An Overview Research of Pre-warning Inspection on Pollution-Flashover of Insulator on Overhead Contact Line in Electrified Railway

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Abstract. This paper investigates the technology for warning of pollution-flashover for insulator installed on overhead contact line in electrified railway. It analyzes the elements resulting in insulator pollution-flashover on overhead contact line. Measuring technique for pre-warning of insulator pollution-flashover is presented and cooperative management actions are introduced depending on status of practical application. From point of maintenance view, the paper suggests that measuring technology for pollution-flashover prediction based on leakage current would be the most feasible solution to realize online monitoring in real time way. Considering research direction on pre-warning of insulator pollution-flashover, key technical topics are listed for future discussing.

Introduction

As the important installation of keeping electrical insulation between overhead contact line and support equipments or other grounding bodies, the insulator not only bears working voltage and various overvoltage, but also bears the weight of the cantenary and the mechanical load generated by the meteorological factors, and it has a great effect on the reliability of the electrified railway traction power supply system. Therefore, it is required that the insulator of overhead contact line has sufficient electrical insulation strength as well as mechanical strength. Under the meteorological conditions of pollution, if the insulator is eroded by dust, salt, chemical particles, etc., it will lead to the significant decrease of the insulation performance, or even worse, will cause partial discharge. If this discharge grew into the breakdown of insulation which is known as flashover, it would lead substation tripping and power supply interruption. If the flashover lasted a longer time, it is commonly impossible for automatic reclosing device to eliminate the faults.

Huge electrified railway network has put forward higher requirements on the reliability of traction power supply systems, the prevention of insulator pollution-flashover is an important measure to improve the reliability of traction power supply system. In the past ten years, the pollution-flashover of the insulator of overhead contact line has become one of the frequent faults [1]. Some pollution-flashover faults are shown in Table 1.

Table 1. Partially collection of cases on pollution-flashover of insulator on overhead contact line.

<table>
<thead>
<tr>
<th>Time</th>
<th>Site</th>
<th>Overview of pollution-flashover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feb 2006</td>
<td>The Beijing-Guangzhou Electrified Railway</td>
<td>Due to the heavy fog weather, pollution-flashover of insulator happened in many sections, resulting in traffic interruption with up to 315 minutes.</td>
</tr>
<tr>
<td>Feb 2007</td>
<td>Daqin Freight Electrified Railway</td>
<td>Due to pollution of coal particles covering on the insulator of cantilever, flashover occurred, result in interrupting of power supply for 277 minutes.</td>
</tr>
<tr>
<td>2009</td>
<td>Qiancao Railway</td>
<td>Qiancao Railway is an electrified railway in the sea area (with a lot of other industrial pollution sources), the number of pollution-flashovers is up to 246 in the whole year.</td>
</tr>
<tr>
<td>Feb 2011</td>
<td>Jingyihuo Railway</td>
<td>Pollution flashover occurred in many sections along the Jingyihuo Electrified Railway (about 75 km), result in interrupting of power supply for 9 hours.</td>
</tr>
<tr>
<td>Jan-Feb 2012</td>
<td>Zhengzhou-Xi'an High-speed Railway</td>
<td>Due to the fog and haze weather, pollution-flashover occurred in many sections nearby Xi'an and Weinan north Stations, the passenger transportation order were seriously interfered, and a number of news media had the reports.</td>
</tr>
</tbody>
</table>
The insulator pollution-flashover of overhead contact line may cause short power outage and interruption of power supply, even more serious is that it may cause the breakage of the contact line, and cause oscillation of the traction power supply system. As far as effective maintenance concerned, it is important to make a systematic study of pre-warning principle and detection technology on insulator pollution-flashover of overhead contact line, to explore the regularity of pollution accumulation on the surface of insulator, so as to improve insulation management.

**Analysis on Pollution-Flashover Factors of Insulator in Electrified Railways**

The 27.5 kV side of the traction transformer of electrified railway is connected to the earth with one phase, when the insulator pollution-flashover happens it is equivalent to two phase short circuit, and the short circuit current can cause the instantaneous trip of the feeder line of the traction substation, interrupting the train power supply. The height of insulator installed on the overhead contact line in electrified railways is lower relative to local power grid, so the pollution of the external insulation of overhead contact line in electrified railways is more serious. The pollution of external insulator on the mixed traction electrified railways both for electric traction and diesel traction is even more critical. In general, three necessary conditions of pollution-flashover separately are pollutants accumulated on the surface of insulator, pollutants layer becoming moist, withstanding voltage. Due to the special operation environment of electrified railways, the factors of insulator pollution-flashover of overhead contact line could be dedicatedly summarized as internal factors and external factors.

**Internal Factors**

Internal factors refers to those come from electrified railway system itself, including voltage fluctuation, electric load impact, pollution from diesel locomotive as well as the dust pollution in tunnels, etc.

1) **Voltage fluctuation**

The voltage of overhead contact line fluctuates in a larger variable values, voltage fluctuation becomes more frequently and even brings about overvoltage when AC-DC-AC traction locomotive had been put into operation. Voltage fluctuation makes it difficult to early warn and prevent pollution-flashover of insulator on overhead contact line.

2) **Electric load impact**

The electric locomotive is a nonlinear electric load, under conditions of engine starting and stopping, passing neutral section, as well as the poor interaction between pantograph and contact line, transient process and overvoltage would be produced, especially for the freight dedicated line which characterized by large load current, pollution-flashover is much more likely to happen.

3) **Diesel locomotive pollution**

The height of insulators installed on overhead contact lines varies from 5 to 7m relative to the surface of the two rails, freight loading height of the vehicle is up to 4.8 m. So the coal powder is easily accumulated on the insulators. In some mixed electrified railways, diesel locomotives and electric locomotives both operate. Emission of diesel locomotive is not only a direct pollution for the insulator of overhead contact line, but also make other dirt easier to stick on the surface due to viscosity. Therefore, diesel locomotive pollution is an important factor of pollution-flashover under particular meteorological conditions.

4) **Pollution in tunnels**

Pollution in tunnels refers to the condition of flying dust, moisture air and water leakage. In some areas, leakage water containing minerals particles directly drips on the surface of insulators of overhead contact lines, and in cold winter, moist pollution layer is frozen, which will reduce the dielectric strength of insulators. Therefore, pollution in tunnels is a triggering factor of pollution-flashover of insulators on overhead contact line in electrified railways.
External Factors

External factors can be divided into external forces, external pollution sources and meteorological conditions.

1) External force

External forces including wind, gravity, electrical field force, etc. Wind will not only accelerate the diffusion of pollution particles, but also play a role in the cleaning of the insulators’ surface. As far as electrified railways nearby the pollution plant concerned, the gravity will attract the larger particles and make it easier to accumulate on the surface of insulator. Under the action of AC electric field force, the dirt is more easily absorbed on the surface of insulator compared to the case of no action of electric field force.

2) External pollution sources

External pollution sources could be generally classified as inland pollution and coastal pollution. Inland pollution mainly comes from the emissions of chemical plant, cement plant, power plant located along the electrified railway as well as the dust generated by automobile running on bridge crossing the electrified railways.

According to the international standard IEC 60815 "Selection and dimensioning of high-voltage insulators intended for use in polluted conditions", contaminant on insulators of overhead contact line could be classified as two types which are named as A and B. Type A is a kind of non-soluble pollutants which could be described as equal salt deposit density or non-soluble deposit density. Type B is a kind of liquid electrolyte on the surface of insulator such as chemical haze, acid rain, coastal water vapor, etc. Type B doesn’t contain non-soluble elements. Conductivity or leakage current is commonly used to measure Type B.

3) Weather conditions

Under dry weather conditions, the surface of the dirty insulators still has very high dielectric strength. But in rainy or humid weather, electrolyte in the pollution layer will dissolve in water, and form a conductive path on the surface of the insulators, which greatly reduces the insulation strength, resulting in pollution-flashover of the insulators under normal operation voltage.

Coastal fog is a foggy weather condition close to coastal areas. What make it differ from inland fog is that it contains a high percentage of sea salt. Sea wind blows coastal fog into the air of inland area close to coast. Particles of salt mixed in the fog will be deposited on the surface of insulators on overhead contact line and reduce the insulation performance.

The meteorological conditions of ice and snow also decrease the electrical strength of insulator on the overhead contact line. In the frozen season, pollutants in atmosphere accumulate on the surface of insulators in two ways. One way is that pollutants has been deposited on the surface of insulators before frozen, the other way is that suspending water vapor has already dissolved or captured the conductive particles in the air before frozen. When the ice or snow melts, the electrical conductivity of the insulator surface will obviously increase, this makes it easier for the flashover to happen under operating voltage, that is also known as icing flashover.

Measurement of Warning Detection for Pollution-Flashover

Measurement of warning detection for pollution-flashover of the insulator on the overhead contact line could be concluded as the following three methods.

Measurement of Equivalent Salt Deposit Density

According to the railway industry standard TB/T 2007-1997 [2], measurement of the equivalent salt deposit density of contamination covered on insulator of overhead contact line is defined as that to use a certain volume of distilled water to clean the surface of the insulator, and then to measure the conductivity of the water, and to take NaCl which produces the same conductivity in the same volume of water as the equivalent salt, to mark the mass with W, divided by the cleaned surface area marked with S. And equivalent salt deposit density is defined by $W_0$ as the following formula.
$W_0 = \frac{W}{S}$  

Measuring procedure see Figure 1.

Equivalent salt deposit density measurement is a quantitative assessment test on the contamination condition of the surface of insulator. According to pollution level standard for overhead contact line insulator in electrified railway [2], pollution level could be inferred from measuring data which is the most important reference for making cleaning plan. The advantage of this measurement method is that it is convenient for application on site. The disadvantage is that it is a kind of static measurement which cannot reflect moist status of the contamination covered on the insulator.

**Measurement of Leakage Current**

Leakage current refers to the current flowing through the surface of insulator pollution layer, characteristics of leakage current reflects the status of the pollution on insulator surface and the status of the moisture. Therefore, from point of view concerning the mechanism of the pollution-flashover, the leakage current is an ideal monitoring parameter [3].

The leakage current monitoring system consists of four parts which are described as the Figure 2.

The leakage current collecting ring is installed on the end of cantilever insulator, as shown in Figure 3. Solar panels, battery, data acquisition unit, wireless transmission unit and other equipment are installed in the appropriate position at the bottom of the support. The leakage current sensor measures current signal, the unit of data acquisition and processing are responsible for receiving the sampled data and controlling GPRS communication unit to transmit data depending on the presetting.
time interval. Monitoring center is equipped with database server for data storage, data analysis and data diagnosis. Data transmission and monitoring structure see as Figure 4.

![Figure 3. Mounted position of leakage current collecting ring.](image)

![Figure 4. Data transmission and monitoring structure.](image)

It is easy to realize on-line leakage current measuring and continuous inspecting without complex equipment. The surface contamination of insulator and the moisture degree of dirt layer could be deduced from dynamic value of leakage current. Compared with the equivalent salt deposit density measurement, continuous measurement of the leakage current belongs to the real-time dynamic inspection, which makes the leakage current monitoring technology gradually become a research focus as far as early warning of insulator flashover is concerned.

**Ultraviolet Shooting Inspection**

When partial discharge of insulator surface occurs, the air will ionize. Under the action of arc, Nitrogen emits ultraviolet with the wavelength $\lambda = 230\sim405$ nm after ionizing in the air. Because of the ozone layer, the ultraviolet wavelength from the solar radiation we received on earth is above 280 nm, so wavelength 230~280 nm belongs to the blind area of solar ultraviolet. If the ultraviolet wavelength 230~280 nm has been inspected by ultraviolet shooting near insulator surface, it would imply discharge is happening.

Quantity of photons is one of indicators for describing intensity of discharge [4], and it is defined as the amount number measured by ultraviolet shooting apparatus under a certain gain. Ultraviolet shooting apparatus is usually embedded vision camera system. The quantity of photon per unit time has a positive correlation with discharging capacity.

The number of ultraviolet photons reflects the polluted conditions and the wetting degree of insulator surface. According to the reference [4, 5], the discharging capacity and the detection distance is a correlation of exponential decay, so it is required to calibrate the measuring result on site application. Regarding 5.5m as standard distance, discharge capacity and detection distance correction formula is shown as the following equation.

$$y_1 = 0.033x_2^3y_2 \exp(0.4125 - 0.075x_2)$$

where:

- $x_2$ - detecting distance.
- $y_2$ - discharging capacity when the detection distance is $x_2$.
- $y_1$ - discharging capacity when the detection distance is 5.5m.

There are two types of ultraviolet shooting inspection way, one is to install ultraviolet apparatus on the roof of inspection vehicle which is used for dynamic inspection, the other is to use ultraviolet apparatus manually for static on site inspecting. These two kinds of testing method can both get the
Technical Management Actions against Pollution Flashover of Insulator on Contact Line

In addition to using inspection installation to monitor hidden danger of pollution-flashover on contact line, technical management actions against pollution flashover are applied as followings based on electrified railway maintenance practice in worldwide:

1. Surveying pollution sources along the electrified railways and mapping pollution distribution, based on that to make cleaning plan for insulator of overhead contact line and to create database for heavy pollution area. Manual cleaning and washing car are both applied to improve productivity.
2. Getting services from the Meteorological Administration and the Environment Protection Agency concerning pollution index, weather forecast, pollution report, etc.
3. Painting waterproof material such as RTV or PRTV on the surface of insulator installed on the contact line.
4. Increasing insulation level by means of replacing porcelain insulator with polymer insulator on contact lines in the heavy pollution electrified railways area.
5. Mounting anti-flashover sheds on insulator of overhead contact line so as to increase creep distance and to improve anti-flashover level.

Conclusion

Technical method and management actions as mentioned above tend to proportionally decrease probability of pollution-flashover. It is impossible for ESDD measuring or ultraviolet shooting to realize on line monitoring the risk of pollution-flashover for insulator on overhead contact line, let alone technical management actions mentioned above. Periodical washing or cleaning would costly consume manual labor and material resources, sometimes pollution-flashover just happens between two periods. One case of pollution flashover means thousands of insulators have been in the risk of flashover in the same area. So the ability to forecast the warning of flashover could directly affect on reliability of traction power supply, on manual cost put into the insulator maintenance on overhead contact line, as well as on utilization efficiency of maintenance window of power supply.

Leakage current characteristics includes plenty of information such as pollution status, humidification degree, withstand voltage, which are closely related to evolution of discharge process. On-line monitoring systems based on leakage current measuring have been applied in power supply system, but few such monitoring system in electrified railways have been reported. To apply on-line monitoring system based on leakage current measuring to forecast the risk of insulator pollution flashover on overhead contact line in electrified railways would be the demand of effective maintenance. What should be further researched and experimented so as to improve pre-warning model of pollution flashover are to measure the leakage current under different weather conditions, under different type of electrified railways such as passenger railway, freight railway, tunnel railway etc., to analyze characteristics of leakage current of insulator in different conditions on overhead contact lines.

References
