Investigation on the Process of Dry Ice Cleaning Insulators

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Abstract. Compared with routine methods, the dry ice cleaning as an innovative, inexpensive and green cleaning technology, has excellent insulation and will not cause the pollution flashover accident. Due to the outstanding performance, the dry ice cleaning is very suitable for the insulator cleaning. In this study, the insulators were cleaned by dry ice with different cleaning parameters. The influence of different cleaning parameters on the dry ice cleaning was studied comprehensively. It is shown that reasonable air pressure, cleaning angle, dry ice mass flow, nozzle speed will improve the dry ice cleaning quality greatly, produce a high-efficiency performance. Furthermore, the dry ice cleaning can wash off the pollution of insulator surface effectively, give an obvious and ideal cleaning effect.

1. Introduction
With the continuous development of social, a higher requirement is constantly put forward for the transmission voltage and grid capacity. However, the major pollutions caused by the large-scale industry such as chemical industry, coal, cement and iron have lead to increasingly serious pollution flashover accidents on the external insulation of power systems. The ugly results will make for a huge loss of the national economic development [1-5]. Since the 1990s, the anti-pollution works of power grid in China have maken a significant process. A series of standards and regulations has been formulated for the pollution flash problem. There are mainly two types of anti-pollution measures for the insulator cleaning at present. One is to change the surface material or structural of insulators, such as using coatings, adjusting the structures of insulator. It’s a traditional technology that has been used for an extended period of time in the power systems, and has achieved partial protective effects. However, the effect of structural adjustment on the insulators is limited, and the coatings have a shortcoming on the service life of the polymer due to the aging problem. As for the coating protection, it needed to be updated and inspected regularly, which will increase the complexity of operation. The second category of insulator cleaning is the application of cleaning methods. But for the traditional cleaning methods, there are various problems in these methods such as mechanical cleaning methods, chemical methods, steam cleaning methods, etc. Especially, with the deterioration of pollution problem, the composition and structure of the dirt layer on the insulator surface will change with different pollution environments. It has a significant meaning to propose a new type, environmentally friendly cleaning method with outstanding cleaning effect, since that the conventional cleaning method can not remove the aged paint very well, which would effect the clean efficiency [6-8].

Dry ice cleaning as an advanced and efficient green industrial cleaning technology began to be used in the domestic industrial field at the late 1908s in the United States. After years of development,
the technology has gradually matured and was widely used in the aviation industry, manufacturing industry and nuclear power industry in Europe or America [9]. Presently, the research on dry ice cleaning insulator contamination technology in China is still in a fledging period. Compared with other cleaning methods, dry ice clean technology has good cleaning effect without conductive problem, and doesn’t cause damage to the cleaning objects. Generally, it’s very suitable for insulator cleaning [10-12].

In the present paper, the process of dry ice cleaning insulators of XP-100 type was studied. The cleaning effect under different conditions is analyzed to obtain the best parameters of dry ice cleaning insulator contamination and promote the application of dry ice cleaning insulator contamination.

2. Dry ice cleaning technology

The dry ice cleaning technology cleans the objects by compressing air and spraying dry ice particles through a special spraying system.

The super low-temperature dry ice particles are accelerated to close to the speed of sound or more by the flow of compressed air, and then the dirt of surface are cleaned by the cold brittle effect and impact effect of the dry ice sublimation process. The cleaning includes three process: (1) High-speed dry ice particles impinge on the surface and produce a great impact; (2) During the dry ice cleaning process, the temperature of the surface dirt suddenly drops resulting in surface embrittlement and warpage, due to the “temperature difference effect” and “low temperature cracking effect”; (3) Super low-temperature dry ice particles enter the contaminations appearing in the cracks, then the dry ice particles rapidly sublime to gas. Their volume expands to 890 times in microseconds, which results in fragmented contaminants are removed from the surface of the object. The peeling is removed by the ablation of the dry ice particles and the purge shear of compressed air [13-16].

Dry ice cleaning technology has the following characteristics: (1) Dry ice cleaning can remove many types of decontamination, and the performance is very well. No pollution occurs during the cleaning process; (2) Dry ice particles don’t have abrasive properties and don’t produce mechanical equipment, parts, and insulators, that can prolong the service life of the equipment; (3) The cleaning medium is dry ice pellets, that has good insulation properties and will not cause the flashover accident of the equipment. There are many factors that affect the dry ice cleaning effect, and any one of these parameter can impact the dry ice cleaning results. The cleaning factors include air pressure, dry ice mass flow, cleaning angle, cleaning distance, nozzle rotation speed, etc [17-18]. The influence of cleaning parameters on the dry ice cleaning process can be investigated by changing different experimental conditions, so as to obtain a better cleaning process for dry ice cleaning and meet the cleaning requirements.

3. Cleaning experiment

The experimental platform in this study consists of a dry ice cleaner, an air compression system, and a rotating test stand. The wanted pressure is provided by the air compression system, the dry ice mass flow is controlled by the dry ice cleaner, and the rotating test stand controls the cleaning angle, the distance and the nozzle speed. Some typical XP-100 ceramic insulators as cleaning objects were used in this experiment to study the effects of dry ice cleaning insulator contamination under different cleaning parameters. The three states of the insulators before smearing, after smearing and after washing are shown in Fig. 1.
Figure 1. Three states of the insulators: (a) before smearing, (b) after smearing and (c) after washing.

It noted that the surface of insulators is cleaned effectively by dry ice. For the surface of insulators, wiping with a wet paper is used to judge level of cleanliness. According to the national standard GB/T 4585-2004 "Artificial pollution tests on high-voltage insulators to be used on a.c. systems", kaolin and commercial pure sodium chloride are used to simulate the natural pollution of the insulator surface, and a certain amount of dextrin is selected to simulate the natural contamination with different degrees of adhesion [19].

In the test process, the dry ice cleaning effect under different parameters was characterized by the equivalent salt deposit density (ESDD) and non-soluble deposit density (NSDD). For measuring the ESDD on the surface of the insulator, a special salt-tight sampling towel is used to wipe the insulator until the surface of the insulator is clean. Then the sample towel stained with insulator contamination was washed by the prepared deionized water till the contamination fully dissolve. The conductivity of soiling solution at 20°C ($\sigma_{20}$) was tested by the conductivity measuring instrument, then the surface salt density of insulator was expressed as the following equation:

$$\rho_{ESDD} = \frac{\sigma_{20}}{24.56} \cdot \frac{V}{100 \cdot A} \quad (1)$$

Where k is the conversion index, which is obtained by looking up the table according to the conductivity $\sigma$ (us/cm) of the sewage liquid. V is the deionized water amount (cm³), and A is the area of the cleaned surface (cm²) [9, 20].

The sewage liquid was filtered by the filter paper after finishing the conductivity measure process. Then the weight of rest dry ash was measured by the balance, the surface NSDD can be expressed as the following equation:

$$\rho_{NSDD} = \frac{m_2 - m_1}{A} \quad (2)$$

Where $m_2$ is the quality of the filter paper with dry dirty and $m_1$ is the quality of the filter paper [21].

4. Characteristic analysis of different dry ice cleaning parameter

In this experiment, kaolin of 4mg/cm² and sodium chloride of 0.4mg/cm² were artificially smeared on the insulator surface in order to simulate the worst e-level fouling grade conditions. The dry ice particles with diameter of 3mm were used as the cleaning medium. The dry ice cleaning distance is set to 15cm and the cleaning time is 30s. For obtaining an optimal dry ice cleaning process, the effect of dry ice cleaning insulators is studied by changing the air pressure, cleaning angle, dry ice mass flow rate, and nozzle rotation speed.

4.1. Performance of air pressure on insulator cleaning effect

During the dry ice cleaning process, the air pressure determines the ejection speed of the dry ice particles. When striking into the surface of insulators, the particles are accelerated to a high speed. The dry ice particles will sublime instantaneously and absorb a large amount of heat, which realizes the conversion between kinetic energy and thermal energy. The air pressures are set 0.3 to 0.8 Mpa, and
the insulators are cleaned with an angle of 60°, a mass flow rate and nozzle speeds of 2 kg/min and 15 r/min, respectively. Figure 2 exhibits the dry ice clean performance.

As shown in Figure 2, with the continuous increasing of air pressure, the ESDD and NSDD residual degree of the insulator surface reduce continuously, the cleaning effect becomes better. But when the pressure reaches 0.7 MPa, dry ice particles get enough kinetic energy as the air pressure continues to increase, the pollution residual degree will not decrease significantly and the residual density of gray and salt remains at about 10%.

4.2. Performance of air pressure on insulator cleaning effect
In the dry ice cleaning process, the cleaning angle directly determines the transfer energy between the impacts of the dry ice particles, and affects the sublimation process of dry ice. The different cleaning angles make the dry ice particles have different vertical impact components. The different cleaning angles are shown in Figure 3.

![Figure 2. Cleaning effect with different air pressure.](image)

![Figure 3. Cleaning effect with different cleaning angle.](image)

![Figure 4. Cleaning effect with different mass flow.](image)
Angles from 60° to 90° was set in this study, the air pressure is 0.4Mpa, the mass flow rate and the nozzle rotation speeds are 2kg/min and 15r/min, respectively.

The test results are shown in Figure 3. As the cleaning angle of dry ice increases from 60° to 90°, the residual degree of contamination on the insulator surface first decreases and then increases. The cleaning effect is optimal at 75°. When the cleaning angle is small, the vertical impact component of the dry ice particles is small and the cleaning effect is not ideal. As the cleaning angle increases from 75° to 90°, the sprayed dry ice particles are more concentrated and the cleaning area is smaller, so that the cleaning effect is not obvious.

4.3. Performance of dry ice mass flow on insulator cleaning effect

The dry ice mass flow directly determines the number of dry ice collisions on the surface of the insulator, thus affecting the insulator cleaning effect. The study used a different mass flow rate of 1.0kg/min to 3.0kg/min to clean the insulator, the air pressure is 0.7Mpa and the cleaning angle is the optimum cleaning angle of 75°, the nozzle rotation speed is 15r/min, respectively.

As can be seen from Fig.4, with the mass flow rate of dry ice increases, the residual degree of contamination on the insulator surface gradually decreases, and the cleaning effect becomes better. However, when the mass flow rate of dry ice reaches 2.0 kg/min, the dry ice particles obtain enough impact force. At this time, the residual degree of contamination will not significantly reduces with a higher mass flow rate. An increasing the mass flow of dry ice can increase the ejection of dry ice particles, but the cost of cleaning will also increase. In comparison, a mass flow rate of 2.0 kg/min is a preferred parameter.

4.4. Performance of nozzle speed on insulator cleaning effect

The nozzle speed can be adjusted by the rotation speed of the rotating disk on the dry ice cleaning test platform. And the nozzle speed of the cleaning device directly affects the cleaning effect and the cost in the actual cleaning. For this purpose, the cleaning effect of different nozzle speeds needs to be determined. The test was conducted using different nozzle speeds from 5r/min to 25r/min to clean the insulators. The air pressure was set to 0.7Mpa, the cleaning angle was 75°, and the dry ice mass flow was 2kg/min.

As shown in Figure 5, it can be seen that the nozzle speed increases from 5r/min to 25r/min, the residual degree of contamination on the surface of the insulator firstly decreases and then rises, the best cleaning effect is obtained at 15r/min. When the nozzle speed of is too large, the time of dry ice particle reacting on the insulator surface contamination is short, which may cause heavy dirt is very difficult to clean. However, when the speed of nozzle is too small, the “minor explosion” effect of dry ice particles at the impact point will reduce the kinetic energy of subsequent dry ice particles. As a result, the cleaning efficiency will be reduced, and at the same time the waste of dry ice will be caused [22].

From the experimental research on different air pressures, cleaning angles, dry ice mass flow rates and nozzle speeds, it is concluded that when the cleaning distance is 15cm, the cleaning time is 30s, the selection with air pressure of 0.7Mpa, cleaning angle of 75°, mass flow rate of 2kg/min, nozzle speed of 15r/min can obtain the best cleaning effect, and the the residual degree of gray and salt remains at about 10%.
5. Analysis of insulator cleaning with different contaminant adhesions
The type and nature of the contamination on the surface of the insulator will lead to different adhesion of the contamination layer, thus affecting the effect of dry ice cleaning. The study simulates varying degrees of contamination adhesion by adding the variational amount of dextrin to kaolin. The different layers of filth are coated on the insulators with the mass ratio of dextrin to kaolin of 2:1, 1:1, 1:2, 1:3, and 1:4. The air pressure is 0.7 Mpa and the cleaning angle is 75°. The insulators were cleaned with a mass flow rate of 2 kg/min and a nozzle rotation speed of 15 r/min.

Figure 6 shows that as the ratio of dextrin to kaolin decreases, the residual degree of contamination on the insulator surface gradually decreases, and the cleaning effect becomes better. When the ratio of dextrin to kaolin is less than 1:3, the dirt adhesion has little effect on the dry ice cleaning performance, and the residual degree of contamination on the insulator surface is about 10%.

6. Conclusion
In this study, the insulators were cleaned by the dry ice particles with different cleaning parameters. The impact of the high-speed movement of dry ice and the cold-brittle effect during the sublimation of dry ice can well remove the contamination on the insulator surface. The investigation of dry ice cleaning process shows that when the cleaning air pressure is greater than 0.7 Mpa, the cleaning angle is 75°, the dry ice mass flow rate is 2 kg/min, the nozzle speed is 15 r/min, the dry ice has the best cleaning effect on insulators at the dry ice cleaning distance of 15 cm, the cleaning time of 30 s. Furthermore, when the adhesion between the dirt and the surface of the insulator is large, the performance of dry ice cleaning will be restrained, so it’s necessary to appropriately increase air pressure or cleaning time; when the adhesion between the dirt and the surface of the insulator is small, the dry ice has a better cleaning effect on insulators and the most of contamination can be removed. In
the cleaning process of insulators, dry ice cleaning is a green environmental cleaning technology, it can give full play to its advantages and achieve ideal cleaning results.

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