Research on carbon emission accounting of SF_6 electrical equipment based on improved random forest algorithm

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Abstract: Due to the large convergence error and high interference coefficient of carbon emissions accounting, research on carbon emission accounting of SF_6 electrical equipment based on improved random forest algorithm is proposed. Firstly, the arc extinguishing characteristics and insulation performance of SF_6 electrical equipment are determined. Then, the differences in the decomposition of substances in SF_6 electrical equipment under various conditions are analysed, and differential optical absorption spectroscopy is used to determine the carbon emission equivalent of the equipment. Finally, the OOB error estimation algorithm is introduced to build an improved random forest algorithm model, and the nonlinear activation function is used to determine the synapse strength, and the information function is used to adjust the convergence value of accounting error to complete the carbon emissions accounting. The results indicate that the proposed method can reduce the convergence value of accounting errors and the interference coefficient of accounting results.

Keywords: SF_6 electrical equipment; carbon emissions; accounting; arc extinguishing characteristics; OOB error estimation; non-linear activation function.

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1 Introduction

With the continuous acceleration of urbanisation in China, people's demands and demands for various energy sources such as electricity are becoming increasingly high. Electric energy, as a key supporting energy for social development, is highly respected and loved by all sectors of society (Tian et al., 2022). In the current era of rapid development, power energy and power supply quality are constantly facing challenges. In order to improve the quality of energy, power enterprises are also constantly innovating and developing, constantly improving and enhancing the issue of power energy. Among them, power equipment is a key part of improving the quality of power energy. In this context, SF_6 electrical equipment emerged (Han et al., 2021). SF_6 is an excellent insulation and arc extinguishing gas, and its special properties make it well applied in power equipment. Common SF_6 electrical equipment includes transformers, circuit breakers, gas insulated switchgear, etc. The application of this gas to electrical equipment effectively improves the performance of power equipment and enhances the quality and safety of power energy transmission (Tang et al., 2021). For SF_6 electrical equipment, the state of SF_6 gas is a key indicator for measuring the state of electrical equipment. If there is a malfunction in the operation of electrical equipment, the problem can be determined by detecting the gas. However, in the long-term gas decomposition of electrical equipment, there have been certain carbon emissions. Carbon emissions are a key factor affecting the entire ecological environment (Sun et al., 2021). The carbon emissions generated during the use and maintenance of SF_6 electrical equipment account for a significant portion of the power system. The calculation of carbon emissions from SF_6 electrical equipment is an important way to measure the quality of electrical equipment. By calculating the carbon emissions of SF_6 electrical equipment, energy efficiency issues during equipment operation can be identified and resolved in a timely manner, improving energy utilisation efficiency and equipment performance. At the same time, enterprises and technical personnel can also be encouraged to engage in technological innovation and green development, promoting the sustainable development of the power system. If the carbon emissions of SF_6 electrical equipment exceed the standard and do not comply with China's energy conservation and emission reduction development strategy (Shi et al., 2021), effective measures need to be taken in a timely manner to reduce emissions. Therefore, it is very important to calculate the carbon emissions of SF_6 electrical equipment. Therefore, researchers in this field have designed many accounting methods and designed many effective methods for this problem.

Gao et al. (2022) proposed a carbon emission accounting method based on Gompertz's law and fractional grey model. In the study of this method, the Gompertz law was used to consider the slowing down of carbon emission growth, and the Gompertz differential equation was established. According to the principle of differential information and the fractional accumulation operator, the differential equation is transformed into a fractional accumulation grey Gompertz model. In addition, the chaotic whale optimisation algorithm was used to optimise the cumulative generation order and gray background values in the proposed model. Then, using Gompertz's dataset and six validation cases on carbon emissions, it was shown that the proposed model exhibited better accuracy in all cases and showed higher efficiency in predicting carbon emissions compared to several existing models. However, the convergence error of this method is relatively large, resulting in poor reliability of the accounting results. Zhang et al. (2022) designed a carbon emission accounting method based on life cycle assessment. Detailed calculations are conducted for carbon balance in this method research. After determining whether UGS is a carbon sink or a carbon source, carbon emissions were evaluated through field investigations, interviews, and model simulations to determine the factors affecting carbon balance and achieve the design of the method. However, when using this method for carbon emission accounting, the interference coefficient of the accounting results is relatively high, resulting in significant errors in the accounting results. Guo and Xu (2022) proposed a carbon emission accounting method to study the optimal scheduling of integrated energy demand response. This study introduces carbon trading mechanisms into the optimisation and scheduling of integrated energy systems. The comprehensive energy demand response mechanism participating in low-carbon economic dispatch is analysed. Elaborated on the relationship between carbon emissions and carbon trading prices in the carbon trading mechanism. Considering the commodity properties of electricity and natural gas loads and the flexible supply characteristics of heat loads, an incentive integrated energy demand response model is established. Finally, with the goal of minimising comprehensive operating costs, a comprehensive energy system model considering power balance and equipment constraints was established to estimate carbon emissions during this process. However, this method is influenced by multiple factors during the process of estimating carbon emissions, resulting in a high interference coefficient in the accounting results.

In order to solve the problem of large convergence error of carbon emissions accounting and high interference coefficient of accounting results in the above methods, this paper designed a carbon emissions accounting method for SF_6 electrical equipment based on the improved random forest algorithm. Random forest is a kind of algorithm based on ensemble learning, which performs well in dealing with complex datasets and classification problems, and has certain anti-interference ability to noise and outliers. For the research of SF_6 electrical equipment carbon emissions accounting, there are nonlinear correlations and complex influencing factors, and random forest algorithm can also capture the nonlinear relationship between features to better realise carbon emissions accounting. However, there are some errors in the calculation result due to the non-pruning of branches for many times in the calculation, and the importance of the equivalent of the calculation cannot be directly determined. In order to better realise the calculation of carbon emissions of SF_6 electrical equipment, this paper uses OOB error estimation method to improve the random forest algorithm. Therefore, based on the improved random forest algorithm, the carbon emission accounting of SF_6 electrical equipment is realised. The method firs, determine the ability of SF_6 electrical equipment to adsorb external electrons and its arc extinguishing characteristics, and calculate the breakdown electric field strength values under different conditions to determine insulation performance. Then, the carbon emission equivalent of the equipment is determined using differential optical absorption spectroscopy. Finally, the OOB error estimation algorithm is introduced to build an improved random forest algorithm model, the nonlinear activation function is used to determine the synapse strength, and the information function is used to adjust the convergence value of the accounting error to complete the carbon emissions accounting research of SF_6 electrical equipment. The technical roadmap studied in this article is described as follows:

Step 1 First, by analysing the molecular structure of SF_6, determine the ability of SF_6 electrical equipment to absorb extra nuclear electrons, so as to determine the arc extinguishing characteristics of SF_6 electrical equipment, analyse the status of SF_6 electrical equipment under different air pressure conditions, calculate the breakdown electric field strength under different conditions, and determine the insulation performance of SF_6 electrical equipment. By analysing the arc extinguishing characteristics and insulation performance of SF_6 electrical equipment, we can gain a deeper understanding of its working principle and performance characteristics, as well as the emission situation and source. This provides a basis for determining the carbon emission process and equivalent of SF_6 electrical equipment, and improves the accuracy of subsequent carbon emission accounting for SF_6 electrical equipment.

Step 2 Secondly, based on the above characteristic analysis, determine the differences in the decomposition of substances in SF_6 electrical equipment under various conditions, and use differential optical absorption spectroscopy method to determine the carbon emission equivalent of SF_6 electrical equipment, achieving the carbon emission process and equivalent research of SF_6 electrical equipment, providing accurate data for subsequent carbon emission accounting and improving the accuracy of accounting.

Step 3 Finally, the OOB error estimation algorithm is introduced to build the improved random forest algorithm model, input the carbon emission equivalent of SF_6 electrical equipment, use the nonlinear activation function to determine the synapse strength, and adjust the convergence value of accounting error with the help of the information function to complete the carbon emission accounting research of the improved random forest algorithm.

Step 4 Experimental research. In order to verify that the proposed method can effectively calculate the carbon emissions of SF_6 electrical equipment, SF_6 gas insulated transformers were selected as the research object, and specific parameters were set in the experimental study. Using method of Gao et al. (2022) and method of Zhang et al. (2022) as comparative methods, convergence error and interference coefficient of accounting results were used as experimental indicators. Under the same parameter settings, the experimental indicators were tested using the proposed method, method of Gao et al. (2022) and method of Zhang et al. (2022), and the results were compared and analysed to verify the effectiveness of the proposed method.

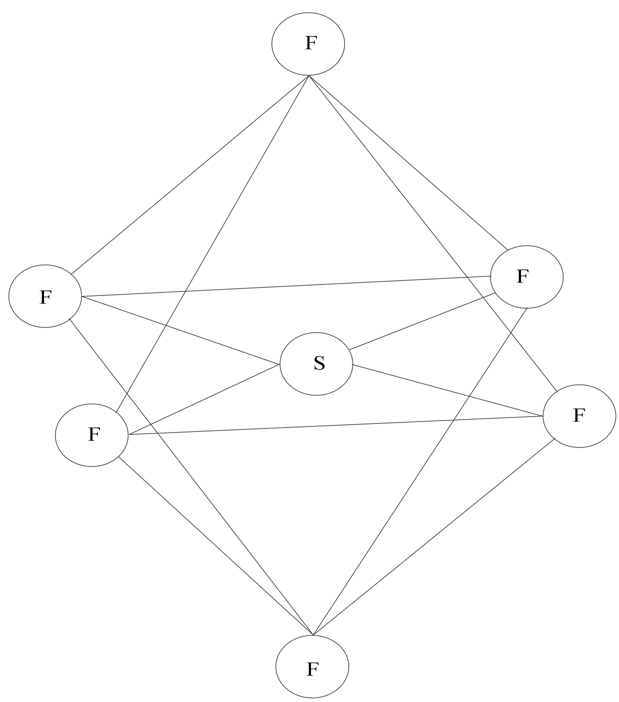
2 Characteristic analysis of SF_6 electrical equipment

In the study of carbon emission accounting, the analysis of arc extinguishing characteristics and insulation characteristics can be achieved from two aspects: analysing the characteristics of SF_6 electrical equipment, which can deeply understand its working principle and performance characteristics, as well as the emission situation and source. This provides a basis for determining the carbon emission process and equivalent of SF_6 electrical equipment, and improves the accuracy of subsequent SF_6 electrical equipment carbon emission accounting. Therefore, the next step is to analyse the arc extinguishing and insulation characteristics of SF_6 electrical equipment, laying the foundation for subsequent research.

2.1 Analysis of arc extinguishing characteristics

In order to effectively calculate the carbon emissions of SF_6 electrical equipment in this study, it is necessary to analyse the characteristics of the special gas SF_6 in the equipment. The carbon and other substances generated by SF_6 electrical equipment under the support of this special gas are key factors affecting carbon emissions (Sun et al., 2022a). Therefore, this study starts with the analysis of SF_6 characteristics, laying the foundation for accurate calculation of carbon emissions in the future. The molecular structure of SF_6 is a symmetrical octahedron, and its schematic diagram is shown in Figure 1.

Figure 1 Schematic diagram of SF_6 molecular structure



It can be seen from Figure 1 that the sulphur atom in the gas is at the core of the gas molecular structure, and other fluorine atoms are at the other top corners of the structure. The covalent chain between the two atoms connects all the components of the gas. The molecular characteristics of this gas are greater than the equivalent diameter of water molecules, and it is about five times heavier than air at the same volume and pressure (Sun et al., 2022b). In the chemical molecular structure of the gas, the fluorine atom is more active, and the distribution of electrons outside the nucleus of the atom is two in the inner layer and seven in the outer layer; When the number of outermost electrons is greater than four, the atomic nucleus will have the ability to adsorb electrons outside the nucleus. From this, it can be seen that the molecule has a strong ability to adsorb electrons, resulting in a certain degree of negative charge. It is precisely this characteristic that enables the gas to have excellent insulation performance, which can be effectively applied to electrical equipment. Using this gas as a high-voltage insulation and arc extinguishing cutoff in high-voltage electrical equipment can improve the insulation and arc extinguishing capabilities of electrical equipment (Cui et al., 2022).

From the perspective of energy conservation in SF_6 electrical equipment, arc extinguishing is the process of converting the electrical energy of the arc into thermal energy, and then absorbing and removing the arc extinguishing medium. The electrical equipment under the action of this gas is carried away from the arc zone through the energy conversion generated during the decomposition of SF_6 gas, reflecting the excellent arc extinguishing performance of SF_6 electrical equipment.

In the analysis of arc extinguishing characteristics of SF_6 electrical equipment, the ability of SF_6 electrical equipment to absorb extra nuclear electrons and the arc extinguishing characteristics of SF_6 electrical equipment are determined by analysing the molecular structure of SF_6, which lays the foundation for subsequent research.

2.2 Analysis of insulation characteristics

The insulation performance of SF_6 electrical equipment directly affects the safe operation of the equipment and the generation of carbon emissions. If the insulation performance of SF_6 electrical equipment is poor, it may lead to internal breakdown, leakage, and other faults, thereby increasing the maintenance and repair frequency and carbon emissions of the equipment. Therefore, the next step is to analyse the insulation characteristics of SF_6 electrical equipment, in order to provide reliable information support for subsequent accounting. The insulation characteristics of SF_6 electrical equipment are mainly reflected in the insulation of gases. However, the insulation characteristics of this gas are also easily affected by the electrode, especially the negative electrode. As the surface area of the electrode increases, its breakdown electric field intensity decreases. If the electrode distribution is uneven, there will be a significant polarity effect (Ma et al., 2022). In practical research, the insulation characteristics of SF_6 electrical equipment are divided into three types. The details are as follows:

Type 1 When the environment is set to a lower electrode distribution, and the electrostatic field distribution in the gas gap of SF_6 electrical equipment is known in an environment with lower gas pressure, the breakdown voltage is:

$$y_i = 89 \times pab\left(1 + \frac{0.17}{\sqrt{p \times R}}\right) \tag{1}$$

In equation (1), y_i represents the breakdown voltage value, p represents the gas pressure, b represents the gas gap width, a represents the electric field utilisation coefficient, and R represents the curvature radius value in the orthogonal direction.

Type 2 When the actual high-voltage equipment is subjected to interference from high electrical levels, SF_6 electrical equipment within the ultra-high pressure range is not only affected by gas characteristics, but also by the surface installation of negative electrodes, thereby affecting the voltage at the discharge point. As its area increases, the breakdown voltage decreases, exhibiting a polarity effect in the non-uniform electric field of this insulation type (Wang et al., 2021). The breakdown electric field strength at this time is expressed as:

$$y_i' = 8.9 \times a\left(\frac{0.17}{\sqrt{pR}}\right) \tag{2}$$

In equation (2), y_i' represents the breakdown electric field intensity value.

Type 3 Under low air pressure, the gas gap in SF_6 electrical equipment will exhibit an uneven state, and in this state, the corona generated by the electric field will cause the entire gas gap to discharge. Due to the improvement effect of corona discharge point, the strength of the breakdown electric field will be ignored at this time.

In the analysis of insulation characteristics of SF_6 electrical equipment, the insulation performance of SF_6 electrical equipment is determined by analysing the state of SF_6 electrical equipment under different atmospheric pressure conditions, calculating the breakdown electric field strength value under different conditions. Based on the above research, we aim to gain a deeper understanding of the working principle and performance characteristics of SF_6 electrical equipment, as well as their emission status and sources, in order to provide a reliable basis for the subsequent carbon emission process and equivalent determination of SF_6 electrical equipment, and to improve the accuracy of subsequent carbon emission accounting for SF_6 electrical equipment. Therefore, in order to achieve accurate carbon emission accounting for SF_6 electrical equipment, the next step is to conduct research on the carbon emission process and equivalence of SF_6 electrical equipment, in order to provide reliable data input.

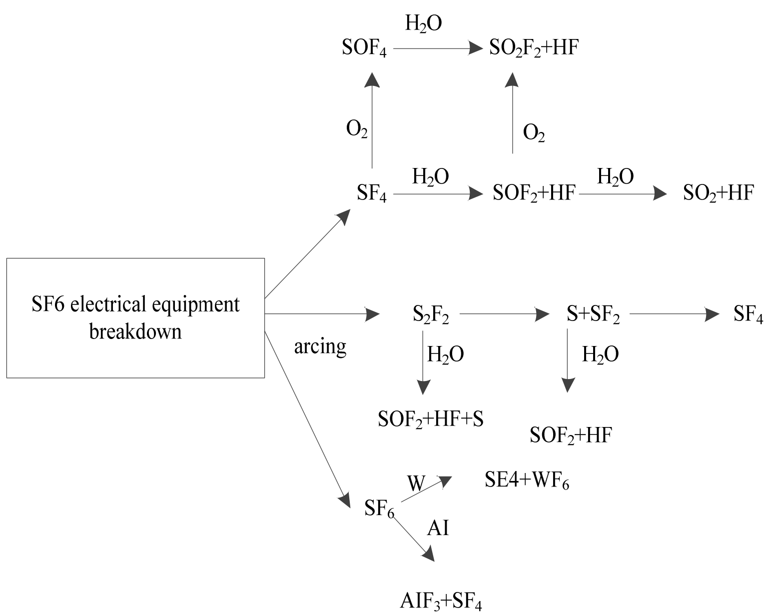
3 Carbon emission accounting of SF_6 electrical equipment based on improved random forest algorithm

On the basis of determining the performance of SF_6 electrical equipment, in order to achieve carbon emission accounting for SF_6 electrical equipment, it is necessary to further determine the carbon emission process and emission equivalent of SF_6 electrical equipment, provide reliable data input for carbon emission accounting, and improve its accuracy.

3.1 Carbon emission process analysis and equivalent determination of SF_6 electrical equipment

Firstly, based on the analysis of the characteristics of SF_6 electrical equipment mentioned above, the carbon emission process of SF_6 electrical equipment was analysed (Liu et al., 2021) to determine the carbon emissions generated and reduce the error in determining emission equivalence. During the operation of SF_6 electrical equipment, due to various factors such as arc and spark, the gas in the equipment will undergo certain decomposition, which includes carbon substances. This gas is insoluble in water and electrical equipment related fluids in electrical equipment. When the temperature is below a certain temperature, the gas does not burn. When the temperature is above this temperature, the gas in the equipment reacts with oxygen, hydrogen and other substances to produce certain carbon substances. The decomposition products of SF_6 electrical equipment under various conditions are shown in Figure 2.

Figure 2 Schematic diagram of substances generated by decomposition of SF_6 electrical equipment



As shown in Figure 2, the carbon emission process of SF_6 electrical equipment is essentially the process of electrical equipment decomposition to generate substances. During this process, it can be observed that the substances generated during its operation are relatively stable, but are prone to certain changes after contact with moisture in the air. Corona plays a crucial role in the carbon emissions of SF_6 electrical equipment during this process. Under this condition, the SF_6 gas in SF $SF_6$6 electrical equipment directly reacts with the insulation material in the electrical equipment, and the carbon content generated under this action is higher than the influence of arc and spark. It can be seen that there are significant differences in the carbon emissions of SF_6 electrical equipment under different operating conditions (Khajehpour et al., 2021). Therefore, this article further identifies the specific elements of carbon decomposition in SF_6 electrical equipment under different environmental effects.

Under the action of an arc, the atomic states in the gas in SF_6 electrical equipment will be decomposed into sulphur and fluorine. When the arc disappears, it will condense again (Yu et al., 2021). The decomposition process is:

$$SF_6 \leftrightharpoons S + 6F \tag{3}$$

In equation (3), S represents single atom sulphur, F represents single atom fluorine, and $\leftrightharpoons$ undergoes mutual conversion.

When the metal vapour generated by SF_6 electrical equipment under the action of an arc undergoes a certain chemical reaction with decomposition products, the generated carbon related substances are represented as:

$$SF_6 + W \rightarrow SF_4 + WF_6 \rightarrow WO_3 + HF \tag{4}$$

When the moisture conditions in the operating environment of SF_6 electrical equipment change to a certain extent, the decomposition result is:

$$SOF_2 + H_2O \longrightarrow SO_2 + 2HF \tag{5}$$

When an arc discharge occurs, in addition to generating the decomposed gases mentioned above, a certain amount of solid powdery decomposition substances will also be generated. This is due to the chemical interactions between the materials of electrical equipment and the solid materials, which also exhibit a certain adhesion effect and reduce the performance of electrical equipment.

When SF_6 electrical equipment encounters spark discharge and corona discharge during operation, certain thermal decomposition will cause SF_6 electrical equipment to decompose into low fluoride compounds of certain carbon. The results of decomposition are:

$$e^- + SF_6 \rightarrow SF_X + (6-x)F + e^- \tag{6}$$

In equation (6), e^- represents the thermal decomposition element and SF_X represents the unknown low fluoride.

When there are still active particles that react with impurities in SF_6 gas under this condition, the obtained result is expressed as:

$$SF_5 + O \rightarrow S_2OF_{10} \tag{7}$$

$$SF_4 + H_2O \rightarrow SOF_2 + 2HF \rightarrow SO_2 \tag{8}$$

$$SF_3 + O \rightarrow SO_2F_2 + F \tag{9}$$

From the above analysis, it can be seen that the main products under discharge conditions such as electric sparks, arcs, and corona contain various carbon substances, which will lead to an increase in carbon emissions and affect the normal operation of electrical equipment. Therefore, after determining the specific elements of carbon decomposition for SF_6 electrical equipment, it is necessary to further determine the equivalent values for this accounting to provide reliable data support for subsequent carbon emission accounting and improve the accuracy of carbon emission accounting. In determining the equivalent value, this article uses differential optical absorption spectroscopy method for analysis (Chen et al., 2021). This method is mainly a key method for detecting gases, which determines the equivalent carbon emissions of SF_6 electrical equipment by inverting the gas concentration through the optical path of the absorption interface and the optical intensity of the light absorbed by gas molecules (Fang et al., 2021). The law of light intensity attenuation it follows is expressed as:

$$G(\delta) = G_0(\delta) \times \exp[-L \times \theta(\delta) \times d] \tag{10}$$

In equation (10), $G_0(\delta)$ represents the intensity value of the initial light inverted by the light source, $\theta(\delta)$ represents the intensity received after gas absorption, L represents the cross-section of gas absorption, and d represents the optical path length value of absorption.

Based on the above principle analysis, this article uses this method to determine the equivalent carbon emissions of SF_6 electrical equipment, and the results are expressed as:

$$G(\delta)' = G_0(\delta) \times \exp\left[-L \times \sum_{i=1}^{n} (\delta) \times d\right] + \varepsilon_i(SF_6) \tag{11}$$

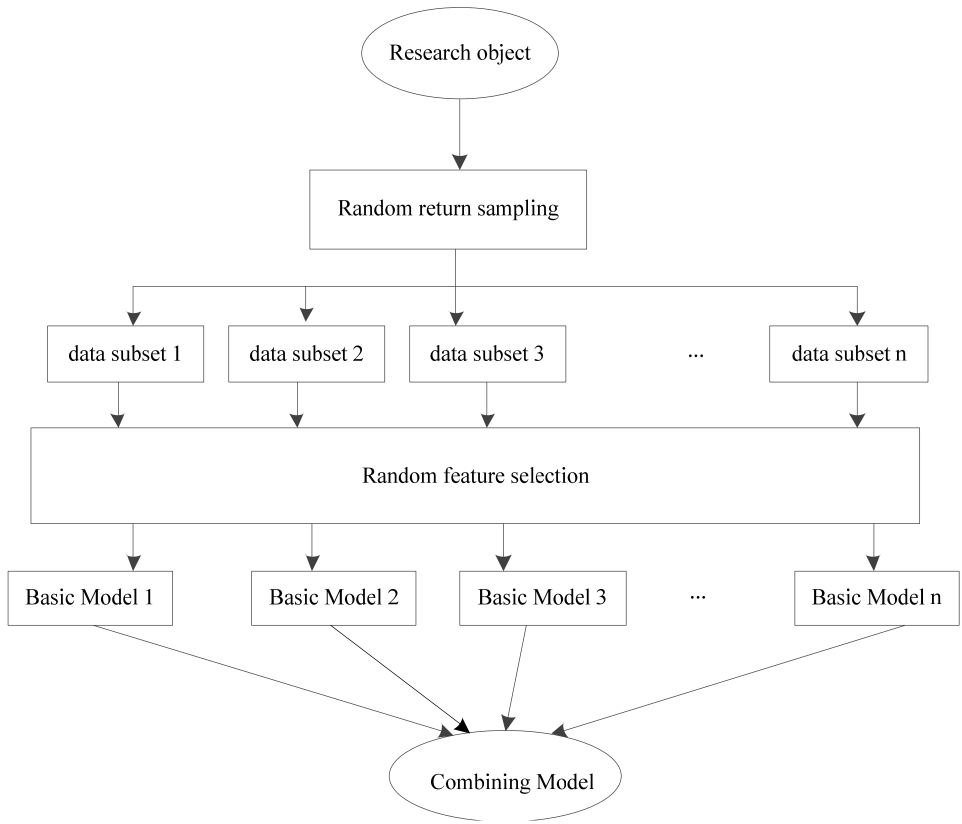
In equation (11), ε_i represents the extinction amount of gas under scattering, and $G(\delta)'$ represents the equivalent value of carbon emissions from SF_6 electrical equipment.

In the study of carbon emission process and equivalence of SF_6 electrical equipment, the differences in decomposition substances of SF_6 electrical equipment under various conditions are analysed to determine the carbon emissions generated. By using differential optical absorption spectroscopy method, the carbon emission equivalence of SF_6 electrical equipment is determined to achieve the study of carbon emission process and equivalence of SF_6 electrical equipment, providing reliable data input for the implementation of carbon emission accounting and ensuring the accuracy of accounting results.

3.2 Design of carbon emission accounting method based on improved Random forest

On the basis of the carbon emission process and equivalent of SF_6 electrical equipment determined above, in order to achieve carbon emission accounting research and reduce the convergence error in carbon emission accounting of SF_6 electrical equipment, this paper introduces the improved random forest algorithm to design the accounting method. The random forest algorithm is an artificial intelligence machine learning algorithm, which has the advantages of flexibility, practicality and better prediction and estimation accuracy. This algorithm is a relatively convenient algorithm by studying the effective integration of research objects (Zhi et al., 2021). The main core idea of this algorithm is to construct multiple decision trees, using each constructed decision tree as a classifier and the research object as the input sample object for input. After input, as many trees as there are, there will be as many results. After the voting decision is made through the random forest algorithm, the target of the category with the highest number of voting results will form the output of the final result. This algorithm is capable of sampling not only the original data but also the entire set of independent variables during voting, thereby obtaining more subsets of input variables (Joo et al., 2021). In this algorithm, all trees are generated by bifurcation without pruning. After repeated many times, all the models are integrated to form a random forest model, as shown in Figure 3.

Figure 3 Schematic diagram of random forest model

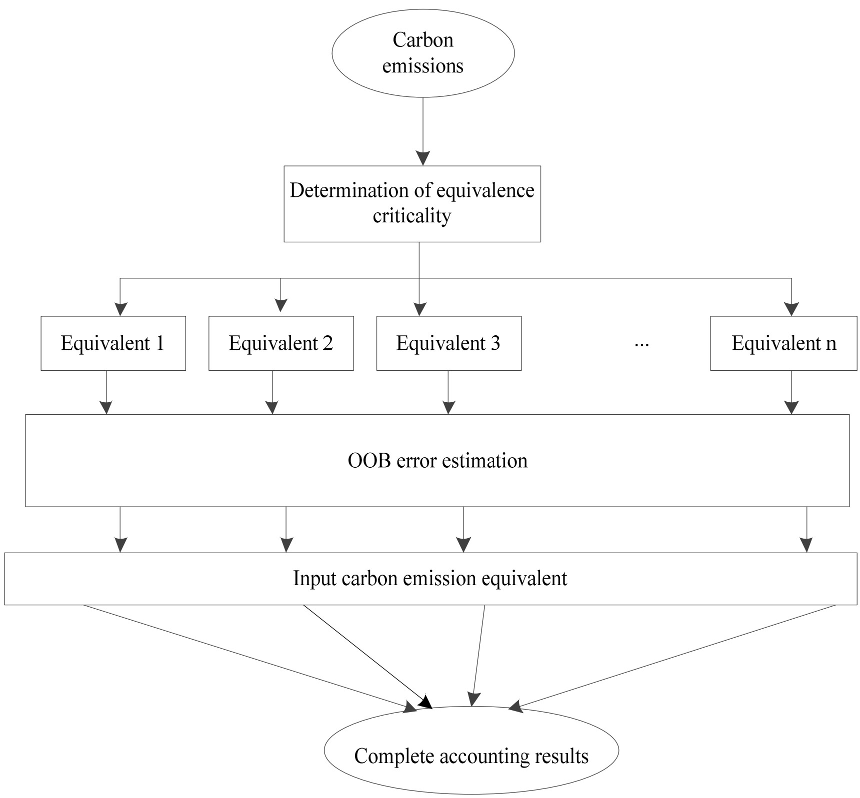


Although the random forest algorithm can effectively realise the accounting of carbon emissions of SF_6 electrical equipment, the non-pruning of branches for many times in the accounting results lead to some errors in the accounting results, and the importance of the accounting equivalent cannot be directly determined. In order to better realise the accounting of carbon emissions of SF_6 electrical equipment, this paper uses the OOB error estimation method to improve the random forest algorithm. The improved random forest algorithm saves the extra data division process, reduces the time and computing resources required, and reduces the over fitting phenomenon. It has high work efficiency and generalisation ability. When random forest randomly generates samples, more than 30% of the sample data is not sampled, which is not conducive to the accounting of carbon emissions of SF_6 electrical equipment. Therefore, using the OOB error meter method, the equivalent carbon emissions of SF_6 electrical equipment calculated are classified and predicted, in order to obtain a classified predicted value. In this estimation algorithm, the equivalent data of carbon emissions from all SF_6 electrical equipment are used as multiple classification predictions, and all of them are summarised to obtain the optimal value for calculating the equivalent. Comparing this value with the initial accounting value will obtain the accounting error value, which is the actual error value in the accounting results. Then, by calculating the average of the actual error values, the critical weight of the equivalent data of carbon emissions from SF_6 electrical equipment is determined. Each tree in the improved random forest can reduce the error result of accounting equivalent with the help of the error estimation algorithm, and research on accounting variables according to the reduced results to improve the accuracy of accounting results. Assuming that there are many trees in the model, the critical weight results of the calculated equivalent carbon emissions of SF_6 electrical equipment are represented as:

$$w_i = \frac{1}{n} \sum_{i=1}^{n} \left(c_i - c_j \right) \tag{12}$$

In equation (12), w_i represents the key weight result of carbon emission equivalent of SF_6 electrical equipment, n represents the number of trees in the improved random forest, c_i represents the initial error value of OOB prediction, and c_j represents the actual error value of OOB prediction.

Figure 4 Schematic diagram of carbon emission model of SF_6 electrical equipment calculated by improved random forest algorithm



According to the above, by using the OOB error estimation method to improve the random forest algorithm, an improved random forest model is constructed. Firstly, the reverse transmission training is carried out according to the learning model of the improved random forest to ensure the stability of the carbon emission equivalent of SF_6 electrical equipment input into the model; then, input the equivalent of each node, and connect each node with a nonlinear activation function to determine the synaptic strength.

Next, determine the cyclic alternation process of carbon emission equivalent of SF_6 electrical equipment during back propagation, and adjust the convergence value of accounting error based on the obtained information function; finally, the carbon emissions accounting results of the improved random forest algorithm are obtained, and the carbon emissions accounting of SF_6 electrical equipment is realised. The improved random forest model constructed by it is shown in Figure 4.

The specific implementation process is described as follows:

According to the learning model of improved random forest, reverse transmission is used for training, which can ensure the stability of carbon emission equivalent of SF_6 electrical equipment input into the model. In addition to the equivalent of each input, connect each node with a nonlinear activation function, connect them synaptically, and determine the synaptic strength, which is expressed as:

$$x(v_i) = \tanh(v_i) \tag{13}$$

In equation (13), $x(v_i)$ represents the strength of synaptic connection, and $h(v_i)$ represents the nonlinear activation function.

When the carbon emission equivalent of SF_6 electrical equipment is back propagation, there is also a positive connection, and the process of cyclic alternation is represented as:

$$x(v_i)' = (1 + e^i)^{-1} \tag{14}$$

In equation (14), e^i represents the forward connection weight value.

Then, adjust the convergence value of the accounting error based on the above model, and the obtained information function is represented as:

$$u_j^m(n) = f\left(\sum_{j=1}^{n} x(v_i)' \mu_i x(n)\right) \tag{15}$$

In equation (15), $u_j^m(n)$ represents the convergence stability value of carbon emission accounting of SF_6 electrical equipment, f represents the activation function, μ_i represents the total amount of accounting equivalents, and $x(n)$ represents the actual value of equivalent input by the model.

Finally, the carbon emission accounting formula of the improved random forest algorithm is obtained as follows:

$$Q(n) = x(n) - \tau \frac{\partial u_j^m(n)}{\partial x(n)} + \beta \Delta p(n) \tag{15}$$

In equation (15), $Q(n)$ represents the carbon emission accounting result of SF_6 electrical equipment, τ represents the learning efficiency of improved random forest model accounting, β represents the momentum parameter, and $\Delta p(n)$ represents the carbon emission accounting error value of SF_6 electrical equipment.

In the implementation of carbon emissions accounting of the improved random forest algorithm, analyse the core ideas and advantages of the random forest algorithm, determine the shortcomings of the algorithm, introduce the OOB error estimation algorithm to build the improved random forest algorithm model, input the carbon emissions equivalent of SF_6 electrical equipment, use the nonlinear activation function to determine the synaptic strength, and use the information function to adjust the convergence value of accounting errors to complete the carbon emissions accounting research of the improved random forest algorithm.

4 Experimental study

4.1 Experimental plan design

In order to verify that the proposed method can effectively calculate the carbon emissions of SF_6 electrical equipment, experimental research was conducted on the proposed method. In the experimental study, SF_6 gas insulated transformers were selected as the research object to calculate their carbon emissions during operation and verify the feasibility of the proposed method. The specific parameters in the study are shown in Table 1.

Table 1 Experimental parameters

Parameter	*Content*
SF_6 gas insulated transformer model	SQFPZ – 63000/110
Rated capacity/MVA	18/62
Phase number	3
Rated frequency/Hz	60
Rated voltage/V	21,000
Insulation medium	SF_6
Impedance voltage/V	10,000–21,000
No load loss/kW	40
Load loss/kW	190

To ensure the reliability of the test results, the initial parameters of the test need to be set before further testing, as shown in Table 2.

Table 2 Initial parameter settings

Parameter	*Content*
Number of decision trees	500
The square root of the number of features	0.5
The maximum depth of the decision tree	None
Minimum number of samples for leaf nodes	1

In order to highlight the effectiveness of the method proposed in this article, method of Gao et al. (2022) and method of Zhang et al. (2022) were used as comparative methods in this experiment. The convergence error and interference coefficient of the calculation results in the carbon emission calculation of SF_6 electrical equipment were used as experimental indicators. The proposed method, method of Gao et al. (2022) and method of Zhang et al. (2022) were used for experimental indicator testing, and the obtained results were compared and analysed, complete the validation of the effectiveness of the proposed method. The calculation formula for accounting accuracy is as follows:

$$P = \frac{n}{N} \times 100\% \tag{16}$$

In equation (16), is the total test sample; to correctly calculate the sample size.

The formula for calculating the convergence error value is:

$$ERRO_i(x) = \frac{1}{m} \sum_{i=1}^{n} l_i / l_j \tag{17}$$

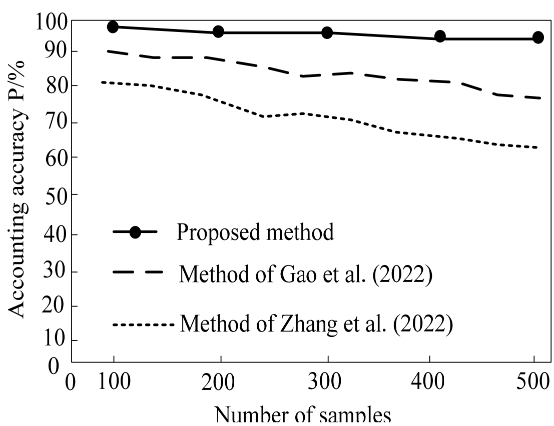
In equation (17), $ERRO_i(x)$ represents the calculation convergence error result, l_i represents the actual calculation convergence error, and l_j represents the ideal calculation convergence error.

The interference coefficient of the accounting results reflects the degree of interference in the accounting results. The higher the coefficient, the greater the interference result, and the range of values is [0, 1].

4.2 Experimental results

The experiment first analysed the accuracy of method in this paper, method of Gao et al. (2022), and method of Zhang et al. (2022) in calculating carbon emissions from SF_6 electrical equipment. The results obtained are shown in Figure 5.

Figure 5 Comparison of accounting accuracy results

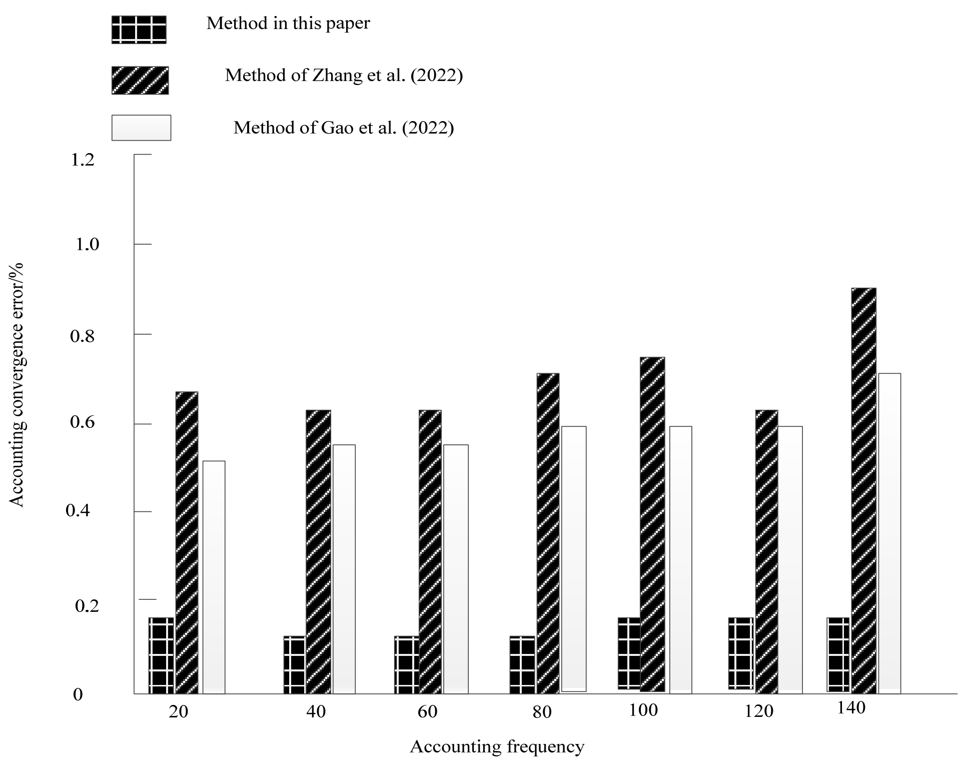


According to Figure 5, it can be seen that the accounting accuracy of method in this paper, method of Gao et al. (2022), and method of Zhang et al. (2022) all show a certain gap with the change of sample size. When the number of accounting samples reaches 500, the accuracy rate of Method in this paper is 97.3%, while the accuracy rates of method of Gao et al. (2022) and method of Zhang et al. (2022) are 80% and 65%, respectively. Comparing the results obtained from the three methods, it can be seen that method in this paper has a higher accuracy and reliability in accounting.

Subsequently, the convergence error results of method in this paper, method of Gao et al. (2022), and method of Zhang et al. (2022) in carbon emission accounting for SF_6 electrical equipment were analysed, and the results are shown in Figure 6.

Analysing the test results in Figure 6, it can be seen that there are certain differences in the convergence error results of method in this paper, method of Gao et al. (2022) and method of Zhang et al. (2022) when calculating the carbon emissions of SF_6 electrical equipment. Among them, from the image results, it can be seen that the convergence error of method in this paper in calculating the carbon emissions of SF_6 electrical equipment is relatively low, and always below 0.2%. The convergence error results of using method of Gao et al. (2022) and method of Zhang et al. (2022) for carbon emission accounting of SF_6 electrical equipment are both higher than 0.5%. Compared with the results obtained by the three methods, the convergence error of the proposed method is lower, indicating that the proposed method has high accuracy and reliability in carbon emission accounting, verifying the feasibility of the proposed method. This is because the proposed method analysed the characteristics of SF_6 electrical equipment before conducting accounting, understood the emission situation and sources of SF_6 electrical equipment, and determined the carbon emission equivalent of SF_6 electrical equipment, providing reliable data input for carbon emission accounting and improving its accuracy. Finally, the Random forest algorithm is improved by using the OOB error estimation method to further reduce the error of the accounting results.

Figure 6 Convergence error results in carbon emission accounting of SF_6 electrical equipment



The experiment further analysed the interference coefficient of the calculation results in the carbon emission accounting of SF_6 electrical equipment using method in this paper, method of Gao et al. (2022) and method of Zhang et al. (2022). The results obtained are shown in Table 3.

From the results in Table 3, it can be seen that there is a significant difference in the interference coefficient results obtained from the calculation of carbon emissions from SF_6 electrical equipment using method in this paper, method of Gao et al. (2022) and method of Zhang et al. (2022). Among them, the interference coefficient of the calculation results in Method in this paper. SF_6 electrical equipment carbon emissions accounting is relatively low, and below 0.13. The interference coefficient of the calculation results in method of Gao et al. (2022) and method of Zhang et al. (2022) shows an upward trend. The interference coefficients of the calculation results in both methods are the lowest, 0.35 and 0.43, respectively, which are higher than the interference coefficient of the proposed method's calculation results. In contrast, the proposed method has better results, indicating that it can reduce the impact of multiple factors and improve the accuracy of accounting results in carbon emissions accounting. This is because the proposed method uses the OOB error estimation method to improve the Random forest algorithm, reduce the over fitting phenomenon, improve the generalisation ability, effectively reduce the interference coefficient.

Table 3 Interference coefficient results of carbon emission accounting results for SF_6 electrical equipment using different methods

Accounting frequency	*Method in this paper*	*Method of Gao et al. (2022)*	*Method of Zhang et al. (2022)*
20	0.11	0.35	0.43
40	0.12	0.38	0.47
60	0.12	0.41	0.52
80	0.12	0.43	0.57
100	0.13	0.46	0.59
120	0.13	0.51	0.61
140	0.13	0.55	0.65

5 Conclusions

This paper designs a carbon emission accounting method for SF_6 electrical equipment based on the improved random forest algorithm. Firstly, by analysing the molecular structure of SF_6, the arc extinguishing characteristics and insulation performance are determined. Then, analyse the differences in the decomposition of substances by the equipment under various conditions, and use differential optical absorption spectroscopy to determine the carbon emission equivalent of the equipment. Finally, the OOB error estimation algorithm is introduced to build an improved random forest algorithm model, input the carbon emission equivalent of SF_6 electrical equipment, use the nonlinear activation function to determine the synapse strength, and use the information function to adjust the accounting error convergence value to complete the carbon emissions accounting research of the improved random forest algorithm. The experimental results show that the convergence error of the proposed method for carbon emission accounting of SF_6 electrical equipment is always less than 0.2%, and the interference coefficient is less than 0.13. This indicates that the method can reduce the convergence error of accounting and the interference coefficient of accounting results is small.

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