The Principle and the Application of Self-cleaning Anti-pollution Coating in Power System

Y J Zhao¹,²*, Z B Zhang³, Y Liu¹,², J H Wang¹,², J L Teng¹,², L S Wu¹,², Y L Zhang¹,²

¹Nari group corporation (state grid electric power search stitute), Naijing, 211106, China
²Beijing Guodian Futong science and technology development corporation, Ltd, Beijing, 100070, China
³Institute of Chemistry Chinese Academy of Sciences, Beijing, 100190, China

Abstract. The common problem existed in power system is analyzed in this paper. The main reason for the affection of the safe and stable operation to power equipment is flash-over caused by dirt and discharge. Using the self-cleaning anti-pollution coating in the power equipment surface is the key to solve the problem. In the work, the research progress and design principle about the self-cleaning anti-pollution coating was summarized. Furthermore, the preparation technology was also studied. Finally, the application prospect of hard self-cleaning anti-pollution coating in power system was forecast.

1. Introduction
With the development of economy, the emission of industrial pollutants is increased year by year. And the air pollution is more and more serious. All kinds of electrical equipment and devices in outdoor power, such as insulator, reactor, electrical cabinets and solar photovoltaic panels, are covered by pollution easily in the electric field or natural environment. The pollution layer on the electric equipment surface, which maybe contain metal particles, oil pollution, dirt, and acid, alkali, salt that can be affected with damp, not only affect the appearance and efficiency of the power equipment, but also cause the accidents, such as leakage, flashing, flash-over and so on in the conditions of fog, dew and rain.

The common used method of preventing and controlling flash over is using anti-pollution coating on the surface of the electric equipment. And the coating system based on polymer silicone rubber is the most widely used. Based on the principle, compared with other types of elastomer coatings, advantage of the room temperature vulcanized silicone rubber anti-pollution flash-over coating is hydrophobicity property and hydrophobicity transfer property, which can ensure that the water is not easy to stay on the surface of the coating, thus preventing the phenomenon of flash-over. The hydrophobicity property is due to the low degree of cross-linking of silicone rubber, and the unresponsive sioloxane with the low surface tends to migrate to the surface. However, it also has a negative effect, such as, the hardness of silicone rubber coating is low, and the hydrophobicity property is directly affected by the rate of the migration of sioloxane polymer. In addition, although Si-CH₃ in the silicon rubber structure has excellent hydrophobicity, the Si-OH has oil absorption property, which makes the coating surface to stain easily. Based on the above reasons, the equipment surface with the anti-pollution coating accumulates pollution easier. This not only affects the appearance, but also the hydrophobicity transfer property will be losing [1]. With the pollution accumulating, even the flash-over accident will happen.
The self-cleaning anti-pollution coatings used on the surface of the electrical equipment can reduce the pollution accumulation. The pollution will be washed down under the wind, rain, washing even if there is a little pollution. The electric power equipment surface can keep clean. This can reduce creepage distance and reduce electrical equipment investment for electrical equipment insulation. Furthermore, using the self-cleaning anti-pollution coating with strong hydrophobic property can effectively prevent moisture condensation and the accident for indoor distribution equipment located in wet regions.

2. Research progress of self-cleaning anti-pollution coating
Self-cleaning coating can achieve self-cleaning effect by changing the surface property of the base material such as glass, ceramics, metal or plastic. With the advantages of water saving, energy saving and environmental protection, it has important application prospects in construction, transportation, new energy and other industries [2, 3]. According to the principle of function, there are two kinds of self-cleaning coatings [3], super hydrophobic surface and super hydrophilic surface. Super hydrophobic surface, also named the "lotus effect", achieves self-cleaning effect by the water droplets scrolling down to wash away pollutants. The reason for the super hydrophilic surface keeping the surface clean is that when water droplets contact with the coating surface spreading rapidly form a uniform water film, because of the dirty gravity, the stain can be effectively taken away.

Considering the actual requirements for the power equipment, water cannot form a continuous film in insulation parts surface layer. The super hydrophobic coating technology is most likely to be applied in the electric power equipment insulation configuration. Organic silicon materials, fluorine materials, and silazane are the commonly used hydrophobic materials.

2.1. Organic silicon materials
Organic silicon has the property of low surface energy due to Si-O and Si-CH$_3$ in the structure. But the biggest disadvantage of this kind of material is that it is soft, low to the mechanical strength and easy to be smudge after curing. Silicone resin or silica sol with branched structure has high hardness after curing, but the coating is crisp and the hydrophobic property is weak because of the reduction of Si-CH$_3$ structure. At present, the superior organic silicon low-surface energy material products mainly come from foreign companies, such as Silres brand silicon resin of Wacker and Hydrozo silica sol of BASF SE. For the above two kinds of materials, the common problem is its low surface energy, which causes the weak adhesion properties to the base material. It greatly increased the construction difficulty and cost if base material processing and surface precoating are needed.

2.2. Fluorine materials
Fluorine polymer materials occupy a large portion in the field of low surface energy materials because of its good chemical stability, corrosion resistance, aging resistance, chemical inertness. The development time of fluorine polymer materials is the longest and the market share of fluorine polymer materials is the highest.

In 1943, DuPont, a foreign company, developed Teflon material, applied for patent, and applied it to high temperature equipment such as non-stick pan, which obtained the ideal application effect. In 1965 ~ 1970, Atotina company and the Elf Altochem company successfully developed poly(vinylidene fluoride) (PVDF) and partial fluorine ethylene-co- tetrafluoroethylene-co-six fluoride resin. But the poor solubility and strong role in water-and oil-repellent made the two kinds of products can only be used in the form of solid powder. The application is limited greatly. Three fluoride vinyl chloride-co-perfluorinated alkyl vinyl ether copolymer (FEVE) resins, which were developed by Japanese Asahi Glass, opened up a new era in 1982. The product not only overcome the defects of PTFE and PVDF sintering to form film at high temperatures, and can be made after dissolved in organic solvent at room temperature curing solvent coatings. DuPont company developed a kind of water-based coating based on poly-perfluorinated alkyl surfactant, which can form a layer of excellent viscosity transparent film after baking at 100 °C. This product has good applications at the car shell protective coating, interior wall coating and ship coating. 3M has developed new fluorine-containing materials, including Scotchgard, which is the most famous brand, which has been widely used. In
addition, Solvay has developed a variety of special fluorinated monomers for low surface coating development for downstream manufacturers.

But general perfluoroalkane resins can be dissolubility and need to be heated and melted to apply. Hybridization with the other organic polymer, can solve the problem of the solubility and room temperature curing. But the low surface energy property, the aging resistance and the service life of perfluorinated resin will be reduced by adding the polyurethane, isocyanate resin into the original materials.

In addition, the fluorine carbon as the main structure of the whole fluorine alkane polymer materials is difficult to degrade, which has certain harm to the environment. Releasing small molecules with no reaction will pollute the environment, and has potential harm to human and biology. Moreover, the fluorine alkane resin material has low surface friction coefficient, good wear resistance. But its adhesion to the base material is poor because of the characteristics of low surface energy. When the fluorine alkane resin material is used as coating, it will affect its reliability. Formation of the fluorocarbon resin after hybridization with other organic resin, improves adhesion. But low coefficient of friction properties of resin is lost for the whole fluorine alkane. Because of the low coating hardness, general hardness under 2 h, and poor wear-resisting performance, the coating has the long-term shortcomings.

2.3. Silazane materials
In recent years, the organic-inorganic hybrid (hybrid) low-surface coating materials have attracted more and more attention, especially the Si-N based silazane resin material has been widely used. The characteristic of this type of material is that the structure contains an inorganic Si-N bond, while the side chain can be organic or H. The Si-N bond in silazane resin is polar, which is easy to combine with all kinds of substrate. Therefore, silazane resin has high adhesion. In addition, silazane can be cured with moisture, which can be single-component with high curing density and a maximum hardness of 9H. Inorganic coatings also have obvious advantages in durability, corrosion resistance and resistance to dielectric erosion. Compared with the traditional organic silicon materials, the curing process does not exist with Si-OH group, which does not cause contamination. In addition, the Si-N polar group in its chemical structure is oriented towards the base material, and the organic Si-CH$_3$ is out. Therefore, the coating can still have the characteristics of low surface energy under the precondition of excellent adhesion. At the same time, the Si-H key in its structure can also make the material have further modification, such as the hydrophobic fluorine structure can be introduced into the material system, which will further improve the self-cleaning performance of the material. The hybrid material has the characteristics of single unit and room temperature curing. It has high density, high hardness and excellent wear resistance. Moreover, the non-degradable materials in the hybrid material have no potential harm to the environment.

At present, the material has been used in high-speed trains in Europe and India, as well as in Japanese cars, which can be used as a water-repellent cleaner to protect the car's paint. There is a series of research results to poly silazane to the Institute of Chemistry Chinese Academy of Sciences, such as the application in military industry and other special areas. In recent years, many researches are development in poly silazane coating to the Institute of Chemistry Chinese Academy of Sciences [4-6]. It has also made significant breakthrough based on the low surface energy of silazane hydrophobic coating.

3. Design principle of self-cleaning anti-pollution coating
Generally speaking, the insulation protection layer of power equipment can be decreased when the power equipment often runs in high temperature, high humidity, and strong light and electrostatic field. The main reasons include: (1) The aging of the membrane materials under the action of wet heat transfer, light, acid and alkali corrosion. (2) The coating cannot have the characteristics of hydrophobic and hate oily. And for a long time, the oil in the environment is deposited on the surface of the coating, which destroys the original micro-nano structure and coating surface. (3) Sand erosion or rain erosion caused by coating in wind, sand and rainstorm.

Based on the above analysis, film-forming material must have aging resistance, hydrophobic, hate oily, high self-cleaning, high mechanical strength and wear-resisting.
A new type of coating material with high hardness, high self-cleaning and excellent insulation performance is developed from silazane polymer. The silicone self-cleaning coating developed has the following characteristics.

### 3.1. Excellent hydrophobic property

Silazane resin can form the silicon oxide as the nuclear material after curing with Si-N chain structure of low surface energy silicon nitrogen resin as film forming material. The formation process is shown in figure 1. If perfluorinated polyether structure is introduced on Si-N structure, the surface energy will be further reduced, which can ensure coating has excellent hydrophobic, water contact angle of 120°, rolling angle of less than 5°.

![Figure 1. Curing process of silazane resin.](image)

### 3.2. High self-cleaning

A suitable TiO$_2$ with photolysis can be added to the micronanometer filler in the design of coating formula with the silazane resin as membrane material. TiO$_2$ is a kind of n-type semiconductor material, and its forbidden band width is 3.2 eV.

When it is irradiated by UV-light with the wavelength less than or equal to 387.5 nm, the electron transition occurs. It will oxidize the surface -OH and H$_2$O to OH radicals. The free radicals, has high activity, can break down most of the organic matter into inorganic small molecules, CO$_2$ and H$_2$O. This also provides guarantee for the self-cleaning of the coating. However, due to the large amount of TiO$_2$ added, the surface hydrophilicity of the coating will be increased. Therefore, the photodecomposition performance of this project only serves as a supplement to oil and gas performance, to achieve high self-cleaning characteristics and not as the main function of coating.

### 3.3. High adhesion

The structure of silazane resin material as film-forming substances contains an inorganic Si-N bond while the lateral base can be organic or H (figure 2). The Si-N bond in silazane hybrid resin material is polar, easy to combine with all kinds of substrate. Therefore, the adhesion property is high.

### 3.4. High hardness

The silazane resin is cured with moisture, with high curing density and a maximum hardness of 9H, with good sand resistance.

In addition, the coating also has obvious advantage in durability, corrosion resistance and resistance to medium erosion ability, which will ensure the excellent aging resistances, anti-corrosion, prevent ultraviolet, heat resistance performance.

### 4. Preparation and construction technology of hard self-cleaning anti-pollution coating

Coating preparation technology is through the choice and cooperation of micro/nano particles to build micro/nano structure of the coating and through design and select the appropriate low surface energy materials for coating film-forming substances. The coating was formed by mixing and grinding micro/nano filler with low surface energy materials. Further through spraying, brush, dip coating and other conventional coating preparation method for the preparation of super hydrophobic coating.

The preparation process of the silazane self-cleaning coating is discussed in this work. Firstly, the micro/nano particles were chosen. Meantime, the surface of nano silica, titanium dioxide, alumina and other inorganic filler were treated by fluoride silane coupling agent in order to obtain the coating with super hydrophobic characteristics and hate oil characteristics. It also can improve the
compatibility of nano particles and nitrogen silicon resin and enhance the storage stability of coatings. Secondly, the prefabricated base glue was obtained by the initial mixing of the inorganic fillers with fluoride silicone resin and surface modification of the special design by the mixer. Thirdly, the prefabricated base glue was treating for a period of time by vacuum kneading machine. Base gum was produced by keeping the vacuum degree and temperature to a certain value. Through vacuum kneading polymer and inorganic filler can be more fully dispersed. Next, the materials produced by vacuum kneading machine will be further porphyries to avoid the possibility of powdery reunite through three roller grinding machines. Finally, mix the base gum with a certain amount of dispersants and a certain amount of dispersants through the two-planar mixer, and make high self-cleaning and anti-fouling flash paint and filling and sealing.

5. The prospect analysis of self-cleaning anti-pollution coating applied in power system

Through the optimization of micro/nano particles and the surface modification, and with low surface energy silicon nitrogen as the membrane material for resin material, the self-cleaning anti-pollution coatings with excellent hydrophobic, excellent self-cleaning, high adhesion and high corrosion resistance, were developed. The coating can satisfy the operation requirements of some electrical equipment. And it should have broad prospect of application in the power system.

5.1. Self-cleaning for Power equipment

The power equipment, which runs in the outdoor, can be accumulated by pollution easily in electric or natural conditions. Especially there are large factories produced dust around the power equipment, the original color of the surface almost cannot be seen, as shown in figure 2.

The surface of power equipment can keep cleaning with coating silicone self-cleaning coating. Even if there is brief surface area pollution, under the irrigation of heavy rain, the surface will remain clean.

Therefore, the silazane hard self-cleaning coatings can be widely used to maintain electrical equipment surfaces cleaning.

Figure 2. Dirty insulators.

5.2. Anti pollution flash-over for power equipment

The reason for the power equipment flash-over is following. First, the pollution layer was formed because of the pollution accumulation on the equipment surface. In dry environment, resistance of pollution layer is very high and the insulation performance will not be reduced. However, in wet environment, such as fog, dew, rain and snow, surface conductivity can be increased and insulation performance can be decreased after the pollution layer is wetting. This will cause flash-over discharge.

Because of excellent hydrophobic and self-cleaning properties of the silazane hard self-cleaning coating, the dust on the surface of the electric power equipment can be effectively removed. Even in the fog, dew, rain and snow weather, the water on the surface of the electrical equipment will be rolled into water droplets. The conductive path can't be formed. Therefore, silazane hard self-cleaning coatings can be widely used in electric power equipment surface to prevent pollution flashover.

5.3. Prevent condensation for power equipment
The environment temperature changes, condensate maybe occur in the surface of the electrical equipment. With condensate formed for long time on the surface of electrical equipment, the cabinet and operating mechanism will be rusted, which will cause the equipment operating mechanism unsmooth, parts corrosion damage and other problems. Therefore, the service life of the equipment cannot meet the design needs [7]. At the same time, the condensate can cause the insulation strength of the insulation material to be reduced, which can cause the accident, such as creepage, flash-over and so on [8].

Because of silazane self-cleaning coating has excellent hydrophobic, water contact Angle of 120°, rolling Angle of less than 5°, can make the water droplets under the action of gravity from the coating surface, thus achieve the goal of surface prevent condensation.

6. Conclusion
The development, design principles and possible applications in power system of silazane self-cleaning anti-pollution coatings were introduced in this paper. Because of the usage of low surface energy silazane as film-forming material make the coating developed has high hydrophobic property, high self-cleaning, high resistance, high adhesion, high hardness and high corrosion resistance. Therefore, the potential application value is existed for anti pollution, prevent flashover and prevent condensation of the power equipment.

References
[1] Wu L S, Zhao Y J, Wang G G, et al, 2015 Silicon. Mater. 29(5) 353-9.
[2] Ganesh V A, Raut H K, Nair A S and Ramakrishna S R, 2011 J. Mater. Chem. 21 16304-22.
[3] Sun X D and Zhang Z Y, 2010 Paint. Coat. Ind. 40(12) 65-71.
[4] Wang D, Zhang Z B, Wang X F, et al, 2017 Micronanoelectr. Tech. 54(8) 514-21.
[5] Zhang Z B, Xiao F Y, Luo Y M and Xu C H, 2013 Paint. Coat. Ind. 43(4) 74-9.
[6] Zhang Z B, Xiao F Y, Luo Y M and Xu C H, 2013 Fine. Spec. Chem. 21(7) 25-8.
[7] He X N and Zhang X, 2013 Sci. Tech. Innov. Herald. 11 27-30.
[8] Yang R and Zhao F, 2014 Major Sci. Tech. 283-4.

Acknowledgements
This work was supported by Beijing Guodian Futong Science and Technology Development CO., LTD (FTZY201706).