V2G CHARGE-DISCHARGE STRATEGY WITH EV MASS APPLICATION

Chenggang Du
Institute of Technology and Management of
Shanghai Municipal Electric Power Company– China
ducg@etc.sh.sgcc.com.cn

Jinghan He
Beijing Jiaotong University - China
jhhe@bjtu.edu.cn

ABSTRACT

V2G is to realize dual direction exchange of energy and information between Electric Vehicle (EV) and grid in controlled condition when EV serves as a mobile energy storage unit after its mass application. Improving the regional grid load curve with mass application of V2G is a complicated optimization problem of high-dimension, multiple variables and multiple constraints. The paper analyzes the features of EV usage needs and impacts on grid from mass application of V2G, establishes a dual direction exchange model between EV and grid with V2G pattern through which does research on charge-discharge intellectual control strategy based on Particle Swarm Optimization (PSO) algorithm and demonstrates calculation analysis of samples.

0 INTRODUCTION

With mass application of EV and in-depth development of Smart Grid,V2G(Vehicle to Grid)[1-2] is becoming the focus of research. V2G is to realize dual direction exchange of energy and information between EV and grid in controlled condition when EV serves as a mobile energy storage unit after its mass application. An enormous number of EVs are applied on the platform of Smart Grid in energy storage of grid, emergency power supply in outage and suppression of load fluctuation etc. [3-6]. If we lose overall intellectual coordinated control on charge-discharge of mass EV, there will bury some hidden defects in security and stability for power supply side; vice versa, we could make rational and orderly charge-discharge through integrated intellectual control on EV which will deal with the problem of grid stability due to overload, peak load leveling, reduction of newly increased generation budget as well as save usage cost of EV and embody the philosophy of demand side response. To study mathematical model and control strategy of dual direction exchange of energy between EV and grid with V2G pattern, the paper analyses the features of EV usage needs and the impacts on grid from its mass application.

1 ANALYSIS OF THE FEATURES OF EV USAGE NEEDS AND THE IMPACTS ON GRID

1.1 Analysis of the features of EV usage needs[7]

The capability of charge-discharge has something to do with the number of EV possessed and daily energy consumption of EV driving etc. when V2G is applied in energy storage. The requirements for EV driving range and duration of charge-discharge differ with running modes which will have a direct effect on charge-discharge strategy making of V2G charge-discharge station. As to commercial vehicles like public buses, it is unfeasible to carry out discharge due to fixed route and time, huge energy consumption; while for passenger vehicles such as official cars, business cars and private cars, thanks to unfixed driving scope, elastic driving range and flexible driving time, they could be employed in energy storage and discharge. With different charge-discharge properties, charge-discharge method and control strategy are different with the type of power batteries and even make a difference to the whole control strategy of charge-discharge station.

1.2 Impacts on grid from EV mass application with V2G pattern

EV mass application will bring about larger battery capacity in future and fast charge-discharge power will reach over 100kw level for single vehicle. Frequent charge-discharge practices will produce huge power surge to distribution network, threaten grid security and bring damages to electric power equipment in case of exceeding operation limit as well. As to typical daily load curve showed in Figure 1, if a scientific and orderly charge-discharge plan in V2G charge-discharge station is realized as illustrated in Figure 2, then at the distribution side we could lower peak-valley difference effectively, uplift load rate, decrease the need of reserve generation capacity and make use of EV's advantage of fast response and high integrated efficiency in energy storage and charge-discharge as well.

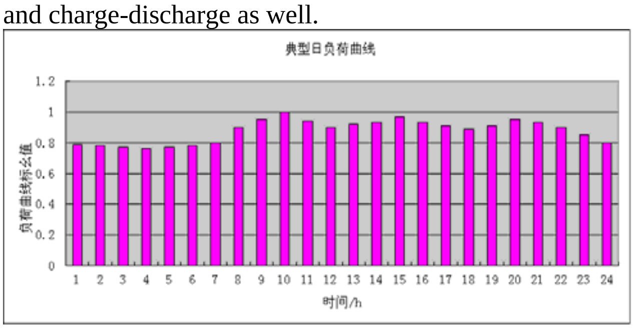

Figure 1 Typical daily load curve

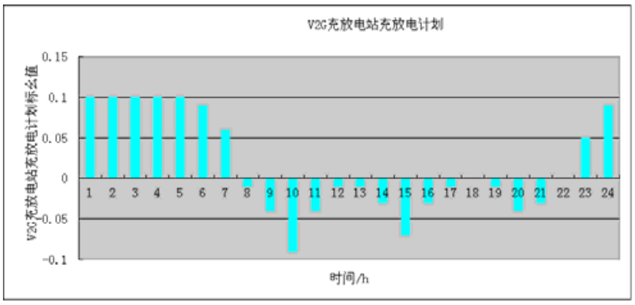

Figure 2 Charge-discharge plan in V2G station

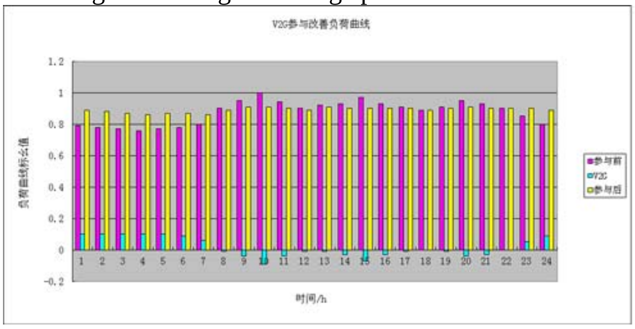

Figure 3 Load curve after improvement with V2G involvement

2 THE MODEL OF DUAL DIRECTION EXCHANGE BETWEEN EV AND GRID WITH V2G PATTERN

After mass application of EV, load curve of regional grid can be improved, when V2G charge-discharge stations connected to grid serving as load and power supply at the same time. As to the improvement of grid load curve and response, the key point is how to make reasonable arrangement for charge-discharge power of V2G charge-discharge stations in jurisdiction in different time based on the existed load curve to realize V2G charge-discharge plan showed in Figure 2. Since V2G charge-discharge stations are numerous, and number of vehicles, available time, initial SOC, charge-discharge power limit, users' SOC limit values are all different with station, leading to charge-discharge power and capacity different from each other, which is a complicated optimization problem of high-dimension, multiple variables and multiple constraints.

2.1 Objective function

The paper divides one day into 24 time periods, with charge-discharge power of each V2G charge-discharge station in every time period as variable, minimum mean square deviation of regional network load curve as objective function, that is:

$$\min F = \sum_{j=1}^{24} (P_{Lj} - P_{arv} - \sum_{i=1}^{n} P_{ij})^2 \quad (1)$$

$$P_{arv} = \sum_{j=1}^{24} P_{Lj} / 24 \quad (2)$$

In equation above, n is number of V2G charge-discharge station; P_{ij} is exchange power of V2G charge-discharge station i in time period j (positive value refers to discharge, negative value charge); P_{Lj} is load power in time period j.

2.2 Restraints

The restraints of V2G charge-discharge station responding to load curve improvement are available time, charge-discharge power and charge-discharge capacity, without considering available time constraint meaning that V2G charge-discharge station could get involved in 24 hours charge-discharge.

1) Power restraint

$$P_{ij\min} \le P_{ij} \le P_{ij\max} \quad (3)$$

In equation above, $P_{ij\max}$ is maximum charge-discharge power of V2G charge-discharge station i in time period j, while $P_{ij\min}$ is minimum charge-discharge power of V2G charge-discharge station i in time period j, which both are affected by number of vehicles, charge-discharge current, real-time voltage of vehicle battery in V2G charge-discharge station i in time period j and distribution network line or transformer capacity connected with V2G charge-discharge station i; P_{ij} is charge (discharge) power of V2G charge-discharge station i in time period j, positive value (negative value) referring to discharge (charge) state of V2G charge-discharge station.

2) Energy restraint

$$\Delta Q_{ij\min} \le \Delta Q_{ij} \le \Delta Q_{ij\max} \quad (4)$$

In equation above, $\Delta Q_{ij\min}$, $\Delta Q_{ij\max}$ are the upper and lower limits of charge-discharge capacity of V2G charge-discharge station i in time period j, which depend on the number of vehicles and upper and lower limits of vehicle battery capacity; ΔQ_{ij} is charge-discharge capacity of V2G charge-discharge station i in time period j.

3 V2G CHARGE-DISCHARGE CONTROL STRATEGY BASED ON PSO

Eberhart and Kennedy proposed Particle Swarm Optimization (PSO) algorithm [8] in simulating bird flock flying and foraging behavior, making group optimum through collective collaboration of birds. The algorithm is of concise concept, convenient practice and little parameter setting and is a high efficient searching method.

3.1 Basic particle swarm optimization algorithm

In search of solution to PSO optimization, every particle has its own position and velocity and a fitness value decided by objective function. First of all, make PSO initialized into a swarm of random particles, every iteration process not completely random and particle updating itself by tracing two extreme values, one is sought by optimal solution particle itself, the other one is sought by optimal solution species group at present. The information of particle I is demonstrated with D dimension vector, position being $X_I = (X_{I1}, X_{I2}, ...X_{ID})$, velocity being $V_I = (V_{I1}, V_{I2}, ...V_{ID})$, other vectors likewise, the updated equation of velocity and position is as follows[8]:

$$v_{Id}^{k+1} = wv_{Id}^{k} + c_1 rand_1^k (pbest_{Id}^k - x_{Id}^k) + c_2 rand_2^k (gbest_{Id}^k - x_{Id}^k) \quad (5)$$

$$x_{Id}^{k+1} = x_{Id}^{k} + v_{Id}^{k+1} \quad (6)$$

In equation above, x_{Id}^k is velocity of particle I in k th iteration in d dimension; w is inertia weight with 1 as basic PSO value; c_1, c_2 are learning factors, usually $c_1 = c_2 = 2$; $rand_1$, $rand_2$ are random number among [0,1] ; x_{Id}^k is present position of particle I in k th iteration in d dimension; $pbest_{Id}^k$ is position of individual extreme value of particle I in d dimension; $gbest_{Id}^k$ is position of global extreme value of whole group in d dimension. In case of particle far away from searching space, velocity v_d of particle in every dimension is restricted among [$-v_{d\max}$, $v_{d\max}$] .

3.2 Restraint treatment method

There are two usual treatment methods to restraints that one is direct change, the other is penalty function method [9]. Considering to many restraints in the problem, restraints on charge-discharge power in single time period in every V2G charge-discharge station, we adopt the former one here---modifying the position of random particles to fulfill the restraints condition that is judgment on whether it satisfied when every new position is generated from each iteration, if not, make modification to position of particle according to equation (7) and (8):

$$P_{ij} = \begin{cases} P_{ij\max}', (P_{ij} > P_{ij\max}') \\ P_{ij\min}', (P_{ij} < P_{ij\min}') \end{cases} \quad (7)$$

$$\begin{cases} P_{ij\max}' = \min(P_{ij\max}, \Delta Q_{ij\max} / \Delta t) \\ P_{ij\min}' = \max(P_{ij\min}, \Delta Q_{ij\min} / \Delta t) \end{cases} \quad (8)$$

In equation above, Δt represents single time period, 1 hour in the paper.

3.3 Basic PSO algorithm procedure

PSO algorithm applied in V2G charge-discharge control strategy minimizes objective function through optimizing exchange power between V2G charge-discharge station and grid in every single time period. The dimension of particle in the paper is $24 \times n$, among which n is number of V2G charge-discharge station, so particle I position is :

$$P_I = [\overbrace{P_{1,1}, P_{1,2} ... P_{1,24}}^{\text{站1的24时刻}}, \overbrace{P_{2,1}, P_{2,2} ... P_{2,24}}^{\text{站2的24时刻}} ... P_{i,j} ... P_{n,1} ... P_{n,24}] \quad (9)$$

Basic PSO algorithm procedure in details:

1) Setting basic parameters, initializing position and velocity of particle;
2) Modifying position of particle according to restraints (7) and (8);
3) Calculating fitness (objective function value) of particle swarm based on equation (1), recording particle best position and group best position;
4) Updating velocity and position of particle in the light of equation (5) and (6);
5) Checking whether velocity exceeds limited value, if so, setting velocity limits as the value and repeating step 2;
6) Calculating fitness of particle swarm, updating and recording particle optimal position and group optimal position;
7) Judging whether it reaches to maximum iteration time, if so, stopping calculation; if not, returning to step 4.

3.4 Calculation analysis of samples

The calculation takes some regional network as an example, load curve of five V2G charge-discharge stations improved, 24 hours load power before improvement is showed in Figure 1.

Figure 1 Some regional network daily load curve

period (hour)	1	2	3	4	5	6	7	8	9	10	11	12
load (kW)	3200	3200	2650	3100	2950	2900	3550	3950	3150	3900	4000	4850
period (hour)	13	14	15	16	17	18	19	20	21	22	23	24
load (kW)	4500	4050	4000	3900	3700	4750	5100	5400	5100	4400	3350	3150

To simplify calculation, we set the charge-discharge power limits of each station as $-1000kW \le P_{ij} \le 1500kW$, charge-discharge capacity limits as $600kWh \le Q_i \le 3000kWh$, if vehicle battery of each V2G charge-discharge station is completely the same then we could seek average initial SOC showed in Figure 2; number of particle in the algorithm is $N = 20$; inertia weight coefficient depends on linear decreasing strategy proposed in document [10], value selection of w relies on equation (10):

Figure 3 Charge-discharge power in each time period in V2G charge-discharge stations（kW）

period / station	1	2	3	4	5	6	7	8	9	10	11	12
1	-189	0	0	0	-235.2	0	0	300	0	0	0	0
2	0	0	-504.1	-600	-425	0	0	0	-600	33.3	0	746.2
3	-477.7	0	-294.8	0	0	0	0	0	-116.7	0	0	0
4	0	0	0	-166.7	-256.5	-325.6	0	0	0	0	133.3	237.1
5	0	-666.7	-417.8	0	0	-641.1	-316.7	0	0	0	0	0
period / station	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
1	0	0	0	33.3	0	0	0	300	0	0	0	-116.7
2	597.5	0	0	0	0	529.8	916.3	874.6	545.1	533.3	0	-600
3	0	0	0	0	0	0	0	0	0	0	-516.7	0
4	35.8	183.3	133.3	0	-166.7	353.5	317.0	0	617.9	0	0	0
5	0	0	0	0	0	0	0	358.8	70.4	0	0	0

$$w = w_{max} - t\frac{w_{max} - w_{min}}{T_{max}} \quad (10)$$

In equation $w_{wax} = 0.95$, $w_{min} = 0.4$, iteration time $T_{max} = 1000$; $v_{max} = 40$, $v_{min} = -40$. Charge-discharge power in 24 time periods in each V2G charge-discharge station (positive value referring to EV discharge, negative value EV charge) is calculated by adoption of basic PSO algorithm, results in Figure 3. It's evident that load curve is improved demonstrated in Figure 4 produced with data in Figure 3 plus -1.

Figure 2 Average initial value of SOC in each V2G charge-discharge station

V2G charge-discharge station	1	2	3	4	5
Average initial value of SOC in each station	50%	80%	40%	70%	60%

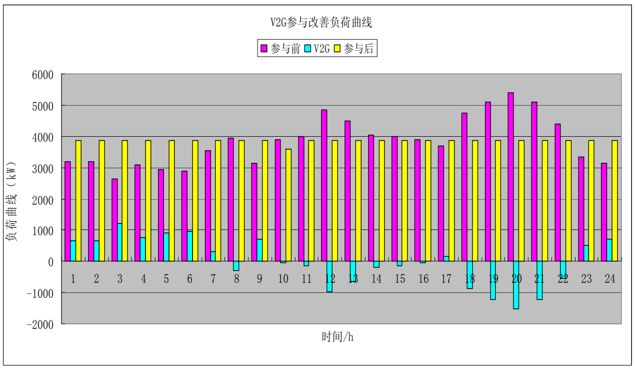

Figure 4 Load curve before and after improvement with V2G involvement

4 CONCLUSION

The paper analyses the impact on grid from mass application of EV combined with features of EV users' needs and change of grid load, constructs dual direction exchange model between EV and grid with V2G pattern, through which does research on intellectual charge-discharge control strategy based on PSO, in the hope of providing new ideas for V2G technology mass application.

REFERENCES

[1] Kempton W., Tomic J., Letendre S., Brooks A. and Lipman T., "Vehicle-to-Grid power: battery, hybrid, and fuel cell vehicles as resources for distributed electric power in California", Working Paper Series with number UCD-ITS-RR-01-03, Jun., 2001.

[2] Kempton W. and Letendre S., "Electric vehicles as a new source of power for electric utilities", Transportation Research, vol. 2, no. 3,1997, pp.157-175.

[3] Brooks, Alec, "Vehicle-to-Grid Demonstration Project: Grid Regulation Ancillary Service with a Battery Electric Vehicle" Report, AC Propulsion, December 2002.

[4] W.Kempton and J.Tomic "Vehicle to Grid Implementation: from stabilizing the grid to supporting large-scale renewable energy", Journal of PowerSources, Volume 144, Issue I, 1 June 2005, pp. 280-294.

[5] W.Kempton, etc, Report from an industry-university research partnership, "A test of V2G for energy storage and frequency regulation in the PJMsystem", Aug 2008

[6] J.Tornic, W.Kempton, "Using fleets of electric-drive vehicles for grid support, "Journal of Power Sources, Vol 168, Issue 2, 1 June 2007, pp. 459-468.

[7] TENG Letian, HE Weiguo, DU Chenggang, LOU Xiaodong, "Power supply modes for electrical vehicles and their impacts on grid opera tion",East China Electric Power, Vol. 37 No. 10,Oct 2009,pp.1675-1677.

[8] Ji Zheng, Liao Huilian, Wu Qinghua, "Particle Swarm Optimization algorithm (PSO) and application". [M]. Beijing: Science Publishing Housing, 2009.

[9] Zhao Jinjin, Li Xin, Peng Yi etc. "Distribution network reconfiguration based on particle swarm optimization algorithm and injection power of distributed generation integrated optimization algorithm", [J] Power Network Technology, 2009,33 (17) 162-166

[10] Liu Junmin, Gao Yuelin, "Chaotic particle swarm optimization algorithm", [J].Computer Application, 2008, 28 (2):222-226.