Status quo and strategy of disposing and recycling waste composite insulators

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Abstract. Composite insulators that have been in service for over 10 years account for more than half of the total number of composite insulators in China. Due to the aging of materials, some composite insulators have to be phased out of the power grid when they approach their service deadline. As the running time increases, the number of waste composite insulators grows year by year. If not disposed properly, the waste composite insulators will cause serious damage to ecological environment. The disposal of waste composite insulators has become an issue that needs to be addressed urgently, so as to ensure the safe, economical and efficient operation of the grid and maintain the healthy and sustainable development of the composite insulator industry. This paper summarizes the status quo of disposing waste composite insulators through a large number of investigations and statistics, and explores the recycling methods of waste composite insulators based on the existing problems. Finally, solutions are provided to recycle waste composite insulators from four perspectives, namely pretreatment before recycling, advanced treatment of silicon rubber, development and verification of recycling products, and recycling and disposal strategy. The recycling and disposal strategy of waste composite insulators is further improved by providing policy guidance, strengthening management and establishing a sound recycling mechanism. The findings can promote the “recycle, decrease and decontamination” of waste from the power grid, and help China build a new green and eco-friendly grid.

1. Introduction
The domestic composite insulators were first introduced into the power grid in 1985. They have been used on a massive scale in the AC and DC power grids since 1995. So far, their performance has been widely praised by production and operation departments. In recent years, composite insulators are not only extensively used in AC lines at various voltage levels, but also used heavily in new lines. In some cases, even the entire line applied composite insulators[1-5]. In 2000, composite insulators were used in the DC line of ±500 kV. In 2005, it was used in batch in 750 kV line. By December 2010, 66 kV and above voltage grade AC/DC transmission lines were carrying 4 196 235 composite insulators. By 2013, the number of composite insulators with voltage level above 35 kV was 891 958 through the official bidding of State Grid. However, the actual total demand of composite insulators that are not included in the bidding of state grid, such as independent bidding of regional power grids, local line management and transformation, and 10 kV distribution network lines, is much higher than the bidding quantity. It is conservatively estimated that the number of composite insulators operating at 66 kV and above has exceeded 10 million in China.
Composite insulators are organic materials with a certain service life. If designed, manufactured, used and maintained correctly, the silicone rubber of mainstream composite insulators generally has a service life of 15-20 years. The first group of composite insulators used in 1985 has operated for 32 years, while those widely applied in 1995 has operated for 22 years. So far, the composite insulators that have been in service for 10 years or more have accounted for half of all composite insulators in the grid [6-8].

Meanwhile, some composite insulators are abnormally aged, fail in advance and have to be scrapped because of their defects in formula design, low quality of raw materials, loopholes in manufacturing management, improper selection, etc. These composite insulators that have reached the end of their service life, aged or failed are also phased out of the grid. The number of waste composite insulators has increased year by year to a very high level. Affected by the service life, the number underwent an explosive growth in recent years. The problems of waste composite insulators present a cumulative trend characterized by sustainable growth. On the other hand, the wastes like structured silicone rubber and cooked rubber are generated by composite insulator manufacturers during rubber mixing, and defective products and scraps are also inevitably generated during molding. A conservative estimate shows that the annual production of composite insulators generates more than 2,000 tons of waste silicone rubber, according to the capacity of composite insulator manufacturers in China [9-11]. Moreover, the percentage of defective products is about 3% (which may slightly vary with the production model and process). Every year, 70,000 tons of silicone rubber is used for outer insulation of composite insulator. All of such silicone rubber will be eventually scrapped and disposed. Since the vulcanization of silicone rubber is irreversible, the waste silicone rubber cannot be reused directly. Manufacturers often collect and dispose them as useless waste on a regular basis. Such collection and disposal are also a waste of resources. Therefore, the disposal of waste composite insulators shall be addressed urgently to ensure the safe, economical and efficient operation of the grid and maintain the healthy and sustainable development of the composite insulator industry [12,13].

This paper investigates the information of a large number of waste composite insulators, such as operating years, fault types and aging degree. Based on the investigation and the research results of State Grid Corporation of China (SGCC), the recycling and disposal strategy for waste composite insulators (including those scrapped in production) is proposed to improve the corporation’s management methods of recycling and disposing waste composite insulators. The proposed strategy can not only realize the reuse of resources, but also play a significant role in promoting the healthy development of the composite insulator industry and establishing a circular economy in the industry.

2. Status quo of recycling and disposing waste composite insulators
Composite insulator is a type of insulator with composite structure consisting of two or more organic materials. The composite insulators running in the power grid are mainly rod-type suspension insulators, which account for more than 95% of all running composite insulators. Other composite insulators have slightly different shapes, but their composition materials are the same. The main components and structure of the composite insulator are shown in Figure 1, including the metal fittings, mandrel, umbrella apron and bonding layer.

If production process and emergencies are excluded, the core rod of composite insulators almost never goes wrong due to aging. The aging problem of composite insulators ultimately comes down to the aging of silicone rubber of its insulating shed. Under normal operating conditions, the degree of aging of silicone rubber will also directly affect the normal operation of composite insulators. Composite insulators are organic materials. When composite insulators are running, their shed will be subjected to the combined effects of temperature, pollution, moisture, partial discharge or high field strength. The shed and jacket made of silicone rubber may have different degrees of aging phenomena like cracks, pulverization and reduced water repellency, which seriously threaten the insulation properties of power transmission and transformation equipment. A large number of experimental studies and operating experience indicate that if designed, manufactured, used and maintained correctly, the silicone rubber of mainstream composite insulators in China generally has a service life
of 20 years. The first group of composite insulators used in 1985 has operated for 30 years, while those widely applied in 1995 has operated for 20 years. Meanwhile, some composite insulators are abnormally aged, fail in advance and have to be scrapped because of their defects in formula design, low quality of raw materials, loopholes in manufacturing management, improper selection, etc. These composite insulators that have reached the end of their service life, aged or failed are also phased out of the grid.

![Figure 1. Main components and structure of composite insulator.](image)

The Administrative Regulations on Physical Assets of Power Grid of State Grid Corporation of China [GW (YJ/2) 408-2014] defines the implementation methods and procedures for waste assets identified as available[14]. The Administrative Measures for Disposal of Waste Assets of State Grid Corporation of China [GW (WZ/2) 127-2016] defines that the waste assets refer to the assets that have gone through the formalities for retirement of fixed assets, the inventories that have gone through the formalities for retirement of liquid assets, the registered low-value consumables that have gone through the formalities for the retirement of non-fixed assets, and other wastes[15]. Both of them provide no clear methods for recycling and disposal of composite insulators after retirement. At present, composite insulators are distributed in various regions of China. The waste composite insulators are usually collected in local areas and treated as wastes. Moreover, since composite insulators are largely dispersed across the power grid, the recovery value of single composite insulator is low. In practice, composite insulators are directly used as waste assets with no disposal value after retirement. Thus, they are generally excluded from the waste management process and disposed on the spot. Such treatment will cause damage to the ecological environment and does not meet the requirements for environmental protection. After composite insulators are scrapped, they should not be treated as waste with no disposal value. Therefore, it is also imperative to improve the recycling and disposal strategy of waste composite insulators by providing policy guidance, strengthening management and establishing a sound recycling mechanism.

### 3. Methods of recycling and disposing waste composite insulators

#### 3.1. Problem analysis and strategy

Decentralized: composite insulators are used in various regions of China. The waste composite insulators are also treated locally. The manufacturers of composite insulators do not have a unified treatment mode of silicone rubber. The dispersed composite insulators need to be recycled and disposed centrally.

Feasibility of centralized treatment: the general cost of road transportation is 0.35-0.4 yuan per ton-kilometer. If the average transportation distance is 1,000 kilometers, the cost per ton of freight to Zhengzhou is 350-400 yuan. If the transportation cost is converted, the cost of rubber powder will...
increase by 0.35-0.4 yuan per kg. The cost of 200-mesh high-performance rubber powder will increase from 2.5 yuan per kg to 2.85-2.9 yuan per kg. The percentage of transportation cost is not large.

Methods of centralized treatment: it is necessary to establish recycling centers for waste composite insulators and waste silicone rubber, and explore the business mode of centralized recycling.

Classification of waste composite insulators: no effective classification method of waste composite insulators has been established. It is impossible to reasonably classify composite insulators with different faults, so the recycling effect is not satisfactory.

3.2. Recycling mode

SGCC shall formulate and release the management measures for recycling and disposal of waste composite insulators.

SGCC and its provincial subsidiaries shall supervise the implementation of the management measures for recycling and disposal of waste composite insulators.

| Treatment after collection | Implementation methods | Advantages and disadvantages |
|---------------------------|------------------------|-------------------------------|
| After the raw materials are collected, the disposal, treatment and product manufacturing shall be completed locally | Establish special bases at each collection point to complete material treatment and product production | Advantages: the round-trip transportation of raw materials is eliminated. It’s easy to open up the local market Disadvantages: SGCC needs to repeatedly invest in equipment, plant and personnel. The technology and management are less controllable |
| After the raw materials are collected, their classification shall be completed locally | Set up a treatment plant of waste composite insulators at each collection point. Arrange material separation equipment. Sell the separated materials like hardware fittings and core rod locally. Transport silicone rubber back to our production base | Advantages: the transportation of materials with small added value like hardware fittings and core rod is eliminated. The technology and management are easily controllable Disadvantages: SGCC needs to repeatedly invest in separation plant and equipment |
| After the raw materials are collected, they shall be transported back to the treatment base | The waste composite insulators and silicone rubber collected at each collection point shall be directly transported back to our production base after simple treatment. The separation of all materials and product processing shall be completed at the production base | Advantages: repeat investment is eliminated. The technology and management are easily controllable Disadvantages: transportation cost increases |

The subsidiaries in cities shall collect the composite insulators retired from the subsidiaries in cities, counties and towns, including those used for spot check and test and the waste composite insulators and silicon rubber from manufacturers. The composite insulators shall be stored centrally. When their number reaches a certain level, they shall be treated uniformly by removing grading rings and the hardware fittings on both ends. Longer composite insulators (>3 m) can be cut for the convenience of transportation. The pretreated composite insulators shall be classified by the diameter of core rod.

The provincial subsidiaries shall entrust a third-party recycling center of waste composite insulators. The waste composite insulators collected by local companies shall be transported to the third-party recycling center for further treatment and production.
All provincial subsidiaries shall copy this model to solve the problems of recycling and disposing the waste composite insulators of SGCC.

The recycling plan of the waste composite insulators collected is shown in Table 1.

4. Disposal strategy of waste composite insulators

According to the status quo and recycling methods of waste composite insulators, it is recommended that the provincial subsidiaries shall entrust a third-party to collect and treat the waste composite insulators. The disposal strategies for different materials are as follows:

- The grading rings and hardware fittings of waste composite insulators shall be removed, classified by the diameter of core rod, and collected and transported by local subsidiaries to the third party center entrusted by provincial subsidiaries;
- The waste composite insulators with their grading rings and hardware fittings removed shall be cleaned in special cleaning equipment to remove the dirt on surface. Since cleaning agent is used during cleaning, the wastewater shall be purified for recycling or non-polluting emissions;
- After the composite insulators are cleaned and dried by standing, their core rods and external silicone rubber jackets shall be separated by the silicone rubber separation equipment. The material separation equipment can adopt a direct-cutting mechanism. Silicone rubber can be directly cut by the annular cutter head. Alternatively, the rotary cutting device can also be used to strip silicone rubber through the high speed rotating cutter head;
- The separated silicone rubber (including the waste silicone rubber of manufacturers) shall be broken by crushing equipment (particle diameter \( \leq 8 \text{mm} \));
- The crushed silicone rubber particles shall be blended with modifier or regenerant in a modification device to complete surface modification or regeneration treatment of particles;
- After surface modification or regeneration treatment in the modification device, the crushed silicone rubber particles can be used for the production of non-toxic and eco-friendly plastic track, sports floor and non-slip plastic sheet;
- The crushed silicon rubber particles shall be further pulverized by the pulverizing and grinding equipment to produce silicone rubber powder with 30-200 meshes;
- The silicone rubber powder shall be blended with modifier or regenerant in the modification device to complete surface modification or regeneration treatment of powder;
- The silicone rubber powder or those after modification/regeneration treatment can be applied to the production of composite materials such as electrical insulating materials (including composite insulators), non-slip coatings, plastic-rubber doping materials, and flame retardant materials;
- The grading rings and hardware fittings on waste composite insulators shall be recovered as scrap metal;
- The core rods of waste composite insulators can be directly used as structural parts and support members for re-use in the industries like daily necessities (e.g. tables and chairs), agriculture and forestry (greenhouses and garden support poles);
- After crushing and grinding, the core rod powder can be used to produce fiber-reinforced plastic (FRP) powder. It can be used as an additive for the production of thermosetting resin products, including epoxy resin products (such as FRP materials), phenolic resin products, urea-formaldehyde resin products, and polyester products.
- The production line, production capacity and subsequent product development of the third-party recycling center in each province shall be determined according to the number and service years of running composite insulators and the annual number of waste composite insulators in the province.

5. Conclusions

Based on the characteristics of the core rods made of glass fiber reinforced epoxy resin and the hardware fittings at both ends, their separation and recycling methods are determined, the conclusion are as follows.
1) The subsidiaries in cities shall collect the composite insulators retired from the subsidiaries in cities and store centrally.

2) The provincial subsidiaries shall entrust a third-party recycling center of waste composite insulators. The waste composite insulators collected by local companies shall be transported to the third-party recycling center for further treatment and production.

3) The grading rings and hardware fittings of waste composite insulators shall be removed, classified by the diameter of core rod, which shall be recovered as scrap metal.

4) The separated silicone rubber shall be broken and blended with modifier or regenerant to be applied to the production of composite materials such as electrical insulating materials, non-slip coatings, plastic-rubber doping materials, and flame retardant materials.

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