IOP Conference Series: Earth and Environmental Science

Research on charging and discharging control strategy for electric vehicles as distributed energy storage devices

To cite this article: Min Zhang *et al* 2018 *IOP Conf. Ser.: Earth Environ. Sci.* **121** 042019

EEEP2017 IOP Publishing
IOP Conf. Series: Earth and Environmental Science **121** (2018) 042019 doi:10.1088/1755-1315/121/4/042019

Research on charging and discharging control strategy for electric vehicles as distributed energy storage devices

Min Zhang, Feng Yang[1], Dongqing Zhang and Pengcheng Tang

University of Electronic Science and Technology of China, Chengdu, 611731, China.

[1] 422375789@qq.com

Abstract. A large number of electric vehicles are connected to the family micro grid will affect the operation safety of the power grid and the quality of power. Considering the factors of family micro grid price and electric vehicle as a distributed energy storage device, a two stage optimization model is established, and the improved discrete binary particle swarm optimization algorithm is used to optimize the parameters in the model. The proposed control strategy of electric vehicle charging and discharging is of practical significance for the rational control of electric vehicle as a distributed energy storage device and electric vehicle participating in the peak load regulation of power consumption.

1. Introduction

As a distributed energy storage device, electric vehicles can adjust the load of power grid peak and valley load value, and increase the share of renewable energy power generation. In the case of blackout or serious disaster, the storage capacity of electric vehicles can effectively guarantee the stable operation of the power grid [1].

Henrik Lund, Willett Kempton analysed the feasibility of the electric car as a distributed energy storage. Electric vehicles discharge electricity into the grid during peak hours, charging for electric vehicles can be profitable during the trough [2]. Fabian Kley et al considered the influence of electric vehicle's user habits, the possibility of electric cars being grid power source by V2G technology and the impact on the peak of power grid [3]. In the literature [4], an electric vehicle charging and discharging control strategy is proposed, which takes into account user's travel needs, battery status during idle period and the contribution to the power system. Literature [5] proposed an electric vehicle scheduling strategy for V2G aggregator, minimize the cost of electricity for users when traveling. In the literature [6], an orderly charging and discharging control strategy for electric vehicles is proposed, minimize the cost of electricity for users.

The main research of this paper is how to control the charge and discharge of electric vehicles to achieve the function of peak load shifting and the lowest cost of electric vehicles.

2. Control strategy of electric vehicle charging & discharging

2.1. First stage model

2.1.1. The objective function. The purpose of this stage is to minimize the cost of electricity vehicle for users, the objective function of this stage is:

$$\min F_1 = \min[\sum_{t=1}^{T} C_{s-t} \times h_t \times p \times \Delta t \times P_t + C_{bat-t}] \tag{1}$$

Where, C_{s-t} indicates whether the electric vehicle is in a running state in the t time period. h_t indicates that the charging and discharging status of electric vehicles in the t time period. p is the charge and discharge power of electric vehicle. Δt is a time period, $\Delta t = 20\min$. P_t is the cost of power grid in the t time period. T is the number of time periods within a day. C_{bat-t} indicates that battery costs for electric vehicles in the t time period.

2.1.2. Constraints. (1) Driving State Constraint of Electric Vehicle

C_{s-t} indicates that the driving state of electric vehicles, which is shown in type (2):

$$C_{s-t} = \begin{cases} 0, v > 0 \\ 1, v = 0 \end{cases} \tag{2}$$

Where, V indicates that the speed of electric vehicles, and the driving state C_{s-t} is determined by the probability of electric vehicles being parked at each period. The way of calculating the parking of the vehicles in a residential area and fit function[7] is shown in type (3):

$$P_{res}^{*}(t) = 1 - 0.54\exp(-(\frac{t-15.07}{5.84})^2) - 0.24\exp(-(\frac{t-9.68}{2.46})^2) \tag{3}$$

(2) Charge & Discharge State Constraint

Divides the day into 72 periods, an electric vehicle in a controlled state that can only be in one state at the t time period, which is shown in type (4):

$$h_t = \begin{cases} -1 \\ \ 0 \ , n = 1, 2, \cdots, N \\ \ 1 \end{cases} \tag{4}$$

Where, $h_t = 1$ indicates that the electric vehicle is charging by power grid, $h_t = -1$ indicated that the electric vehicle is discharging into power grid, $h_t = 0$ indicates that no action was taken on electric vehicle.

(3) SOC Constraints

In order not to affect the life of electric vehicles and users' requirement, the SOC of electric vehicles needs to be in the certain range: $0.2 \le SOC \le 0.9$. In this paper, the SOC is not less than 0.6.

(4) Charge & Discharge Power Constraints

The charging and discharging power is p=5kw.

(5) Battery Cost Constraint

Assume the temperature and discharge power of the electric vehicle battery remain constant, estimate the cost of battery loss by calculating the energy that electric vehicles transfer to the grid, which is shown in type (5), C_{bat} means the purchase cost of electric vehicle battery, L_c means the number of charge and discharge cycles of electric vehicles, d_{DOD} means discharge depth.

$$C_{dis} = \frac{C_{bat}}{L_c Q_b d_{DOD}} \tag{5}$$

The loss of electric energy due to various factors is called power loss cost during the parking, it is shown in type (6):

$$C_e = (SOC(t_{end}) - SOC(t_{begin})) \times Q_b \times \mathrm{P}_1 \tag{6}$$

Among them: C_e is battery cost, t_{begin} means the moment of parking, t_{end} means the moment when electric vehicle start again, Q_b is the rated capacity of the battery pack, P_1 stands for the price of electric for the electric vehicle charging.

To sum up, the battery cost of electric vehicles is shown in formula (7):

$$C_{bat-t}^{n} = C_e + C_{dis} \tag{7}$$

2.2. *Second stage model*

2.2.1. The objective function. The purpose of the second stage model is to solve the set of solutions which make the user load curve smooth in the case of the lowest cost of the user's electric vehicle, the objective function of this stage is as follows:

$$\begin{aligned} minF_2 &= min\left(Household\ micronetwork\ load\right) \\ &= max\left(Charging\ and\ discharging\ load\ of\ electric\ vehicle\right) \\ &= max\left(\sum_{t=1}^{T} |\,C_t \times h_t\,| \times p \times \Delta t\right) \end{aligned} \tag{8}$$

2.2.2. The constraints. (1) Total cost constraints of electric vehicles

In the case of the lowest total cost of the electric vehicle, the constraint on this stage.

(2) Other constraints

The other constraints are similar to the constraints of the first stage model.

2.3. *Improved discrete binary particle swarm algorithm*

Particle Swarm Optimization algorithm(PSO), the formula of velocity and position are shown in equation (9,10).

$$v_{iD}^{t+1} = \omega \times v_{iD}^{t} + c_1 \times rand() \times (p_{iD} - x_{iD}^{t}) + c_2 \times rand() \times (p_{gD} - x_{iD}^{t}) \tag{9}$$

$$x_{iD}^{t+1} = x_{iD}^{t} + v_{iD}^{t+1} \tag{10}$$

Where, ω is weight, c_1, c_2 are learning factors, $rand()$ represents the random number that varies evenly from 0 to 1.

Discrete binary particle swarm optimization, the velocity formula is shown in formula (9), the position formula is shown in equation (11,12):

$$Sigmoid(v_{iD}(t)) = \frac{1}{1+e^{-v_{iD}(t)}} \tag{11}$$

$$x_{iD}(t) = \begin{cases} 1, rand() < Sigmoid(v_{iD}(t)) \\ 0, otherwise \end{cases} \tag{12}$$

Among them: the function of $Sigmoid$ is the probability of changing the position of the particle. Speed $v_{i,j}$ represents the probability $x_{ij} = 1$, which is transformed by using the formula (11).

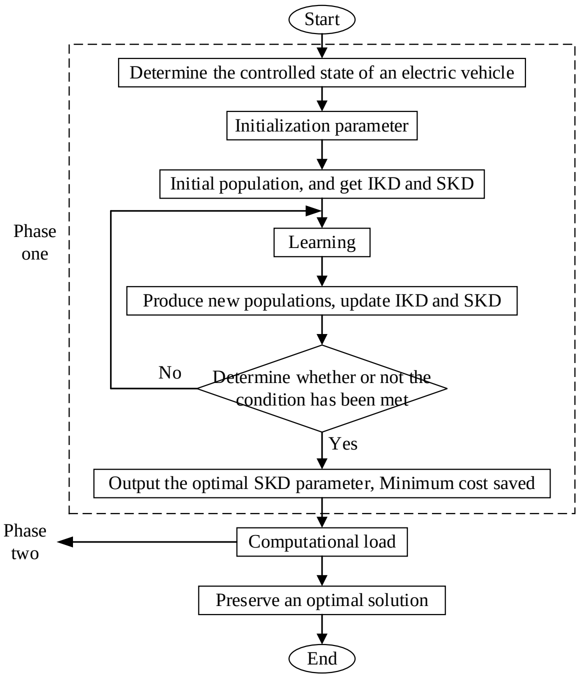

Figure 1. Control strategy flow chart of electric vehicle charging and discharging.

When the electric vehicle is parked($C_s = 1$), there are three states of electric vehicle, charging($h_t = 1$), discharging ($h_t = -1$) and no operation($h_t = 0$). 01 indicates electric vehicle is in charging, 10 indicates electric car is in discharging, and 11 indicates that no action on the electric vehicle. Flow chart of charging and discharging control strategy for electric vehicle based on improved DBPSO is shown in figure 1, corresponds to the first and second stages of the model.

3. Results analysis

In this paper, the battery parameters are the actual data of Nissan's new leaf battery in 2017, the rated capacity is 30kWh, full electricity needs 6 hours, the battery cost is 5499 dollars (consider the old battery) and the cycle life is 3000 times [8]. Initial SOC of electric vehicles is set to 0.2, simulation environment is Matlab2010a.

Random charging strategy does not take into account the price impact. No matter in the time of high electricity price or low price of electricity, electric cars will be charged to electric vehicles as long as electric cars are needed, so the cost is the highest. Minimum charge charging strategy takes into account the effect of the electricity price, charging the electric car at low electricity prices, so the cost will be greatly reduced. In our method, electric vehicle charging in low-price-time (electric car act as a load of family micro grid), while discharging in high-price-time (electric car act as a distributed storage device). The cost of the user is further reduced by considering the effects of electricity prices and electric vehicle discharge factors.

Table 1. Cost and load data for three strategies.

	Cost（$）	Load（kw）
Random charge strategy	3.5733	58.3333
Minimum charge strategy	1.3883	55.0000
This strategy	1.0333	53.3333

In table 1: three strategies are compared, considering the factors of power grid price and V2G technology of electric vehicle, the cost of users can be reduced, the electric vehicle charging and discharging control strategy proposed in this paper can effectively reduce the load when electric vehicles are connected to the grid.

3.1. Cost analysis

BP neural network short-term electricity price forecasting method[9] was adopted to forecast the electricity price in California, USA in July 2007, the time-of-use pricing model is shown in table 2. In this paper, according to the parameters of different time periods, the results of different control strategies are showed in figure2-4.

Table 2. Predicts the time-of-use pricing model.

Period	Price	Period	Price	Period	Price	Period	Price
1	0.053	7	0.095	13	0.061	19	0.108
2	0.052	8	0.067	14	0.072	20	0.105
3	0.045	9	0.063	15	0.044	21	0.073
4	0.055	10	0.058	16	0.044	22	0.073
5	0.069	11	0.067	17	0.041	23	0.060
6	0.061	12	0.059	18	0.063	24	0.073

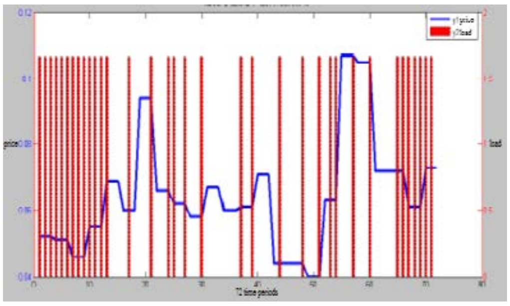

Figure 2. Under random charge strategy.

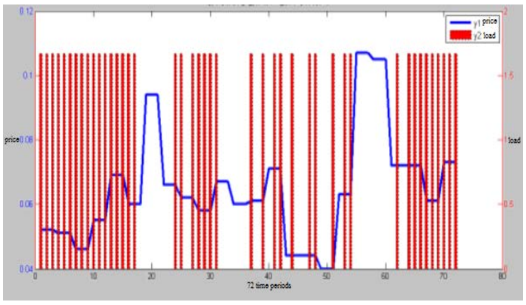

Figure 3. Under Minimum charge strategy.

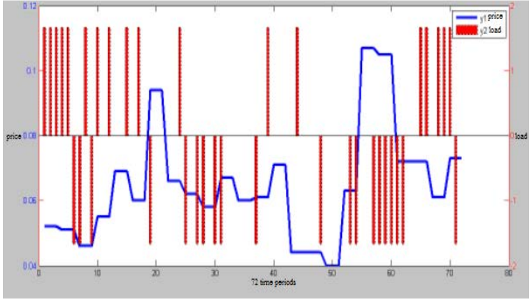

Figure 4. Under this strategy.

According to the above chart, electric vehicle V2G technology can effectively reduce the user's cost.

3.2. Load analysis

The trend extrapolation [10] is used to predict household load, such as table 3. The results of different strategies are showed in figure 5-7.

Table 3. Predicted load model.

Period	Load	Period	Load	Period	Load	Period	Load
1	67	7	73	13	100	19	100
2	67	8	78	14	98	20	93
3	64	9	77	15	84	21	100
4	68	10	90	16	80	22	94
5	69	11	89	17	84	23	71
6	68	12	95	18	98	24	69

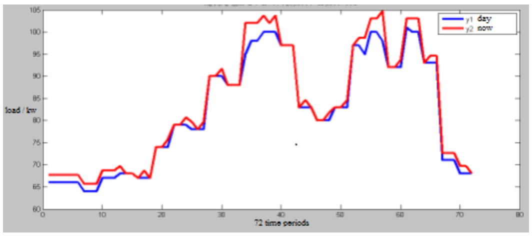

Figure 5. Under random charge strategy.

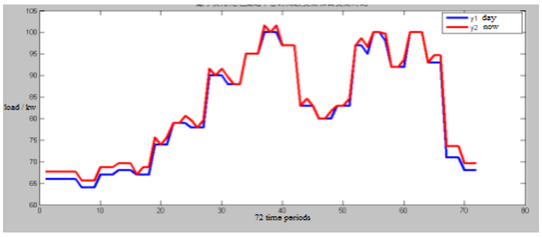

Figure 6. Under minimum charge strategy.

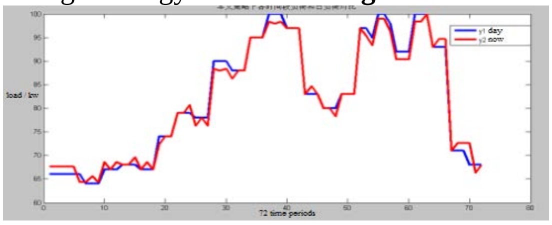

Figure 7. Under this strategy.

From the above chart, the load vale increasing and the peak load decreasing can reduce the power pressure of the home micro grid during peak load.

4. Conclusions

Section 3.1 and Section 3.2 are compared between the power grid and load, the simulation results show that the charging and discharging control strategy of electric vehicle based on the two-stage model has better results in terms of both user cost and load. Not only will the cost of the user be the lowest, but it will also enable a large number of electric cars to join the family micro network, which have the least impact on the family micro grid.

References

[1] Pang C, Aravinthan V and Wang X 2014 Electric vehicles as configurable distributed energy storage in the smart grid *Power Systems Conference(PSC)* 1-5

[2] Henrik Lund and Willett Kempton 2008 Integration of renewable energy into the transport and electricity sectors through *J. V2G[J]* 3578-3587

[3] Fabian Kley, Christian Lerch and David Dallinger 2011 New business models for electric cars-A holistic approach *J* 3392-3403

[4] Yutaka Ota, Haruhito Taniguchi, and Jumpei Baba 2015 Implementation of autonomous distributed V2G to electric vehicle and DC charging system *J. Electric Power Systems Research* 177-183

[5] Chao Peng, Jianxiao Zou and Lian Lian 2017 An optimal dispatching strategy for V2G aggregator participating in supplementary frequency regulation considering EV driving demand and aggregator's benefits *J. Applied Energy* 591-599

[6] Yu Hao-ming, Huang Chun and Zhao Wei 2014 Coordinated Charge and Discharge Control Strategy Based on Time-of-use Price from Electic Vehicle Customer Side *J* 95-98

[7] Zhang Hongcai 2014 A Prediction Method for Electric Vehicle Charging Load Considering Spatial and Temporal Distribution *J. power system automation* 13-20

[8] http://www.sohu.com/a/118862868_448326 *EB/OL*

[9] Yuxiao Huang 2016 Strategy Research for Household Electricity Loads Considering Electric Vehicles *D. University of Electronic Science and technology of China*

[10] Yang Hong-Tzer, Huang Chao-Ming 1998 New short-term load forecasting approach using self-organizing fuzzy AEMAX models *IEEE Transactions on Power Systerms* 217-225