Analysis of Carbon Footprint in the Manufacturing of Oil-Immersed Distribution Transformers

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Abstract: This paper establishes a model for the carbon footprint of 10kV oil-immersed transformers, a typical material in power distribution networks. It also calculates the production carbon footprints of three manufacturers respectively. The calculation results show that during the production process, the carbon footprint of raw materials makes the most significant contribution, while the carbon emissions from production energy consumption are also prominent. Carbon emissions in other states such as transportation, testing, and waste disposal are relatively low. In addition, the carbon footprint of each stage of the production process is analyzed and compared separately, and the results indicate that the transformer body drying process has relatively high carbon emissions. Furthermore, based on the analysis results, measures to reduce carbon emissions in the production of power distribution transformers are proposed.

Keywords: Power Distribution Transformer; Production Cycle; Carbon Footprint Model; Carbon Emission Reduction

1. Introduction

With the continuous development and expansion of power grids, carbon emissions generated during the production of grid materials have attracted considerable attention. Along with the proposal of the dual carbon targets [1-2], the enhancement of socio-economic development and environmental protection awareness has led to increasing attention to environmental impacts, making low-carbon production particularly prominent [3-4]. As a key link in energy transmission, the production of grid materials mostly relies on traditional processes. Currently, there is a lack of accurate assessment of carbon emissions during the production of typical grid materials and effective guidance methods for corresponding emission reduction, resulting in excessive carbon emissions in the production process.

Power distribution transformers are important and widely used equipment in power grids, undertaking the tasks of power transmission and conversion in the power system [5]. Carbon emissions from transformers account for approximately 4% of the total carbon dioxide emissions of the power system, reaching 730 million tons [6]. The carbon emissions of transformers cover the entire life cycle, from the transportation of raw materials to the production, assembly, transportation, operation and disposal of components. At present, some literatures have analyzed the carbon footprint of power distribution transformers. Cai [7] calculated the carbon emissions of four common types of power distribution transformers, and the results showed that the carbon emissions of power distribution transformers account for more than 98% of the total carbon emissions of transformers, and pointed out that the energy efficiency level of transformers is crucial for reducing carbon emissions. However, the paper did not involve carbon emissions during the transformer production process. Wang [8] et al. analyzed and compared the life cycle carbon emissions of oil-immersed power distribution transformers, but lacked a detailed analysis of carbon emissions in the manufacturing processes. Li [9] also calculated and analyzed the life cycle carbon emissions of oil-immersed power distribution transformers in the Xinjiang power grid and proposed measures to reduce carbon emissions, but the description of carbon emissions in the production of power distribution transformers was not detailed enough, and the proposed carbon emission reduction measures did not focus on the production processes. Tomazs [10] conducted a life cycle carbon footprint accounting for two power distribution transformers in Poland with capacities of 31.5 MVA and 25 MVA respectively, and proposed the use of advanced materials and design solutions to reduce the carbon emissions of power distribution transformers. However, the carbon footprint of the production processes of power distribution transformers still did not receive attention.

This paper conducts a detailed analysis of the production processes of 10kV oil-immersed power distribution transformers and presents a carbon footprint calculation model for the production stage. Based on data collected from four manufacturers, carbon footprint calculation and analysis are carried out. Finally, suggestions for reducing carbon emissions in the production of power distribution transformers are put forward according to the results.

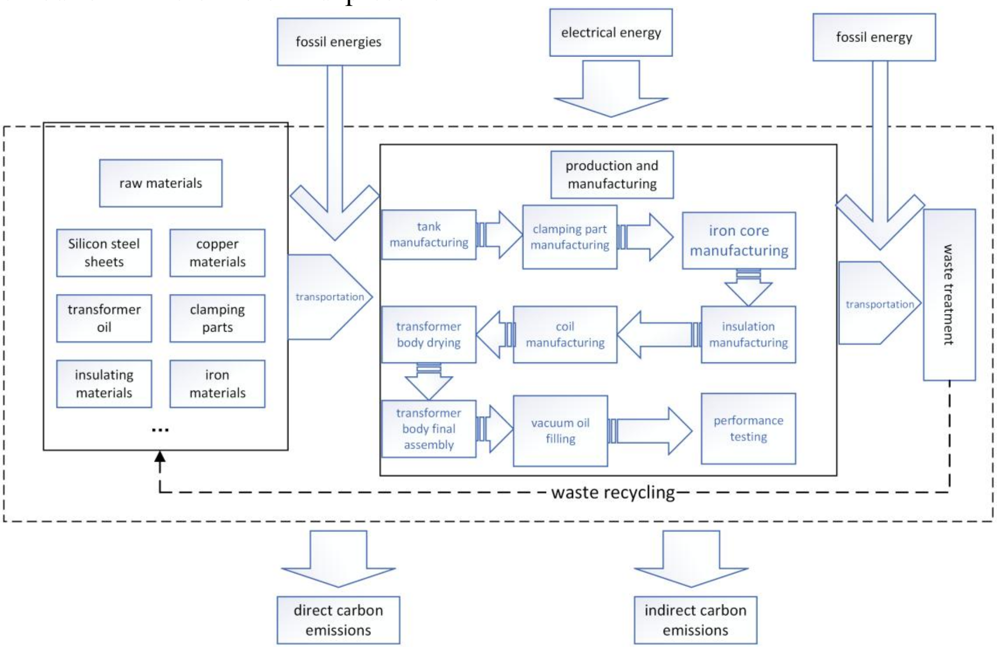

Figure 1. Carbon Emission Boundary Diagram of the Oil-Immersed Transformer Production Stage

2. Carbon Footprint Model for the Production of Oil-Immersed Power Distribution Transformers

2.1 System Boundary

The system boundary for the carbon footprint accounting of oil-immersed power distribution transformers production cycle revolves around the manufacturing process of transformers, i.e., from the acquisition of transformer raw materials to the delivery of finished products. Its foreground processes include transformer production processes, such as fuel tank manufacturing, clamping part production, iron core manufacturing, insulation part manufacturing, coil manufacturing, transformer body assembly, transformer body drying, vacuum pumping, oil filling, etc. The background processes include the production processes of energy sources such as electricity, using China's Product Life Cycle Database (CPLCD). The carbon emission boundary of the oil-immersed transformer production stage is shown in Figure 1.

2.2 Production Carbon Footprint Calculation Model

The carbon footprint of the power distribution transformer production cycle mainly consists of five parts: raw materials, raw material transportation, production, and waste disposal. It can be expressed as follows:

$$C_{Total} = C_M + C_T + C_P + C_D \qquad (1)$$

Among them, C_M represents the total carbon footprint of various raw materials, C_T denotes the carbon footprint during raw material transportation, C_P stands for the carbon footprint in the manufacturing process, and C_D is the carbon footprint of waste disposal. They are detailed as follows:

$$C_M = \sum_{i=1}^{N_1} M_i F_i \qquad (2)$$

Here M_i is the mass of the i-th raw material; F_i is the carbon emission factor of the i-th raw material.

$$C_T = \sum_{j=1}^{N_1} M_j D_j T_j \qquad (3)$$

Here Dj refers to the average transportation distance of the j-th type of raw material;T_j represents the carbon footprint factor per unit weight and per unit transportation distance under the transportation mode of the j-th type of raw material.

$$C_P = \sum_{i=1}^{N_2} C_i = \sum_{i=1}^{N_2}\sum_{j=1}^{N_3}(E_{ij} \times F_{ij}) \quad (4)$$

Here, C_i denotes the carbon footprint of energy consumption corresponding to the i-th production process; E_{ij} represents the consumption of the j-th type of energy in the i-th production process;F_{ij} stands for the carbon footprint factor of the j-th type of energy in the i-th production process.

$$C_D = \sum_{i=1}^{n}(WD_i \times D_{W-i} \times T_{W-i}) \quad (5)$$

Here WD_i represents the discharge amount of the l-th type of waste to be disposed of; D_{w-i} denotes the average transportation distance of the l-th type of waste to be disposed of; T_{w-i} refers to the carbon footprint factor per unit weight and per unit transportation distance under the transportation mode of the l-th type of waste to be disposed.

3. Case Study

Taking the S20-400kVA three-dimensional wound core oil-immersed transformer as an example, the carbon footprint calculation was conducted based on the survey data from four transformer manufacturers. The following calculation results are allocated to a single transformer.

3.1 Comparison of Carbon Footprint Values of Each Component in the Production Cycle

As shown in **Table 1**, within the carbon footprint of the production cycle, the carbon footprint from raw materials makes the most significant contribution, accounting for over 91.375% (based on actual data). The carbon footprint generated in the production stage ranks second in terms of contribution. In contrast, the carbon footprint values of other links such as raw material transportation and waste recycling transportation are relatively negligible. Furthermore, the difference in the carbon footprint of raw materials among various manufacturers is no more than 2%, which verifies the basic accuracy of the collected data. However, there is a substantial discrepancy in the production-stage carbon footprint across different manufacturers. This variation indicates that the advanced level of manufacturing equipment and processes differs among the manufacturers.

Table 1. Composition of Carbon Footprint in the Production Cycle of Distribution Transformers

Manufacturer	Raw materials	Transportation of raw materials	Process in production	Waste recycling and transportation	Total carbon footprint value
A	5103.881	27.347736	136.2312	16.38	5260.835
B	4718.505	25.012104	883.787	6.552	5619.212
C	4509.39	73.54425	630.9414	6.552	5210.607
D	5089.471	28.071888	91.4328	0.16068	5202.451

3.2 Comparison of Carbon Footprint Values (Energy Consumption Values) of Each Process in the Production Stage

Figure 2 presents the energy consumption values of each process in the production stage of power distribution transformers, which can be converted into carbon footprint values. As can be seen from **Figure 2**, the carbon footprint value of the transformer body drying process accounts for a relatively large proportion.

It can be seen from Table 1 that raw materials account for an extremely large proportion of the production carbon footprint of power distribution transformers. From Figure 2, it is evident that among the carbon footprints of each process in the production stage, the transformer body drying process has the largest proportion, exceeding 91.375% (to be filled in with actual data). Therefore, to reduce the carbon footprint of the power distribution transformer production cycle, low-carbon raw materials can be developed as substitutes. In production, special attention should be paid to reducing the energy consumption of the transformer body drying process.

From the above, it can be seen that for a single distribution transformer of the same model, the amount of raw materials used by each manufacturer is not significantly different. Therefore, when conducting carbon footprint verification of the manufacturer's products, the focus can be on the energy consumption of transformer production. It can be accurately measured by using carbon verification measuring instruments in the production workshop. Moreover, in the accounting of the carbon footprint of distribution transformer production, It can find that apart from the carbon footprint of raw materials and production processes, the carbon footprint of other parts is relatively small and difficult to accurately calculate. For example, transportation of raw materials, transportation of finished products, and discharge of waste.

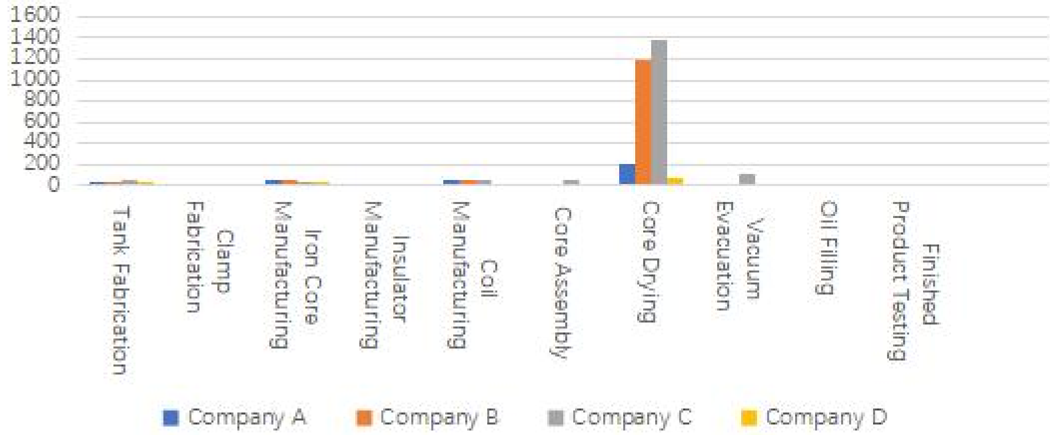

Figure 2. Comparison of Energy Consumption in Each Production Stage of S20-400kVA Transformer

4. Conclusion

This paper studies the carbon footprint of the production cycle of 10kV oil-immersed power distribution transformers, filling the gap of insufficient relevant research in the current industry. A carbon footprint calculation model for the production cycle of power distribution transformers is established. Through on-site investigations of four transformer manufacturers, relevant data are collected, and carbon footprint calculations are carried out respectively based on the model. Analysis of the calculation results leads to the conclusion that the carbon footprint of raw materials accounts for the vast majority of the total carbon footprint in the production cycle. In addition, the carbon footprint of the transformer body drying process also accounts for a very large proportion of the production stage. Therefore, to reduce the carbon emissions in the production cycle of power distribution transformers, efforts can be made in two aspects: first, develop low-carbon raw materials as substitutes; second, improve processes with high carbon emissions such as transformer body drying to reduce carbon emissions. The research object of this paper is the carbon footprint of the production cycle of 10kV oil-immersed power distribution transformers, and the research method can be extended to the calculation and analysis of the production carbon footprint of other power grid materials.

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