Research on the problem of solar energy storage system based on AHP

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Abstract. Solar energy storage, while currently widely used as a clean and sustainable resource, is a critical issue that impacts the widespread use of solar energy technology. Using solar power to provide electricity can overcome the constraint of avoiding geography, which is crucial for the electricity problem associated with homes built in remote areas. However, it is limited by the sun's irradiation. We should solve the electricity storage problem to support energy requirements at night and on a cloudy day. In our paper, we are tasked to evaluate the utility of battery storage system based on the energy needs and individual's preferences. Considering individual's needs and preferences, we proposed a generalized evaluation model based on AHP method. The method is based on the choice of variables that influence battery storage system section in question 1 and goes through a hierarchical analysis model to calculate the weights of variables. AHP method can effectively represent the preferences of individuals. Besides, we proposed a set of functions to evaluate the satisfaction of individual under each factor by considering individual's expected cost and energy requirements. Finally, we talk about the future of cement batteries. The benefits and drawbacks of cement batteries as energy storage equipment are examined, focusing on cost, safety, and environmental contamination concerns. Furthermore, we assessed the future utility of cement battery in terms of cost, usable capacity, continuous power rating, instantaneous rower rating, lifetime of battery, and other factors.

Keywords: Solar energy storage, fuzzy comprehensive evaluation, AHP, weights

1. Background of Solar Storage

Energy crisis is the biggest problem facing mankind in the 21st century. As a renewable resource, solar energy is inexhaustible. Therefore, the development and utilization of solar energy is of great significance to alleviate the energy crisis. At the same time, in some remote areas, due to the high cost of setting up power supply facilities, to provide electricity for off the grid home through solar energy has become the first choice. However, the use of solar power also has disadvantages, that is, the solar panel does not generate electricity or the power supply is insufficient at night and on a cloud day. Therefore, we need to store the excess electricity generated during the day for people's use at night and on a cloud day.
Considering that the price of battery is relatively expensive, we need to select the appropriate battery storage system according to the actual power demand of each home. Battery storage system selection problem aims to evaluate different types and quantities of battery packs and select the best system. Due to the high cost of battery, the power storage capacity is limited. Because each family has different power demand, including the output power and total power consumption of the power supply system. In addition, the economic situation of each family is also different. Therefore, we need to select the best battery storage system for each family according to the power demand and actual situation of each family.

2. Assumptions and Variables

2.1 Assumptions

Assumption 1: The battery can be fully charged by the electricity generated by solar energy before the night.
Justification 1: The electricity generated by solar panels is related to the illumination radiance and is affected by factors such as illumination intensity and temperature. Therefore, the electricity generated in different seasons is different.
Assumption 2: The change of battery performance with service time is not considered.
Justification 2: After the battery is used for a long time, its capacity and output power will change to some extent. In this paper, we assume that the capacity and output power of the battery remain unchanged during its service life.

Assumption 3: In this paper, the power consumption is calculated when the cloud weather is 1 day.

Justification 3: In practice, the weather conditions are complex, and the cloud weather may last for a long time. Too extreme weather conditions are not considered in this paper. Therefore, suppose that the cloud weather lasts for 1 day.

2.2 Variables and Notations

The variables used in our models and their meanings are list in Table 1.

Table 1 Symbols and Definitions

Variables	Meaning
W	power consumption, in kWh
p	power rating
t	using time of electrical appliances
$\tilde{p}_i$	the average power of the unit area
$\tilde{t}$	average usage time of each person
u_i	control variable. u_i =1: electrical appliances is used at night; u_i =0 electrical appliances is used at daylight
e	electricity generated during the day
p_i'	instantaneous power rating of the i-th electrical appliances
b_i	membership degree system belongs to v_i .
v_k	$V = \{v_1, v_2, \cdots, v_k, \cdots, v_m\}$ is the comment set
R	fuzzy comprehensive evaluation
A	weight vector of factors

3. Questions for Energy Storage Needs Analysis

This paper studies the selection of solar energy storage system for off grid families. Due to the different power consumption of each family, the demand for battery storage system is also different. Therefore, when studying the battery storage system, we first need to analyze the solar energy storage requirements according to the electricity consumption of a home. In this section, we analyze the main factors affecting energy storage needs of off grid families, including energy consumption and continuous rated power and instantaneous rated power. We list the questions as follows to help energy-storage analysis:

What electrical equipment are using energy in this home? What is the quantity of each kind of electrical appliance? The use of electrical appliances is the most direct factor leading to power demand. Different electrical appliances have different functions, and the power demand is also different. Therefore, when analyzing the energy storage of off grid families, we first need to count the types and quantity of electrical appliances in the home.

How many people in the off-the-grid home? The number of family members is one of the important factors affecting the power demand of a family. The greater the number of family members, the higher the demand for electric energy consumption. For example, the greater the number of people, the corresponding use time and quantity of electrical appliances will increase.

What is the power of each electric appliance? The power of electrical appliances is the most direct factor affecting power demand. On the one hand, power is the key factor affecting power consumption. On the other hand, the total power of all electrical appliances used at each time affects the power demand of the energy storage system.

How long does each electrical appliance last every day? When are they used? The daily service time of electrical appliances is another key factor affecting the daily power consumption and the basis for calculating the total power consumption at night and on cloud day energy storage.

What is the area of the house? The use of some electrical appliances is related to the area of the house, such as lighting, space heating and air conditioner. For example, the lighting power per unit area of different homes is roughly the same. The larger the house area, the greater the power used. When the lighting time is the same, the larger the house area, the more power consumption.

Household power consumption is generated by the use of electrical appliances. The power consumption of each electrical appliance is equal to the product of electrical power and working time. The calculation method is as follows:

$$W = pt \tag{1}$$

where W denotes power consumption, in kWh. p denotes the power rating. t denotes the using time of electrical appliances. Therefore, for the electricity energy storage demand analysis of off grid families, it is necessary to understand the types and duration of electrical appliances used every day.

As shown in Figure 1, the statistical results of household electricity energy consumption in the United States are given. The table shows the proportion of energy consumption for different purposes.

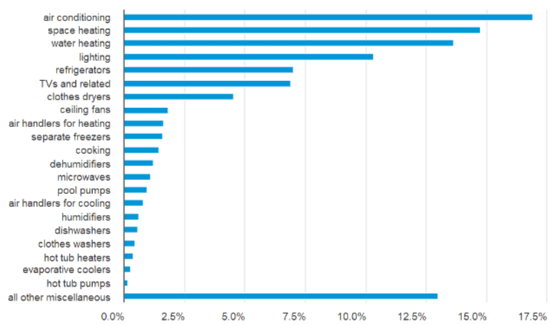

Figure 1 Residential site electricity consumption by the end use, 2015 [3]

When analyzing the power demand of off grid households, select the types of electrical appliances according to the end use of electricity consumption in Figure 1. It should be noted that figure 1 shows that the electricity consumption of in the grid homes' residential site by the end use. Off the grid home is different from that of in the grid home. For example, the large power consumption of space heating and air conditioner will bring higher requirements to the energy storage system.

4. Basic Evaluation Model of Battery System Recommendation

4.1 Factors of Batter Storage System Selection

In this section, for the design of energy storage system, because the price, instantaneous rated power, continuous rated power and available capacity of each battery are different, the power demand of users is also different. We mainly consider the following six factors to evaluate the solar energy storage system. This paper mainly considers six factors: price, service life, instantaneous rated power, continuous rated power, available capacity and round-trip efficiency.
x1: Total price
x2: Lifetime
x3: Continuous rower rating
x4: Instantaneous power rating
x5: Usable capacity
x6: Round-trip efficiency

4.2 Fuzzy Comprehensive Evaluation Method

4.2.1 Evaluation Model

Fuzzy comprehensive evaluation is a commonly used evaluation method. Fuzzy comprehensive evaluation is based on fuzzy mathematics and applies the principle of fuzzy relation synthesis [4,5]. The characteristic of fuzzy comprehensive evaluation method is that the evaluation objects are carried out one by one, and there is a unique evaluation value for the evaluation objects, which is not affected by the set of objects in which the evaluation objects are located. The mathematical model of fuzzy comprehensive evaluation is divided into one-level model and multi-level model. The one-level model is also called single-level evaluation model.
This paper quantifies some factors that are not clear and difficult to quantify, such as the safety, price, service time, power and capacity of solar energy storage system, which is helpful to our choice of solar energy storage system. For the selection of solar power storage system, an evaluation model based on comprehensive evaluation method is established. The specific method is defined as follows:
The first step, we define $\mathbf{x}=\left(x_1,x_2,\cdots,x_m\right)$ as factor set. Where $\mathbf{x}$ denote a battery storage system , m denotes the number of variables used for evaluation. In this paper, let $x_1,x_2,\cdots,x_6$ denote the price, service capacity, service life, continuous rated power and instantaneous rated power。According to the variables we considered in section 4.1, Firstly, the model structure of fuzzy comprehensive evaluation is established, as shown in the figure below,

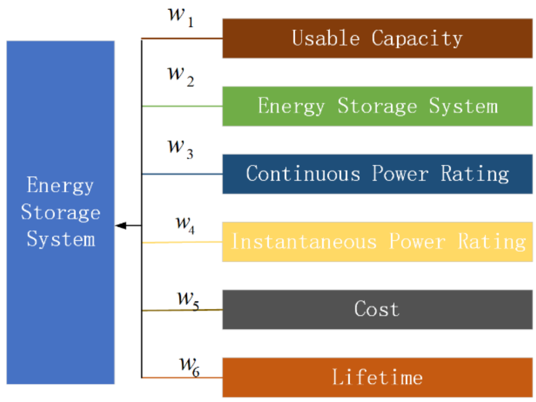

Figure 2 Fuzzy comprehensive evaluation model structure

Secondly, the comment set of solar storage system is established $V=\left\{v_1,v_2,\cdots,v_k,\cdots,v_m\right\}$. When evaluating solar power storage, it can be divided into a certain level. In this paper, from the acceptance degree of users, we divide the evaluation levels into five levels: very satisfied, relatively satisfied, generally satisfied, dissatisfied and very dissatisfied. We score the five levels as 10 points, 8 points, 6 points, 4 points and 2 points respectively. Therefore, the comment set is represented as $V=\left\{10,8,6,4,2\right\}$.
Based on the model structure of solar energy storage system in Figure XX, we establish a single-layer fuzzy comprehensive evaluation function as follows:

$$B=A\circ R$$

Where $B=\left(b_1,b_2,\cdots,b_m\right)$ the fuzzy comprehensive evaluation vector, $b_i,i=1,2,\cdots,m$ denotes the membership degree system belongs to v_i. R represents the evaluation matrix in fuzzy comprehensive evaluation

$$\mathbf{R}=\begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{pmatrix}。$$

where r_{ij} the membership of the ith factor a of any system to the comment v_i . In the evaluation of solar energy storage system, we consider n indexes, each index corresponds to m evaluation levels, and the size of evaluation matrix R is $n\times m$.

4.2.2 Weights of Factors by AHP

Analytic hierarchy process (AHP) is a common evaluation method. It is a combination of qualitative and quantitative methods proposed by American operations research scientist sati. We use analytic hierarchy process to calculate the weight of factors.
Solve the weight vector A, that is, to $A=\left(a_1,a_2,\cdots,a_k\right)$. $a_1,a_2,\cdots,a_k$ Respectively

represent the weight of each factor in the solar power storage system. In Figure 2, among the six factors in our comprehensive evaluation system, users will choose the system suitable for them according to their own needs and preferences. In other words, the importance of the six factors in the comprehensive evaluation is different, the status is important, and a greater weight should be given; On the contrary, a smaller weight should be given. In this paper, the model analytic hierarchy process is used to determine the weight. The basic principle of this method is to start from the hierarchical structure of the comprehensive evaluation system given in (1), compare the indexes of the same layer or domain according to the importance of power consumption for the indexes in each criterion, and construct the judgment matrix according to the judgment scale and meaning of 1-6:

$$\mathbf{D} = \left(d_{ij}\right)_{n\times n} = \begin{pmatrix} d_{11}\ d_{12} \cdots d_{1n} \\ \vdots \quad \vdots \quad \vdots \quad \vdots \\ d_{n1}\ d_{n2} \cdots d_{nn} \end{pmatrix}$$

The rule of assignment of comparison matrix $\mathbf{D}$ is as in Table 2:

Table 2 Scale Rules of Comparison Matrix

values	Meaning
1	and are of the same importance
3	is slightly more important than
5	is more important than
7	is strongly more important than
9	is extremely more important than
2,4,6,8	Median between the neighboring scale values above
Reciprocal	

According to the preference of host of off the grid home, the judgment matrix is constructed according to the assignment rules in Table XX D。Then, the eigenvalue and eigenvector of the judgment matrix are calculated by solving the eigenvalue problem in formula (XX). Among them, the largest eigenvalue is $\lambda_{\max}$. The corresponding eigenvector is $A_{\max} = \left(a_1, a_2, \cdots, a_n\right)$. Then, we got the solution of the weights vector.

$$\mathbf{DA} = \lambda_{\max}\mathbf{A}$$

4.3 Experimental Results and Analysis

In this section, we verify the effectiveness of the generalized evaluation model based on AHP according to the actual energy storage needs and preference data of the 1600 square home. We firstly establish the comparison matrix for this home.

$$\mathbf{M} = \begin{bmatrix} 1 & 2 & 3 & 5 & 7 & 3 & 9 \\ 1/2 & 1 & 2 & 4 & 5 & 2 & 6 \\ 1/3 & 1/2 & 1 & 3 & 4 & 1 & 5 \\ 1/5 & 1/4 & 1/3 & 1 & 3 & 1 & 2 \\ 1/7 & 1/5 & 1/4 & 1/3 & 1 & 2 & 3 \\ 1/4 & 1/2 & 1 & 1 & 1/2 & 1 & 3 \\ 1/9 & 1/6 & 1/5 & 1/2 & 1/3 & 1/3 & 1 \end{bmatrix}$$

Through programming calculation, we got the weight vector is

$$\mathbf{w} = (0.355, 0.226, 0.147, 0.079, 0.071, 0.09, 0.032)$$

CR = 0.024, it passes the consistency test, and the best system is as follow,

Table 3. The price of this system is 6500 dollars.

Battery 1	Battery 2	Battery 3	Battery 4	Battery 5
0	0	0	0	1

5. Cement Battery

5.1 Benefits and Losses of Cement Battery

Professor Tang Luping of Chalmers University of Technology's Department of Architecture and Civil Engineering and his colleagues developed the cement battery in 2021 [6]. Cement batteries can be utilized in construction as a practical material. Cement is one of the main components of concrete, which is widely utilized in various structures such as houses, bridges, etc. That is, in the future, we will be able to apply the cement battery technology in house construction to create a massive "House battery." The benefits and drawbacks of cement batteries are discussed further below.

Advantages of cement battery

Cement battery is of great significance to solar storage and has broad application potential in future solar storage systems. The following are the primary benefits of cement batteries:

The Space needed for the cement battery is small. A cement battery adds some carbon fiber and metal fiber mesh to the building, which does not require additional space, especially in tall buildings.

Material costs are inexpensive and environmental contamination is minimal. Cement battery's primary material is existing building materials, which introduces extra functions of concrete buildings. Thus it has extensive future development potential. Furthermore, the cement battery does not require the addition of other chemicals, and its pollution level is lower than existing batteries.

Huge storage capacity. Even though the average energy density of the current Cement battery is just 7 Wh/m2 (or 0.8 Wh/L), however, there is still much space for advancement in this technology, and gigantic concrete buildings can be seen everywhere. The capacity of a cement battery is very objective if the entire house is converted into one.

However, cement battery also has its shortcomings, mainly including the following aspects:

Service life issues. Buildings with concrete structures have a longer life span that the cement battery cannot last. Therefore, the service life of the cement battery will be a considerable challenge.
Safety. Different from existing batteries, cement batteries are the development of the functions of concrete structures. This means that the cement battery will be directly exposed to the natural environment and corroded by wind and rain. Therefore, its safety will be a potential danger. At the same time, the concrete solidification process may create some gaps that will affect the cement battery's performance.
It cannot be replaced because the service life of the building is much longer than the cement battery. After the cement battery is completed, due to long-term usage, the electricity storage will gradually decrease. It is challenging to replace the internal materials, and the replacement cost is high, which is almost impossible.

The feasibility of a Cement battery for an off-the-grid home or any home
In the future, with the progressive development of cement battery technology, the battery system technology is utilized in the concrete structure to provide electricity for low-power electrical equipment such as lighting, which can be effective in the construction of off-the-grid homes or any home. Ensure lighting time and save power resources

5.2 Cement Battery vs. Currently Available Batteries

To analyze the possibility of cement battery application in the future, we should compare cement batteries to existing available batteries based on the factors influencing the home’s selection. Therefore, we need to understand the following information about cement batteries:
Cost. For the cost calculation of cement batteries, we need to understand the material cost per unit volume of the common concrete and cement battery concrete. In addition, the construction of the cement battery will be more complicated. Therefore, it is necessary to understand the construction cost per unit volume of the common concrete and cement battery concrete.
Battery Life-time. Battery lifetime is an essential property of a battery. Until today, the existing chemical battery technology is relatively mature.

Round-trip efficiency of cement battery. Round-trip efficiency is an important performance indicator of a battery.
Because of the addition of new materials, the concrete with cement battery function will affect the strength of the concrete. We must first determine the material strength, then calculate the area of the structure that may be utilized to construct the cement battery, and then determine its capacity.

6. Conclusion

This paper studies the solar-storage system problem. In terms of electricity accounting, we developed a practical, simple, and effective electricity accounting method by studying the relationship between the power of each electrical appliance, the length of usage, the area of the house, and the number of household members. We also developed an evaluation method based on the AHP method for evaluating battery storage systems. This method uses the analytic hierarchy process to calculate each factor's weight to express the individual's preference for choosing the battery. Then, through the satisfaction function based on energy storage needs, the preferences and needs of each home are fully considered. Finally, through comparative analysis, the effectiveness of this method is verified.

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