Energy Efficiency Evaluation of EV Charging Network Based on Fuzzy Comprehensive Assessment

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Abstract—**People began to focus on the energy efficiency of EV charging facilities with the rapid development of EV. The energy efficiency evaluation of EV charging network requires a comprehensive reflection of the entire and all aspects of the network. This paper aims to propose a method and a model of energy efficiency evaluation. Firstly EV efficiency factors were analyzed, which were conducted hierarchical classification, and then to calculate factor weights using the G1 group method. Finally energy efficiency evaluation model was established by the analysis of factor set, evaluation set, weighting factor based on fuzzy comprehensive evaluation principle. Simulation results show that the result of energy efficiency evaluation by this model not only contained the retail network energy efficiency, but also reflected the various aspects of the network. The model reflected energy efficiency of the whole network meticulously and roundly, which has a strong practical value.**

Keywords-component; electric vehicle; energy efficiency; fuzzy comprehensive assessment; G1 group

I. INTRODUCTION

As a type of New Energy Vehicles, EV possess the advantage that fuel vehicles are beyond comparison and come into being the research emphasis in the world. In China, the development of the new energy automotive industry, dominated by EV, has listed in "the 12th Five-Year Plan", becoming a major project in promoting energy conservation, emission reduction and updating the industry[1-2].

When EV is in large-scale application, the research on energy efficiency of charging facilities, serving as a type of conversion of electrical energy device ,along with the establishment of integrated EV charging evaluation system, contribute to enhancing the operation efficiency of charging facilities, and guarantee the optimization in equipment use and system operation, which have great social value[3-4].

Therefore, for the energy efficiency evaluation of EV charging network, we conducted comprehensive hierarchical evaluation by using fuzzy set theory in this paper. Dividing EV efficiency factors into two grades and conducting comprehensive hierarchical evaluation by fuzzy comprehensive evaluation method, help to understand the energy efficiency level of the whole network, as well as the energy efficiency level of the each charging facilities in

different operation mode and charging mode[5-6].

In order to study the efficiency factors of EV charging network, this paper ignored internal circuit loss in power electronic devices such as motors, and study the electric conversion and utilization efficiency form the whole behavior of charging electric.

According to the researches in REF[7-8],there can be 6 factors that may have influence on the EV charging network which will be discussed in the following part.

II. THE ENERGY EFFICIENCY RESEARCH BASED ON THE FUZZY COMPREHENSIVE EVALUATION METHOD

The fuzzy comprehensive evaluation method is an effective, multi-factors decision making method that can evaluate many issues which can be influenced by many factors in various aspects[9].

When we use the fuzzy comprehensive assessment , let the $U = \{u_1, u_2, \cdots u_n\}$ be the n factors and $V = \{v_1, v_2, \cdots v_m\}$ be the m evaluations. However, these factors lies in different aspects, thus the weight of factors can be different. And comprehensive evaluation should be V on a fuzzy subset.

$$\underset{\%}{B} = (b_1, b_2, \cdots, b_m) \in F(v) \qquad (1)$$

In the formula above, the entire fuzzy subsets of the universe of V consist $F(v): b_j (j = 1, 2, \cdots, m)$ is the subordinate degree of v_j to fuzzy set $\underset{\%}{B}, \underset{\%}{B}(v_j) = b_j$;the integrated evaluation set $\underset{\%}{B}$ depends on the subordinate degree of each factor, which means the subordinate degree of each factor is a fuzzy subset of U: $A = (a_1, a_2, \cdots, a_n) \in F(U)$, $\sum_{i=1}^{n} a_i = 1$,where a_i denotes the weight of i-th factors. If given the weight set A, we can calculate a integrated evaluation set B.

Considering the ambiguity of the EV charging network, we classified the factors that is related to EV charging network efficiency to get a hierarchical clustering[13]. Firstly we use fuzzy comprehensive evaluation method to assess the lower index, then the senior index. Figure 1 shows the procedures of Fuzzy Comprehensive Assessment Method evaluation.
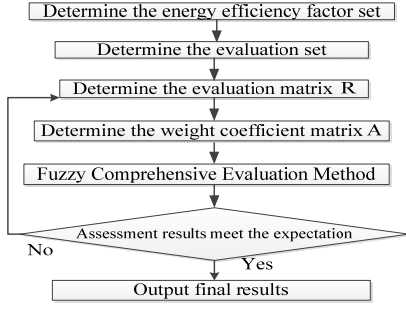
Figure 1. Procedure of fuzzy comprehensive assessment

A. Determine the energy efficiency factor set Abbreviations and Acronyms

Combining the actual live investigation and the efficiency research of factors of EV charging facilities, a system for evaluating EV energy efficiency was established[10-11]. Then we made three charging voltages: U_1 for dispersion slow charging; U_2 for fast charging; U_3 for charging stations. As for dispersion low charging station and fast charging station, we established secondary energy efficiency indicator of EV charging station as followings: the efficiency of distribution network, the efficiency of transformers, the efficiency of charger, the efficiency of power transfer facilities, the energy efficiency of power plant position and the energy efficiency of battery distribution. The assessment model overall were shown in Figure 2, the energy efficiency set is as follows[9].

$U = \{U_1, U_2, U_3\}$,where $U_1 = \{u_{11}, u_{12}, u_{13}\}$ $U_3 = \{u_{21}, u_{22}, u_{23}\}$
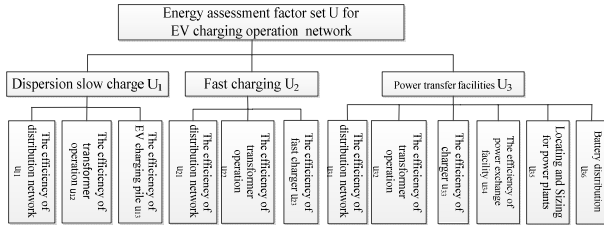$U_3 = \{u_{31}, u_{32}, u_{33}, u_{34}, u_{35}, u_{36}\}$

Figure 2. Evaluation model of EV charging network

B. Determine the evaluation set

Let $V = \{v_1, v_2, v_3, \cdots, v_n\}$ be the assessment set of efficiency for EV charging network. And the set is suitable for all assess factors. However, the establishment of V has a vital impact for the efficient evaluation for EV charging. According to issue we discussed in part 1, we divided the EV energy efficiency evaluation stage into six indicators which are shown in TABLE I.

TABLE I.   ENERGY EFFICIENCY EVALUATION SET OF EV CHARGING NETWORK

Indicators level	content
Fist grade V_1 错误！未找到引用源。	Lowest energy efficiency, the most unreasonable use of power
Second grade V_2	Lower energy efficiency. more unreasonable use of power
Third grade V_3	Low energy efficiency, unreasonable use of power
Fourth grade V_4	Average energy efficiency, reasonable use of power
Fifth grade V_5	High energy efficiency, more reasonable use of power
Sixth class V_6	Highest energy efficiency, the most reasonable use of power

C. Determine the assessment matrix basing on the fuzzy comprehensive evaluation method

For single factor assessment, by the fuzzy mathematics formula :

$$\underset{\sim}{f} : U \rightarrow F(V) \tag{2}$$

$$u_i \mapsto \underset{\sim}{f}(u_i) = (r_{i1}, r_{i2}, \cdots, r_{im}) \in F(V) \tag{3}$$

The fuzzy map $\underset{\sim}{f}$ could gain the fuzzy-relation set $\underset{\sim}{R} \in F(U \times V)$, which means $R_f(u_i, v_i) = f(u_i)(v_i) = r_{ij}$. Thus we can show $\underset{\sim}{R}_f$ with a fuzzy matrix named $R \in u_{n \times m}$:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \tag{4}$$

Where r_{ij} is the subordinate degree of the i-th energy efficiency factor set to the j-th assessment set, which is decided by the subordinate degree function:

$$r_{ij} = f_{ij} = \sum_{j=1}^{n} f_{ij} \tag{5}$$

The f_{ij} in the formula is the power of the i-th energy efficiency factor u_i set to the j-th assessment set v_j .

D. Determine the weight coefficient matrix

The weight of indicators is somehow reflection of the related importance in the assessment system. However, it is always the key issue that how to determine the weight coefficient[12].

The process of G1 method which is also called the rank correlation analysis is as follows:

First: determine the rank relation

In the process of G1 method, if the importance of the relative evaluation criteria of some certain energy efficiency factor u_i is greater than that of u_j ,we mark $u_i > u_j$. And if the evaluation factors $u_1, u_2, u_3 \cdots$, u_n has the relation as follows : $u_1 > u_2 > u_3 \cdots > u_m$,then we call the assessment factors are orderly by ">".

Second: determine the value of s_k

After determining the ordering relation, we used s_k to demonstrate the ratio of importance of u_{k-1} and u_k in the energy efficiency set U:

$$s_k = a_{k-1} / a_k \qquad (6)$$

Where a_k represent the weight of the k-th factor in the energy efficiency set U. The meaning of s_k was shown in the TABLE II.

TABLE II.　　ORDER RELATION AND IMPORTANCE INDEX

S_K	Description
1.0	u_k has the same importance as u_{k-1}
1.2	u_{k-1} is a little more important than u_k
1.4	u_{k-1} is more important than u_k obviously
1.6	u_{k-1} is more important than u_k strongly
1.8	u_{k-1} is more important than u_k extremely

Third: calculating the weight coefficient of a_k

$$a_n = \left(1 + \sum_{k=2}^{n} \prod_{i=k}^{n} s_i \right)^{-1} \qquad (7)$$

$$a_{k-1} = s_k a_k (k = n, n-1, ..., 3, 2) \qquad (8)$$

Fourth step: determine the comprehensive weight

When we hire L experts to evaluate a same issue, due to the different ordering relations given by different experts, there may be two kinds of possibilities that: the L ordering relation are consistent or the L ordering relations are inconsistent.

Let the L_1 experts ($1 \leqslant L_1 \leqslant L$) of the L experts gave the same ordering relation, and we can use s_{ih} to show the value of s_i, where $h = 1, 2, \cdots L_1$:

$$S_i = \frac{1}{L_1} \sum_{h=1}^{L_1} s_{ih} \qquad (9)$$

Put the formula (9) in the formula (8) and (7), and we can calculate the weight coefficient $a_i^{(1)}$ of the L_1 experts determined. After that, we continue to seek if there were some same ordering relations in the $L-L_1$ experts, and if there existed a same ordering relations, we will calculate the weight $a_i^{(2)}, \cdots$ according to the formula (7) to (9) until the rest of the L_e ordering relation are all different. Thus we calculated the every weight coefficient made by the L_e experts, and then calculate the arithmetic average comprehensive value $p_i^{(e)}$. At last, the weight coefficient determined by L experts are as follows:

$$A = c_1 p_i^{(1)} + c_2 p_i^{(2)} + ... c_e p_i^{(e)} \qquad (10)$$

Where $c_i = L_i / L$ is the proportion of a certain weight coefficient determined by a certain expert to all experts.

E. Determine the model of the comprehensive evaluation

We used the hierarchical comprehensive assessment method to evaluate the energy efficiency of EV charging network, and gained the comprehensive evaluation results of factor set U_i by complex arithmetic:

$$B_i = A_i \circ R_i = (b_{i1}, b_{i2}, \cdots, b_{im}) \qquad (11)$$

$$b_{ij} = \sum_{k=1}^{n} (a_{ik} r_{ik}) \quad 1 \leq j \leq m \qquad (12)$$

After we gained the evaluation results of the second grade factor set, we evaluated the first grade factor set which meant that we evaluated the fuzzy assessment space (U, V, R). However, the assessment matrix R of the factor set U was consisted of the comprehensive output B_i of the second factor :

$$R = \begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_L \end{bmatrix} = \begin{bmatrix} A_1 & \circ & R_1 \\ A_2 & \circ & R_2 \\ \vdots & \vdots & \vdots \\ A_L & \circ & R_L \end{bmatrix} \qquad (13)$$

Above all, the final comprehensive evaluation system of the energy efficient evaluation factor set u of the EV charging network is shown as follows:

$$B = A \circ R = (b_1, b_2, \cdots, b_m) \qquad (14)$$

III. EXAMPLES ANALYSIS OF ENERGY EFFICIENCY EVALUATION

Select a certain region in some typical city, where there are several dispersed charging piles, rapid charging station and EV charging station. The energy efficiency evaluation system is showed in Fig.[2].

A. Calculation of energy efficiency evaluation

Adopting the G1 group method introduced above to calculate each factor weight, we get the energy efficiency factor set weights

$$A = (0.3 \ 0.4 \ 0.4)$$

Second-level factor set weights are

$$A_1 = (0.2 \ 0.2 \ 0.6) \qquad\qquad A_2 = (0.2 \ 0.3 \ 0.5)$$

$$A_3 = (0.1 \ 0.1 \ 0.4 \ 0.2 \ 0.1 \ 0.1)$$

By fuzzy comprehensive evaluate U1, we get fuzzy evaluation matrix

$$R_1 = \begin{bmatrix} 0 & 0 & 0.1 & 0.2 & 0.5 & 0.2 \\ 0 & 0 & 0.1 & 0.5 & 0.4 & 0 \\ 0 & 0.1 & 0.2 & 0.6 & 0.1 & 0 \end{bmatrix}$$

The evaluation result of U_1 :

$$B_1 = A_1 \circ R_1 = \begin{bmatrix} 0.2 \\ 0.2 \\ 0.6 \end{bmatrix}^T \circ \begin{bmatrix} 0 & 0 & 0.1 & 0.2 & 0.5 & 0.2 \\ 0 & 0 & 0.1 & 0.5 & 0.4 & 0 \\ 0 & 0.1 & 0.2 & 0.6 & 0.1 & 0 \end{bmatrix} =$$

$$= \begin{bmatrix} 0 & 0.06 & 0.16 & 0.5 & 0.24 & 0.04 \end{bmatrix}$$

By the sane way, we get The evaluation result of U_2, U_3, U_4

$$B_2 = A_2 \circ R_2 = \begin{bmatrix} 0 & 0.03 & 0.08 & 0.63 & 0.24 & 0.02 \end{bmatrix}$$

$$B_3 = A_3 \circ R_3 = \begin{bmatrix} 0.02 & 0.06 & 0.19 & 0.54 & 0.13 & 0.06 \end{bmatrix}$$

Therefore we get fuzzy evaluation matrix of energy efficiency set U:

$$R = \begin{bmatrix} B_1 \\ B_2 \\ B_3 \end{bmatrix} = \begin{bmatrix} 0 & 0.06 & 0.16 & 0.5 & 0.24 & 0.04 \\ 0 & 0.03 & 0.08 & 0.63 & 0.24 & 0.02 \\ 0.02 & 0.06 & 0.19 & 0.54 & 0.13 & 0.06 \end{bmatrix}$$

Then we get the result of energy efficiency evaluation of EV charging network after criticism:

$$B = A \circ R = \begin{bmatrix} 0.008 & 0.051 & 0.148 & 0.555 & 0.196 & 0.042 \end{bmatrix}$$

B. Result analysis

By calculating, the result of energy efficiency evaluation of EV based on fuzzy comprehensive strategy is showed in Tab.[3]

TABLE III.　RESULTS OF ENERGY EFFICIENCY ASSESSMENT

The factor of energy efficiency	Evaluation results					
	Grade one	Grade two	Grade three	Grade four	Grade five	Grade six
U	0.08	0.051	0.148	0.555	0.196	0.042
U_1	0	0.06	0.16	0.5	0.24	0.04
U_2	0	0.03	0.08	0.63	0.24	0.02
U_3	0.02	0.06	0.19	0.54	0.13	0.06

Among the result of energy efficiency evaluation of EV charging network, there 6 memberships graded 0.555 are maximum, Based on maximum membership principle, the evaluation result is graded the fourth-stage: energy efficiency is general and energy consumption is reasonable. This result indicated that energy efficiency is general and energy consumption is reasonable in generally.

In the evaluation set, three grades including the fourth, the fifth and the sixth grade are treated as the case that the level of energy efficiency and energy consumption are reasonable. We could regard the factors rated as the fourth, the fifth or the sixth stage as reaching the standard. In the Fig about the comprehensive evaluation of EV charging network, about 89.3% evaluation experts agree the integral energy efficiency level of EV in this region reaches the standard. As for each charging link, about 78% evaluation experts agree dispersed slow charging stations reach the standard. About 89% evaluation experts agree rapid charging stations reach the standard, while about 73% evaluation experts agree charging stations reach the standard

For further analysis, we might as well rank the energy efficiency evaluation set by score, where the total points is 100.Grade 0,30,50,60,80 and 100 from the first-stage to the sixth-stage, respectively and get the point table as TABLE IV

TABLE IV.　RESULTS OF ENERGY EFFICIENCY ASSESSMENT

Factor of energy efficiency	Point of evaluation	Rank
U_1	63	2
U_2	63.9	1
U_3	60.1	3

We can know from the Fig that the all factors of each charging link reach the standard, while the energy efficiency level is near qualified state and has a huge rising space.

IV. CONCLUSION

This paper proposed a method and a model of energy efficiency evaluation by studying the EV charging network efficiency factor. Given the fuzziness of energy efficiency evaluation, the EV efficiency factors were conducted hierarchical evaluation by using fuzzy comprehensive evaluation method in this paper. This method not only contained the various aspects of the network, but also reflected the retail network energy efficiency. With the example verification, this method proved a great practical value.

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