

# Optimal Control Strategy of Electric Vehicles Based on the Adaptive Mutation of PSO Algorithm

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**Abstract**—The development of technology concerned of electric vehicles and the expansion of Charging facilities scale, researching on Vehicle-to-Grid (V2G) technology has been increasing concerned in recently. Not only taking power from the grid to charge the batteries on these vehicles, but the power could also be transferred into the grid from their batteries when parked, which is known as Vehicle-to-Grid(V2G) concept. The key research technique is proposing a control strategy for scheduling usage of available energy storage capacity from electric vehicles reasonably and effectively in a certain scale plot. This paper establish the mathematical model which concludes two constrain conditions to simulate electric vehicles level the load curb. Then a new adaptive mutation particle swarm optimizer, which is based on the variance of the population's fitness is presented. A critical adaptive mutation operator is put forth in this algorithm in which mutation probability is decided according to the variance of the population's fitness and the current best solution, which improve the ability of algorithm to break away from local optimum. The last, example results show applicability and effectiveness of the algorithm which schedule vehicle for leveling a load curb.

**Keywords**—V2G; electric vehicles(EVs); control strategy; adaptive mutation particle swarm optimizer(AMPSO);

## I. INTRODUCTION

Electric vehicles will become one of the important daily traffic vehicles depending on their pro-environment, energy saving, low carbon and lower operation cost. Electric vehicles with V2G technology can provide ancillary services and energy, such as frequency regulation and spinning reserves, to the electricity grid[1]-[3], and can also mitigate renewable energy sources such as wind power as an energy buffer[4]in order to guarantee the quality of the grid. However, a large fleets of EVs unregularly exchange energy with grid will be bound to bring lots of negative impacts into the power grid[5], so it is important to arrange EVs to charge reasonably and regularly. At the same time according to statistics, electric vehicles are driven on average only about 5% of the time in a day, in principal making them available for the remaining 95% of time for load control purposes[6], which provide precondition for discharging briefly at times of peak system demand through V2G technology.

An autonomous distributed V2G control scheme which considered charging request and battery condition was proposed in[7]. Binary and integer versions of Particle Swarm Optimization(PSO) in same algorithm were used to optimize the model of unit commitment(UC) with V2G for minimizing total running cost in[8]-[9]. Base on real-time power prices, [10]proposed binary particle swarm optimization(BPSO) to figure out the appropriate charge and discharge time throughout the day, in order to find optimal solutions that maximize profits to each owner while satisfying system and owners' constrains.

In this paper, an EVs' charge and discharge model is established in section II. Aiming at this model, a new adaptive mutation particle swarm optimizer(AMPSO), is presented on section III to realize the intelligent scheduling of EVs storage capacity in a parking lot. There is a case in section IV to validate the new algorithm.

## II. MATHEMATICS MODEL OF CONTROL STRATEGY OF V2G

EVs are parked could be used to charge in the load valley and discharge during the peak demand periods in order to level a day load curve was given for reducing the difference between peak and valley. In this paper, electric vehicles are viewed as mere tools to response load curve, and are not considered about daily journey needs and the batteries service life. In other words, EVs could be applied during 24 hours.

### A. Objective Function

$$F_{\min} = \sum_{j=1}^{24} (P_j - \sum_{j=1}^{24} P_j / 24 - \sum_{i=1}^n P_{ij}) \quad (1)$$

Where, n :the number of EVs

$P_j$  :the load power at the time of period j

$P_{ij}$  :the charge or discharge power of the  $i$ th EV at the time of period j, positive is defined as charge and negative is defined as discharge

### B. Constrain Conditions

#### 1) Battery capacity constraints:

a) *Considering limited charge/discharge capacity: The charging capacity is less than one third of the rated capacity, and discharging capacity is no more than twice the rated capacity.*

b) *Considering available space of the batteries: Available space of the batteries depends on SOC<sub>ij</sub>, but the minimum of SOC(state of charge) is 0.2, and the maximum of SOC is 1.*

c) *SOC<sub>ij</sub>: SOC of the ith EV at the time of period j*

2) *Line power constrains: The charge and discharge power are no more than 15Kw. So the charge/discharge power as flowing:*

$$\begin{cases} 0 \leq P_{ij-d} \leq \min(15, 2P_{iN}, (SOC_{ij} - SOC_{\min}) * P_{iN}) \\ -\min(15, 1/3P_{iN}, (SOC_{\max} - SOC_{ij}) * P_{iN}) \leq P_{ij-c} \leq 0 \end{cases} \quad (2)$$

$P_{iN}$ : the rated active power of the  $i$ th EV, which is rated voltage of batteries multiplied by rated capacity

$P_{ij-c} / P_{ij-d}$ : the charge /discharge power of the  $i$ th EV at the time of period  $j$

### III. THE ADAPTIVE MUTATION PARTICLE SWARM OPTIMIZATION ALGORITHM

PSO is a population-based iterative stochastic optimization algorithm, which modeled the motion of flock of birds and the school of fishes. The PSO uses a simple mechanism that mimics swarm behavior in birds flocking and fishes schooling to guide the particles to search for globally optimal solutions[11]-[12]. A swarm is considered to be a collection of particles, where each particle represents a potential solution to a given problem and contains two factors: position and velocity. Every particle changes its position within the swarm with a velocity. Indeed, it 'flies' in the search space to find out the optimal solution. Initially, a population of random solutions is generated and a random velocity is also assigned to each particle. For example, the location of the  $i$ th particle is represented as

$X_i = [x_{i1}, x_{i2}, x_{i3}, \dots, x_{iD}]$ , the rate of the velocity for the

$i$ th particle is represented as  $V_i = [v_{i1}, v_{i2}, v_{i3}, \dots, v_{iD}]$ . Also, each particle has a memory which keeps track of its previous best position and corresponding fitness. The previous best position is called ' $pBest$ ' of a particle. The best of all the ' $pBest$ ' value among all of particles is referred to as the ' $gBest$ ' of the swarm. The basic conception of the PSO technique is that every particle always approaches to its ' $pBest$ ' and ' $gBest$ ' positions with the iteration and calculation of computer program. The velocity and position of each particle are updated according to the following equations:

$$\begin{aligned} v_{ij}^{(s+1)} &= \omega v_{ij}^{(s)} + c_1 rand_1 (pbest_{ij}^{(s)} - x_{ij}^{(s)}) \\ &+ c_2 rand_2 (gbest_{ij}^{(s)} - x_{ij}^{(s)}) \\ (3) \quad x_{ij}^{(s+1)} &= x_{ij}^{(s)} + v_{ij}^{(s+1)} \end{aligned} \quad (4)$$

Where,  $\omega$ : inertia weight

$c_1, c_2$ : learning factors, which are set to 2

$s$ : the current iterations

$i$ : the  $i$ th particle

$j$ : dimension

The position of each particle represents charge or discharge power of all of vehicles in twenty-four hours. There are 30 particles are mentioned in this algorithm. In this paper, each particle has the following fields for using V2G participate level load curve.

Particle  $i$  { Dimension:  $N*24$ ;

position matrix: a  $1 \times (N*24)$  real-valued row vector

$$X_{ij} = [x_{i1}, x_{i2}, \dots, x_{i24}, x_{i25}, x_{i26}, \dots, x_{i48}, \dots, x_{iD}];$$

velocity: an  $1 \times (N*24)$  real-valued row vector

$$V_i = [v_{i1}, v_{i2}, \dots, v_{i24}, v_{i25}, \dots, v_{i48}, \dots, v_{iD}]; \}$$

PSO of employing real coding is characterized by simple and run fast, without selection, crossover and mutation. However, during the running time other particles easily converge to a particle which has the best fitness. If the best position is local optima, then prematurity phenomenon will be occurred.

Considering the premature convergence problem of Particle Swarm Optimization(PSO), a new Adaptive Mutation Particle Swarm Optimization(AMPSO) is presented to improve PSO global optimal searching ability, which is based on the variance of population's fitness. Through researching the variance of the swarm fitness, we can obtain particles' gathering condition: the less the variance is, the more congregated particles are. The swarm fitness variance is defined as following:

$$\sigma^2 = \sum_{i=1}^n \left( \frac{f_i - f_{avg}}{f} \right)^2$$

$$f = \begin{cases} \max \{ |f_i - f_{avg}| \}, & \text{if } \max \{ |f_i - f_{avg}| \} > 1 \\ 1, & \text{others} \end{cases}$$

$$f_{avg} = \frac{1}{N} \sum_{i=1}^N f_i$$

(5)

$$P_m = \begin{cases} 0.1 \sim 0.3, \sigma^2 < \sigma_d^2 \text{ \& } f(gBest) > f_d \\ 0, & \text{others} \end{cases}$$

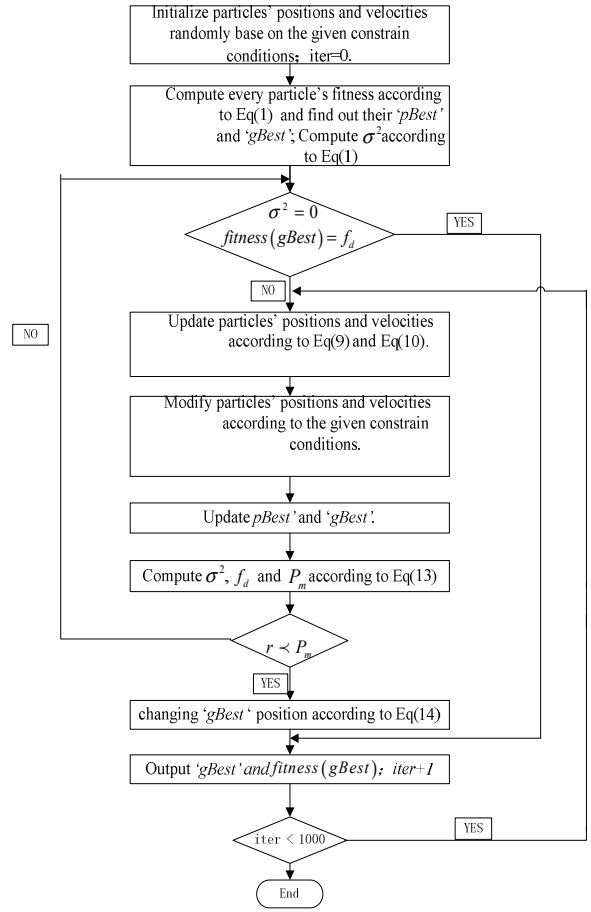
(6)

$$gBest_k = gBest_k * (1 + 0.5\eta), \eta \in Guass(0,1) \quad (7)$$

where, N : the total number of particles

k : the kth dimension in a particle

When  $\sigma^2 = 0$ , the PSO algorithm is convergent, which can't decide, however, the convergence is local or global. Adding a condition is whether the relevant best fitness is the theoretic global optimal solution or the anticipant global optimal solution  $f_d$  to this. If both conditions ( $\sigma^2 = 0$  and  $f(gBest) = f_d$ ) are satisfied, the algorithm converges globally. Otherwise, the algorithm is plunging into the local optimum. The basic idea of the new adaptive PSO with mutation is a random mutation operator is used to disturb the global optimum 'gBest' when the PSO algorithm has plunged into local optimum. In other words, in the disturbing time, we will design mutation as stochastic operator to change 'gBest' position randomly, which will change 'gBest' position according to a certain probability  $P_m$  as Equation(6). AMPSO algorithm process is presented as following:



#### IV. THE CASE STUDY

In the early stages of development of V2G technology, a small fleet of EVs could be used as responsive load to response load curve. In this case, Various sizes of EVs (300,400,500,600) would be divided into twenty groups for reducing the dimension of algorithm and complexity of dispatching. The initial SOC of each EVs batteries is 0.3 and other constrain conditions have been presented in part II. The parameters of the battery are shown in TABLE I and the load curve of a certain area is given in Figure I.

TABLE I. THE PARAMETERS OF THE BATTERY OF EVs

Battery Type	Rated Voltage of Batteries / (v)	Rated Capacity/ (A·h)	Rated Power (Kw)
	360	80	28.8

TABLE II. THE FITNESS OF DIFFERENT ALGORITHM IN SERIOUS FLEETS EVs

The number of EVs(/group)	15	20	25	30
PSO	5337100	2777400	6154600	3498100
AMPSO	143060	43336	55604	98675

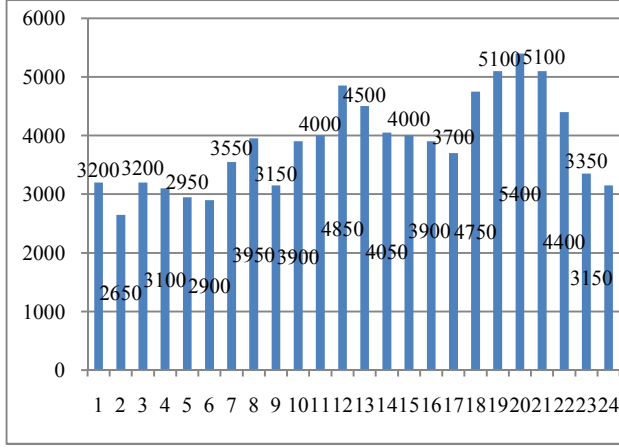


Figure I. The daily load curve in a certain area

#### A. Simulation result

- The AMPSO and PSO are both used to optimize the control strategy that EVs are provided as responsive loads to participate in dispatching in 24-interval hours and the corresponding fitness are shown as TABLE II.
- Obviously, Figure II show that the fitness were obtained by AMPSO algorithm are all shorter than ones were obtained by standard PSO algorithm, which confirm that AMPSO receive a more satisfactory optimization result than the standard PSO algorithm. In these fitness were calculates by standard PSO, there is a obvious fluctuation and not the convergent trend. But the fitness is the shortest only when the size of EVs is 400 in AMPSO algorithm, which means a rather good result was achieved in this case.
- In theory, the more the number of EVs is, the smaller the population's fitness. Although the fitness have an uptrend with the increase of EVs size, this may be a sign that the minimum responsive power EVs provide exceed the power to adjust load curve needed. Because the size of EV is so larger to control the available capacity of EVs to satisfy the requirement of grid easily. In conclusion, it is necessary the available capacity of EVs with V2G are used to response load curve must match the control power needed.

- Base on the optimal condition that is the value of fitness is 43336, comparing the load curve with V2G with the load curve without V2G in the following Figure II.

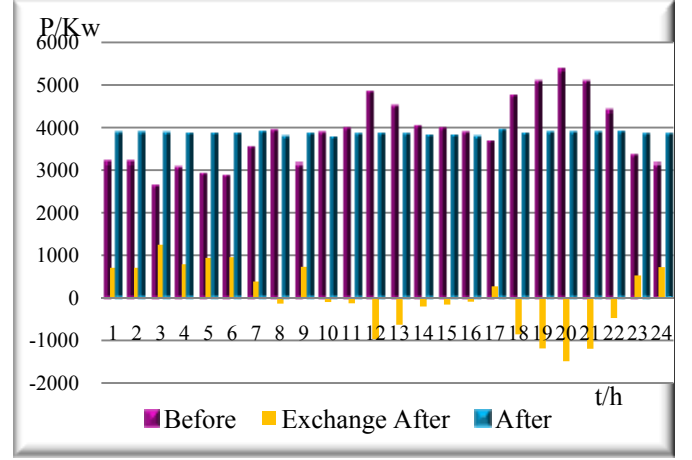


Figure II. The daily load curve before and after V2G participate in schedule

#### B. Results analysis

The value of load curve in each time period is stand at about 4000Kw after adding vehicles with V2G to grid regularly, which means the effect of leveling the given load curve is remarkable. So the result has verified that the AMPSO algorithm is applied to EVs' scheduling control strategy is possible and effective.

### V. CONCLUSIONS

- In this paper, the mathematical model for simulating EVs participate in load response through the method of charge and discharge was implemented. Inspite of considering two constrain conditions about batteries and lines, the available time of EVs was not considered.
- A new adaptive mutation PSO algorithm was presented to optimize the control strategy of the electric vehicle fleets, then the feasibility and effectiveness of the algorithm were proved in the given case.
- This strategy presents a idea that a large flees of EVs divide into several groups to reduce the complexity of each vehicle is dispatched by control center, which provide a method to resolve larger fleets of EVs with V2G technology participate in grid in the future.

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