Stackelberg Game. IEEE Transactions on Vehicular Technology 2016; 65:1043-1058.

[4] Liu Z, Wu Q, Huang S, et al. Optimal Day-ahead Charging Scheduling of Electric Vehicles through an Aggregative Game Model. IEEE Transactions on Smart Grid, 2017;17:1-1.

[5] Liu X, Gao B, Wu C, et al. Demand-Side Management With Household Plug-In Electric Vehicles: A Bayesian Game-Theoretic Approach. IEEE Systems Journal 2017;16:1-11.

[6] Zhao T, Li Y, Pan X, et al. Real-time Optimal Energy and Reserve Management of Electric Vehicle Fast Charging Station: Hierarchical Game Approach. IEEE Transactions on Smart Grid, 2017;15:1-1.

[7] Mediwaththe C P, Smith D B. Game-Theoretic Electric Vehicle Charging Management Resilient to Non-Ideal User Behavior. IEEE Transactions on Intelligent Transportation Systems 2018;10:1-10.

[8] Ovalle-Villamil A, Fernandez J, Hably A, et al. An Electric Vehicle Load Management Application of the Mixed Strategist Dynamics and the Maximum Entropy Principle. IEEE Transactions on Industrial Electronics 2016;10:1-1.

[9] Wu T, Ma L, Mao Z, et al. Setting up charging electric stations within residential communities in current China: Gaming of government agencies and property management companies. Energy Policy 2015;77:216-226.

