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Optimizing the Load Curve of Electric Vehicle Battery Swapping Station

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***Abstract*—To develop electric vehicle (EV) is an efficient method to deal with energy shortage and environment pollution. Based on the comparison among three battery charging modes, this paper first clarifies the advantage of battery swapping mode. Compared with normal charging mode and fast charging mode, battery swapping mode is much easier to control the charging and discharging behaviour of EVs. Reflect on the load curve, the load curve of EV battery swapping stations (EVBSS) have more potential to be optimized. Then, the profit pattern, load characteristics and effects to grid of the mode is analysed in detail. After that, an optimal charge/discharge strategy for an EVBSS is established and studied. And the optimized load curve of an EVBSS can be obtained. Furthermore, sensitivity analysis is made to improve the profit of the EVBSS. Finally, some conclusions are made, and some suggestions for electric vehicle development are prospected.**

***Index Terms*—Battery swapping station; electric vehicle; load characteristics; optimal charge/discharge strategy.**

I. INTRODUCTION

The development of electric vehicles (EVs) has been a consensus in response to energy shortage and environment pollution worldwide. In China, it is predicted that the retain number of automobile will be over 200 million in 2020. They will consume more than 55 % of the total petroleum consumption in the country, namely about 400 million tons every year. The energy consumption is huge, while a mass of pollution is also ineluctable. In this context, EV industry is faced with a unprecedented development opportunity.

However, with the rapid incensement of EVs, if their charging behaviours are unordered, they will bring potential threats to the security and reliability of power system operation [1]. Conversely, if their charging even discharging behaviours are well ordered, EVs can safely access to power systems in a large scale, and bring benefits in the meanwhile [2]. In other words, well ordered EVs can be regarded as flexible loads in the grid, which can participate in the optimal operation of power systems [3].

At present, there are mainly three charging modes for EVs, namely normal charging mode (NCM), fast charging mode (FSM), and battery swapping mode (BSM). Different from NCM and FCM, BSM can not only control the electricity charging behaviours, but also control the electricity discharging behaviours by EV battery swapping station (EVBSS). The EVBSSs can be regarded as energy storage systems, and bring benefit to power systems both in security and economy.

This paper first makes a detailed comparison among the three charging modes for EVs, and focuses on an analysis of the advantage of BSM. Then, the profit pattern and load characteristics of EVBSSs are analyse, and their effects to power systems can be concluded. After that, a linear optimization model for EVBSS operation is established, and simulated on the IEEE 14-bus test system. Finally, some conclusions and perspectives are made.

II. COMPARISON OF EV'S CHARGING MODES

A. EV Charging Modes

As it is mentioned above, there are mainly three charging modes for EVs at present. Their characteristics are briefly introduced as below:

1. NCM, or slow charging mode. In this mode, EVs are linked and charged from normal AC power sources. This charging mode is comparatively simple, and the charging current is comparatively small. But EVs need a comparatively longer time to be fully charged. Thus, this charging mode is mainly used in residential districts or parking garages. However, as the wide distribution of charging-piles, the arbitrariness of charging behaviours are large. Power grid operators can hardly manage or forecast the charging behaviours.
2. FCM, or emergency charging mode. In this mode, EVs are linked and charged from large-current cables of AC charging-piles. About 70 %~80 % of the full battery capacity can be charged in a fast time. This charging mode is suitable for traffic flow populated areas or in emergency. Similar with NCM, charging behaviours can also hardly be managed or forecasted in FCM. Meanwhile, due to the large charging current, the battery life will be shortened.
3. BSM, or mechanical charging mode. In this mode, EVs swap their empty batteries in EVBSSs, and EVBSSs charges the empty batteries in other times. Usually, the charging time is arranged during the light-load periods. Thus, peak load shifting can be realized, and EVBSSs can pay a comparatively low electricity price to the grid. However, BSM puts forward comparatively high standardization requirements to battery charging technology, battery specification, interface standard, etc.

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B. Advantage of Battery Swapping Mode

Compared with NCM and FCM, BSM is easy to operate and maintain, and easy to manage centrally. Thus, it has been regarded as an important battery charging mode, and has a wide application prospects.

In BSM, on one hand, BSS can charge batteries (buy electricity from the grid) during light-load periods with a comparatively low electricity price, which will help to reduce the operation cost. On the other hand, BSS can discharge batteries (sell electricity to the grid) during heavy-load periods with a comparatively high electricity price. This undoubtedly increases the BSS's revenue. Besides, such a profitable behaviour objectively realize peak load shifting, which means it also benefits the grid.

To the grid, EV charging/discharging management based on vehicle to grid (V2G) technology has to depend on vehicle-mounted smart chargers on the EVs to realize intelligent energy storage [4]. However, such smart chargers are difficult and complex to realized, and will increase the battery management costs. Besides, as the distribution of EVs is uncertain, intelligent energy management on single units can still not be well utilized by the grid [5].

For the above reasons, if V2G can be transfer to B2G (battery to grid), the managed and controlled objective can be transfer from single EV to EVBSS. And then, centralized management and control of EV batteries can be realized.

In conclusion, EVBSS can gain profits both from EV owners and grid. Meanwhile, its electricity charge/discharge behaviours objectively realize peak load shifting. Thus, EVBSS increase its profit while also improve the security and economy of grid operation.

III. PROFIT PATTERN AND LOAD CHARACTERISTICS OF EVBSS

A. Profit Pattern of EVBSS

As it is mentioned above, EVBSS mainly benefits from two respects, namely the EV owners and the grid.

As for the EV owners, EVBSS charges batteries during light-load periods from the grid with a comparatively low electricity price, and sells the full-charged batteries to the EV owners in a high price. The profits owned can be expressed as

$$f_1 = \sum_{i=1}^{N} [\lambda_{sell} \times C - \bar{\lambda}_i \times C / \eta_c - a_0], \quad (1)$$

where N refers to the battery swapping demands in the research period; C (kWh) refers to the battery capacity; λ_{sell} (\$/kWh) refers to the electricity sold to EV owners; $\bar{\lambda}_i$ (\$/kWh) refers to the average charging electricity price for the i^{th} battery; η_c refers to the charging efficiency; a_0 (\$) refers to the battery depreciation for a charge/discharge cycle.

Equation (1) can be divided into two parts as (2), where f_{1-1}=$(\lambda_{sell} \times C - a_0) \times N$ refers to the fixed incomes and costs, f_{1-2}=$\sum_{i=1}^{N} (\bar{\lambda}_i \times C / \eta_c)$ refers to the variable costs.

$$f_1 = f_{1-1} + f_{1-2} = (\lambda_{sell} \times C - a_0) \times N - \sum_{i=1}^{N} (\bar{\lambda}_i \times C / \eta_c). \quad (2)$$

On the other hand, as for the grid, EVBSS charges (buy electricity from the grid) during light-load periods in low prices and discharges (sell electricity to the grid) during heavy-load periods in high prices. Such profits can be expressed as

$$f_2 = \sum_{i=1}^{M} (\bar{\lambda}_{d,i} \times \eta_d - \bar{\lambda}_{c,i} / \eta_c) \times C_i - a_0 \times TC, \quad (3)$$

where TC refers to the charge/discharge times; η_d refers to the discharging efficiency; $\bar{\lambda}_{d,i}$ and $\bar{\lambda}_{c,i}$ refer to the average discharging and charging electricity price for the i^{th} charge/discharge. Obviously, only when the difference between the buying and selling is larger than the battery depreciation, such a charge/discharge behavior is profitable.

Thus, the total profits gained of the EVBSS in the research period is f=$f_1 + f_2$.

B. Load Characteristics of EVBSS

Based on the profit pattern analysis of EVBSS above, it can be concluded that:

1. When the battery swapping demand and price are fixed, the profits from the EV owners are fixed. If the EVBSS wills to gain a larger profit, to reduce its own operation costs is the only way. That means EVBSS should reduce its battery charging costs to the greatest extent. Thus, on the promise of satisfying battery swapping demands, EVBSS should charge its battery during light-load periods in low electricity prices as far as possible.
2. Under the time-of-use (TOU) or step tariff electricity price mechanisms, if the difference of electricity price between heavy-load and light-load is large enough, EVBSS can increase its profit by charging during light-load periods and discharging during heavy-load periods. The precondition is that the EVBSS has enough batteries to guarantee that such a behaviour will not affect the basic battery changing demands. The boundary condition is that the profit gained from every charge/discharge cycle is larger than the depreciation cost.

Further, the load characteristics of EVBSS appear clear:

1. The load of EVBSS is ordered and controllable, and its time distribution mainly depends on the charge/discharge strategy of the EVBSS. Thus, the load of EVBSS can be regarded as a kind of flexible load.
2. As the electricity price under TOU or step tariff mechanisms usually has a positive relationship with load level, namely heavy load corresponds to high electricity price while light load corresponds to low electricity price, EVBSS will try its best to charge during light-load periods and discharge during heavy-load periods. Thus, EVSS can realize peak load shifting, which facilitate the security and economy of power system operation.
3. Taking the maximum profits as the operation strategy of EVBSS, can meet the interest requirements of EVBSS

operators, as well as be an important basis for grid operators to analyse EVBSS loads.

C. Effects to Grid

As it is analysed above, EVBSS can realize peak load shifting, which can benefit the grid both in security and economy. As for the economy, peak load shifting can reduce power losses efficiently. The power loss reduction will be analysed from transformers and transmission lines respectively.

1) Transformers

Taking the power loss calculation of double winding transformer as an example to clarify the loss reduction of peak load shifting. Assume that the apparent power of the transformer is S_H and S_L respectively, the short-circuit loss is P_k, and the nominal capacity is S_N. Then, the total power loss of the transformer during a certain period is as

$$\Delta E_{T,loss} = \left(S_H / S_N\right)^2 \times P_k \times h_H + \left(S_L / S_N\right)^2 \times P_k \times h_L, \quad (4)$$

where h_H and h_L are the duration of heavy-load period and light-load period respectively.

Assume that the difference between heavy-load power and light-load power is ΔS, namely $S_H = S_L + \Delta S$; and the heavy-load period and the light-load period is equal, namely $h_H = h_L = h$. Then, if $k \times \Delta S\,(0 < k < 1)$ is shifted from heavy-load period to the light-load period, the total power loss of the transformer is as

$$\Delta E'_{T,loss} = \left\{\left[S_L + (1-k)\times \Delta S\right] / S_N\right\}^2 \times P_k \times h + \\ + \left[(S_L + k \times \Delta S) / S_N\right]^2 \times P_k \times h = \\ = [2S_L^2 + 2S_L \times \Delta S + (1-2k+2k^2)\times(\Delta S)^2] \times P_k \times h / S_N^2. \quad (5)$$

The difference between $\Delta E_{T,loss}$ and $\Delta E'_{T,loss}$ is the transformer loss reduction after peak load shifting, which should always be positive

$$\Delta E_{T,loss} - \Delta E'_{T,loss} = 2P_k \times h(k-k^2)\times(\Delta S)^2 / S_N^2 > 0. \quad (6)$$

2) Transmission Lines

As for transmission lines, the total power loss during a certain period can be expressed as

$$\Delta E_{loss} = R(P_H^2 \times h_H + P_L^2 \times h_L) / (V^2 \cos^2 \varphi), \quad (7)$$

where V refers to the node voltage amplitude; R refers to the transmission line resistance; φ refers to the power factor angle; P_H and P_L refer to the average active power during heavy-load period and light-load period respectively; h_H and h_L refer to the duration of heavy-load period and light-load period respectively.

Similarly, assume that the difference between heavy-load period and light-load period is ΔP, namely $P_H = P_L + \Delta P$; and the heavy-load period and the light-load period is equal, namely $h_H = h_L = h$. If $k \times \Delta P\,(0 < k < 1)$ is shifted from heavy-load period to the light-load period, the total power loss of the transmission line is as

$$\Delta E'_{loss} = \frac{R}{V^2 \cos^2 \varphi} \times \\ \times \{[P_L + (1-k)\times \Delta P]^2 \times h + (P_L + k \times \Delta P)^2 \times h\} = \\ = \frac{R \times h}{V^2 \cos^2 \varphi} \times \\ \times [2P_L^2 + 2P_L \times \Delta P + (1-2k+2k^2)\times(\Delta P)^2]. \quad (8)$$

The difference between ΔE_{loss} and $\Delta E'_{loss}$ is the transmission line loss reduction after peak load shifting, which should always be positive, too

$$\Delta E_{loss} - \Delta E'_{loss} = 2R \times h \times (k - k^2) \times \\ \times (\Delta P)^2 / (V^2 \cos^2 \varphi) > 0. \quad (9)$$

IV. OPTIMAL MODEL

Taking maximum benefits of the EVBSS as the objective $f = f_1 + f_2$, an optimal charge/discharge strategy model for an EVBSS in 24 hours can be established. To simplify the model, it is established under such assumptions:

1. The research period, namely 24 hours, is divided into 24 periods, corresponds to 0:00~1:00, 1:00~2:00, … , 23:00~0:00 every day.
2. Assume that the battery capacity is C, and it need time T to be fully charged. Then, the charging power is $P_c = C / T$, and $P'_c = P_c / \eta_c$ when the charging efficiency is considered.
3. Assume that the batteries discharge power at their maximum power $P_{\max}$ when sell electricity to the grid, and the actual discharging power is $P'_{\max} = P_{\max} \times \eta_d$ if the discharging efficiency is considered.
4. The charging or discharging is continues, namely it will not be paused once started.
5. The number of full-charged batteries should always satisfy the demand forecast at the beginning of a period, which means the arrival distribution will not affect the charge/discharge strategy of the EVBSS.
6. The empty batteries swapped for the EVs during the i^{th} period will be arranged at the next period.

Then, the model established can be as:

$$\begin{cases} \max \;\; F_{1d} = \lambda_{sell} \times C \times N + \sum_{t=1}^{24}\sum_{i=1}^{T_w} \lambda_t \times P'_{\max} \times W_t^{(i)} - \\ - \sum_{t=1}^{24}\sum_{i=1}^{T_m} \lambda_t \times P'_c \times M_t^{(i)} - a_0 \times (N + TC), \\ s.t. \;\; N_t + X_t + J_t + K_t + \sum_{i=1}^{T_m} M_t^{(i)} + \sum_{i=1}^{T_w} W_t^{(i)} = Z, \\ \quad X_t + M_t^{(T_m)} + J_t = N_{t+1} + X_{t+1} + W_{t+1}^{(1)} + J_{t+1}, \\ \quad N_t + W_t^{(T_w)} + K_t = M_{t+1}^{(1)} + K_{t+1}, \\ \quad M_t^{(i)} = M_{t+1}^{(i+1)}, W_t^{(i)} = W_{t+1}^{(i+1)}, \\ \quad \sum_{i=1}^{T_m} M_t^{(i)} \le M_{\max}, \\ \quad TC = (\sum_{t=1}^{24} P_{\max} \times W_t) / C, \end{cases} \quad (10)$$

where $N_t, X_t, J_t, K_t, \lambda_t$ refer to the battery swapping demand quantity, backup battery quantity, keep-full battery quantity, keep-empty battery quantity, and electricity price during the t^{th} period respectively; Z and $M_{\max}$ refer to the total battery quantity and charger-pile quantity in the EVBSS respectively; N refers to the total battery swapping demands during the day.

As for charging, if a battery needs T_m periods to be fully charged, then its charging process can be divided into T_m parts. $M_{\text{t}}^{(i)}(i=1,2,...,T_m)$ refers to the battery quantity that at the i^{th} charging part during the t^{th} period. Similarly, as for discharging, if a battery needs T_w periods to be fully discharged, then its discharging process can be divided into T_w parts. $W_{\text{t}}^{(i)}(i=1,2,...,T_w)$ refers to the battery quantity that at the i^{th} discharging part during the t^{th} period.

The optimal model established is actually a linear optimal model, and it is solved using LINGO in this manuscript.

V. SENSITIVITY ANALYSIS

The optimal solution of a mathematical model is meaningful when the mathematical model can reflect the real problem. Actually, the analysis is not finished when using the model in this manuscript yield the optimal solution, because parameters in the linear programming problem are always changing. The parameters in the model are just forecast to the future and the initial data to estimate the parameter are also changeable.

The most important part of the sensitivity analysis is getting the sensitive parameters. These sensitive parameters have a great influence to the final income and the charge/discharge strategy.

A standard form of the linear programming model is:

$$\begin{cases} \max \; Z = C \times X, \\ s.t. \;\; A \times X \leq B, \\ \quad\quad X \geq 0, \end{cases} \tag{11}$$

where Z, X, C, A, B refer to the maximizes of the linear programming model, variables, coefficients of the variables in the objective function, coefficients of the variables in the constraints, constants on right-hand side of the constraints.

If the constant on the right-hand side of the constraints is changed, assumed that only one constant b_r is changed, from b_r to b_r', $b_r' = b_r + \Delta b_r$, b is changed to $\bar{b}$. The optimal solution is b^* after b is changed, $b^* = B^{-1}\bar{b}$, the most favourable value of objective function is Z^*, $Z^* = y^*\bar{b}$, B^{-1} is the matrix of the decision variables in the simplex tableau, y^* is the coefficient of the slack variables after b is changed.

VI. CASE STUDY

Assume that there an imaginary EVBSS, its battery parameters are as Table I.

From Table I, it can be easily found that $a_0 = 240 \times 30 / 4000 = 1.8$ \$, $T_m = 2$ h, and $T_w = 1$ h.

The electricity price, battery swapping demands, backup quantity during the day are listed in Table II.

TABLE I. OPERATION PARAMETERS OF EV BATTERIES.

Index	Parameter
Battery capacity C/(kWh)	30
Charging power P_c/(kW)	15
Max charging power P_{max}/(kW)	30
Charge/discharge efficiency/(%)	95
Battery cost/(\$·(kWh)$^{-1}$)	240
Cycle life/(time)	4000

TABLE II. ELECTRICITY PRICE, BATTERY SWAPPING DEMANDS, AND BACKUP QUANTITY IN 24 HOURS.

t	λ_t	N_t	X_t	t	λ_t	N_t	X_t
1	0.06	50	10	**13**	0.08	80	15
2	0.05	30	5	**14**	0.09	60	10
3	0.05	30	5	**15**	0.10	50	10
4	0.06	50	10	**16**	0.12	140	20
5	0.08	60	10	**17**	0.13	200	25
6	0.12	100	15	**18**	0.15	150	20
7	0.14	150	20	**19**	0.17	100	15
8	0.15	130	20	**20**	0.18	60	10
9	0.14	100	15	**21**	0.17	80	10
10	0.13	60	10	**22**	0.15	100	15
11	0.10	50	10	**23**	0.10	70	10
12	0.09	50	10	**24**	0.08	50	10

From Table II, it can be found that the total batter swapping demand during the day is N = 2000. The battery swapping peaks are a bit earlier than the grid load peaks, because morning battery peak usually appears before people start their work (morning grid peak), and afternoon battery swapping peak usually appears before people get home (afternoon grid peak). Besides, EV owners should pay \$6 every time for battery swapping, which includes \$3.6 for the electricity price, \$1.8 for the battery depreciation, and \$0.6 for the EVBSS's profit. That means, the fixed income for one battery swapping is \$4.2 if the electricity charging cost is not considered.

Then, case study is made under two cases. Case 1: $Z = 1100$, $M_{\max} = 400$; Case 2: $Z = 1200$, $M_{\max} = 450$.

TABLE III. EVBSS MAXIMUM DAILY PROFITS.

Income and expense	Case 1	Case 2
Fixed incomes / ×10^3 \$	8.400	8.400
Profits from selling electricity / ×10^3 \$	0.154	0.666
Total charging costs/ ×10^3 \$	4.784	4.938
Battery depreciation[a] / ×10^3 \$	0.054	0.234
Total profits F_{1d} / ×10^3 \$	3.716	3.894

Note: [a] only refers to the battery depreciation that battery buy electricity during light-load periods and sell electricity during heavy-load periods.

From Table III, it can be seen that both in case 1 and 2, the EVBSS gains profits from the grid by low-price-charge and high-price-discharge. The difference is that in case 2, as the EVBSS has more batteries and charging-piles, it has more opportunity to gain profits from the grid. Table IV shows the operation data of the EVBSS during 24 hours in case 2.

Load power of the EVBSS during 24 hours is shown in Fig. 1, where positive power refers to charging from the grid and negative power refers to discharging to the grid. And the TOU reflects the grid load. Usually, high electricity price corresponds to a heavy grid load, while low electricity price corresponds to a light grid load.

TABLE IV. EVBSS OPERATION DATA DURING 24 HOURS.

t	$M_t^{(1)}$	$M_t^{(2)}$	$W_t^{(1)}$	J_t	K_t	t	$M_t^{(1)}$	$M_t^{(2)}$	$W_t^{(1)}$	J_t	K_t
1	100	350	0	0	690	**13**	70	380	0	355	320
2	350	100	0	325	390	**14**	380	70	0	680	0
3	100	350	0	395	320	**15**	0	380	0	700	60
4	350	100	0	690	0	**16**	0	0	0	930	110
5	0	350	0	730	50	**17**	0	0	0	725	250
6	0	0	0	975	110	**18**	0	0	0	580	450
7	0	0	0	820	210	**19**	0	0	0	485	600
8	0	0	0	690	360	**20**	0	0	130	300	700
9	0	0	0	595	490	**21**	0	0	0	220	890
10	0	0	0	540	590	**22**	0	0	0	115	970
11	0	0	0	490	650	**23**	50	0	0	50	1020
12	380	0	0	440	320	**24**	350	50	0	0	740

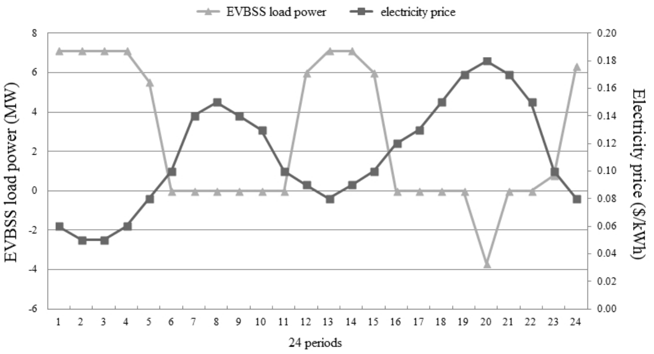

Fig. 1. EVBSS load power during 24 hours.

From Fig. 2, it can be clearly seen that the EVBSS charges during the light-load periods and discharges or does not charge during the heavy-load periods, which realizes peak load shifting.

Further, assume that the above EVBSS is accessed to the IEEE 14-bus test system [6] on bus 2. And the load multiples *k* in 24 hours is as shown in Table V.

TABLE V. LOAD MULTIPLES IN 24 HOURS.

t	*k*	*t*	*k*	*t*	*k*
1	1.05	**9**	1.45	**17**	1.40
2	1.00	**10**	1.40	**18**	1.50
3	1.00	**11**	1.25	**19**	1.65
4	1.05	**12**	1.20	**20**	1.7
5	1.15	**13**	1.15	**21**	1.65
6	1.35	**14**	1.20	**22**	1.55
7	1.45	**15**	1.25	**23**	1.25
8	1.50	**16**	1.35	**24**	1.15

Taking the minimum grid operation costs in 24 hours as the objective function, namely (12), two cases are compared. One is that the EVBSS charges using the optimal strategy proposed above, while the other is that the EVBSS charges disorderly (fitting according to the disordered charging load in [7]–[10], the power factor of EVBSS is always 0.95, and its discharging to grid is not considered)

$$f_{\text{cost}} = \sum_{t=1}^{24} \sum_{i=1}^{Ng} (a_i P_{Gi}^2 + b_i P_{Gi} + c_i), \tag{12}$$

where N_g refers to the generator number in the system; a_i, b_i, c_i refer to the economy coefficient of the i^{th} generator; P_{Gi} refers to the active power output of the i^{th} generator.

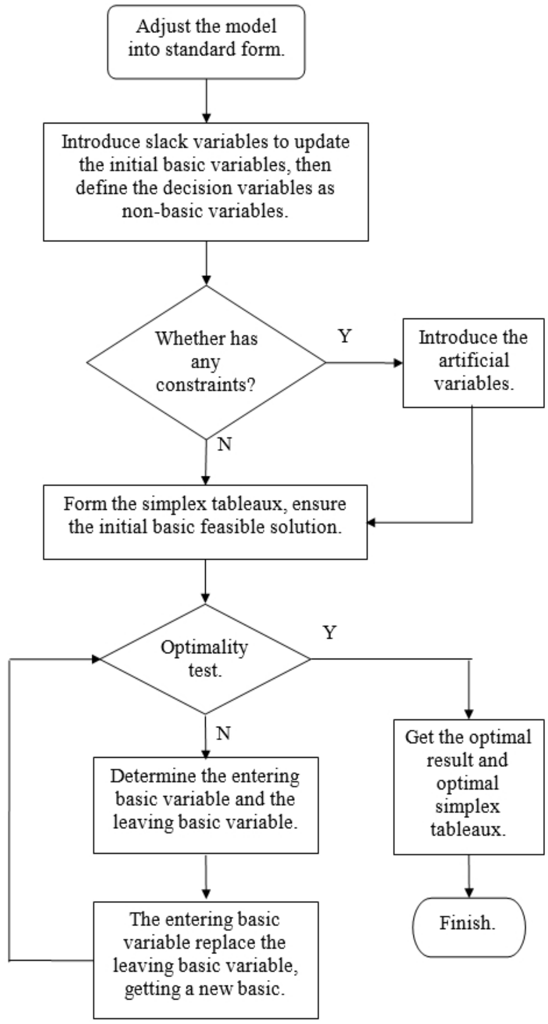

Fig. 2. Flow chart for forming the optimal simplex tableau.

TABLE VI. COMPARISON OF SYSTEM OPERATION ECONOMY.

	Orderly charge	**Disorderly charge**
Total operation costs / $	279,250.95	279,797.03
Total energy losses / MWh	230.67	231.78

Table VI shows that whatever the total operation costs or the energy losses, the grid shows a better performance when the EVBSS charges orderly using the strategy proposed.

In case 2, making the sensitivity analysis, the increased value of the EVBSS benefits will be yielded after the battery depreciation cost or battery number is increased one unit, the increased value is as show in Table VII.

TABLE VII. SENSITIVITY ANALYSIS.

Changed parameter	**Increased EVBSS benefits**
Battery depreciation cost	-4.11
Battery number	0.81

In case 2, the changed EVBSS benefits will be yielded after changing the battery depreciation cost from -40 %~40 % or the electricity price which following the rule that both increased 10 %~40 % the electricity cost during the heavy-load periods, such as period in 7, 8, 9, 19, 20, 21 and decreased 10 %~40 % the electricity cost during the light-load periods, such as period in 1, 2, 3, 4.The value is as show in Table VIII.

TABLE VIII. COMPARISON OF EVBSS BENEFITS WHEN EACH PARAMETER CHANGED.

Electricity price changed degree/%	EVBSS benefits/$	Battery depreciation cost /$	EVBSS benefits/$
-40	3305.66	1.08	5483.41
-30	3385.72	1.26	5067.26
-20	3542.35	1.44	4673.02
-10	3698.98	1.62	4279.83
0	3894.28	1.81	3895.28
10	4135.81	1.98	3512.92
20	4457.67	2.16	3134.16
30	4869.62	2.34	2773.44
40	5568.05	2.53	2412.72

It is more clearly that transferring the data in the Table VIII into a diagram which is shown as Fig. 3.

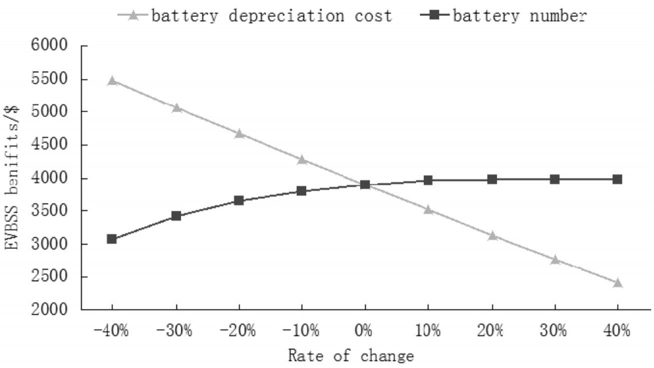

Fig. 3. EVBSS Tendency of EVBSS benefits when each parameter changed.

From Fig. 3, it can be clearly seen that the EVBSS benefits increased slowly when the battery number is increased, it will be saturation when the battery number increased more than 10 %. The battery number is not a sensitivity parameter. On the other side, the EVBSS benefits decreased deeply when the battery depreciation cost is increased, the sensitivity of this parameter is much higher than the battery number. Battery number is a sensitivity parameter.

VII. CONCLUSIONS

Based on the analysis on profit pattern and load characteristics of EVBSS, this paper established an optimal charge/discharge model for EVBSS by considering the effects to grid. Taking the minimum grid operation costs in 24 hours as the objective function, case study shows that the optimal strategy can not only help the EVBSS gain more profits, but also realize peak load shifting for the grid, which creates a win-win business between EVBSS and the grid. What's more, in the same setting background, whatever the total operation costs or the energy losses, the grid shows a better performance when the EVBSS charges orderly using the strategy proposed.

As the energy storage function, EVBSS loads affect the energy consumption distribution of the grid in different time. With the larger scale of EV application, EVBSS can bring more benefits to power systems, such as balancing the uncertainties of renewable energy power, participating system backup, etc.

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