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Feasibility of E-Field Method for Faulty DC Insulators Live Detection

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Abstract: - Researches on the DC power system were mainly focused on the equipments of power station in the past. Little attention was paid on the insulators, especially on the insulator live detection. In this paper, firstly, the component of DC insulator electric field is analyzed, then the feasibility of on-line detection of DC insulators by use of electric field method is discussed based on the investigating DC insulator electric field component distribution characteristic. Research results indecated the DC insulator electric field is composed by the DC electric field and harmonic electric field; DC electric field distribution curves were disorderly and unsystematic, it is easily influenced by external factors and isn't fit to detect faulty insulator; Harmonic electric field distribution is stabler and smaller influenced by external factors, it can effectively find out the internal short circuit defect in composed insulator and faulty porcelain insulator, harmonic electric field can be used to detect insulators.

Key-Words: - DC insulator, on-line detection, DC electric field, Harmonic electric field, Electric field method

1 Introduction

DC high voltage power transmission was rapidly developed in electric power transmission, because it has series of advantages in comparison with AC high voltage transmission . While DC power transmission embodies advantages, it also takes the detection problem on DC insulators.References[1,2] show that: under similar geographical environment, metal terminal corrosion and filth extent of DC insulators are more serious compared with AC insulators, and the damaged coefficient grows higher. Metal terminal corrosion was the main reason that caused porcelain insulators damaged. Moreover, because of the effect of polarity, DC porcelain insulators also emerge descending and aging problem of electric and mechanical capability that caused by ion migration. (The meaning of the ion migration was the alkali metal in porcelain insulators moves along one direction under DC electric field operation.) The filth is the main reason that caused composite insulator damaged. The aging and damaging rate of DC insulators was 10^{-4}order of magnitude, and 10^{-5}order of magnitude to AC insulators.

At present, research on DC power system was mainly concentrated on the equipments used in power station. Litter attention was paid on transmission line insulators, especially on insulators live detection. But many methods had been used to on-line detecting AC insulators such as electric filed method, Spark gap method [3~7]. According to the effect of practical detecting AC insulators, the electric field method was better than others, it could detect faulty porcelain insulators and the internal defect of composed insulators in AC transmission [3,4].we can take it as reference to detect DC insulators. In this paper we investigate feasibility of Electric field method to on-line detect DC insulators.

2 Theory of Electric Filed Method

The electric filed method to judge the insulation defect of insulator is foundation on the shape of the electric field distribution curve along the axis-direction of insulators.

Theory calculation and practical measurement shows that the electric field distribution curve along axis direction of good insulator is smooth under high voltage operation. Its distributive characteristic is: the strength is strongest as closing to the metal high-voltage terminative field, the strength of the field decreased rapidly follow with moving close to the terminal-touch, and it increased as close to the mental terminal connecting to ground, which indicated as curve A in Fig 1. While faulty porcelain insulator or internal insulating defect of composed insulator, the electric field strength would decrease in correspond position, then the electric field distribution curve of insulator would never smooth but distorted in the corresponding position which like the curve B in Fig. 1[8~11].

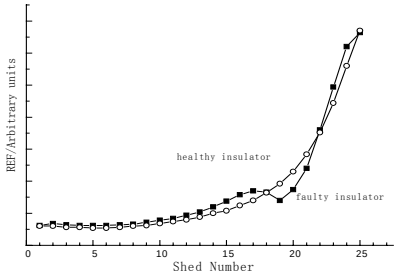


Fig.1 Sketch map of electric field distribution curve of insulator string

3 Electric Field Compents Analysis of DC Insulators

In the DC transmission line, because the voltage wave shape on the AC side of device of conversion current station was not totally sinusoidal shape, the wave shape of DC voltage was not smooth and invariable, but contain many kinds of weight harmonic, in detail current conversion station was a harmonic source, it would generate characteristic harmonic weight and uncharacteristic harmonic weight on the DC side. If the pulse number of one conversion current device was p, the number of times of harmonic generated by the conversion current device could be expressed as followed: $n = k * p$, where k was any positive integer. The characteristic harmonic weight was related to the working condition of current conversion device including the voltage on the valve side, the angle of extinguish arc, the angle of fold arc and the position of conversion transformer tapping; un-characteristic harmonic generally was generated by the asymmetry between the system and devices. So the voltage operating on the insulators of DC current line could be expressed as followed:

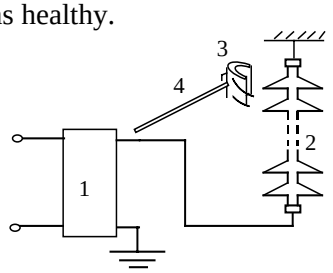
$$U_d = \nu_d + \sum u_{d(n)} \qquad (1)$$

Where ν_d stand for DC weight, $\sum u_{d(n)}$ stand for harmonic weight, According to the electric field method theory, if the insulator has defect, both the electric field of DC voltage and electric field of harmonic voltage would distort in the defect position and could give out the information of defect. Therefore, measuring electric field of DC voltage and electric field of harmonic voltage could be used to on-site detect DC insulators in theory.

4 Research E-field Method Feasibility

4.1 Detecting DC E-field of insulator

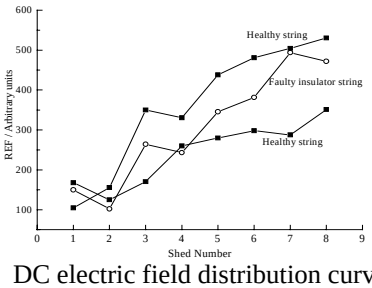
In laboratory, composite insulators and porcelain insulators were detected under 50 kV DC voltage operation. The experimental circuit for detection was shown in Fig.2. In experiment, the porcelain insulator spicemen was XP-7 kind, the amount was nine pieces in all. Among which ,eight piece were health, and one piece was faulty. The faulty insulator came from the field and the resistance value was 5MΩ. The two composed insulators spicemen were 110kV voltage grade insulator, the length is 110cm and there is not any difference with the appearance.the 1st composite insulator has an artificial short circuit defect on the high voltage terminal (the defect was a thin copper wire of diameter1.2mm, long 15cm between the external layer and the core, and it connected to the high voltage terminal metal). The 2th composite insulator was healthy.



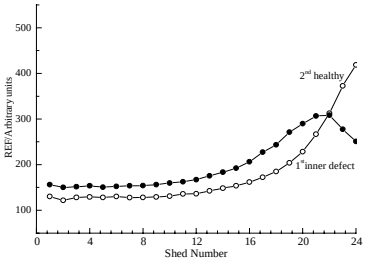
1. DC voltage source 2. Insulator bunch
3. DC Electric field tap 4. Insulator pole

Fig.2 Experiment circuit

The results of detection was shown in Fig.3. In the Fig.3, the ordinate shows the relative electric fields strength (REF) along axis-direction of insulator bunch. According to the theory of measuring, the introduction of detector would influence the real value of electric field strength, but the rule of electric field method was based on the form of electric field's strength distribution curve and it had something to do only with the relative value of the electric field strength distribution shape, so we adopt the concept of relative electric field strength.The abscissa expresses the shed Number of the insulators.



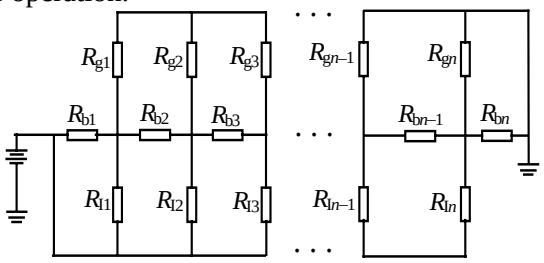
(a) DC electric field distribution curves of porcelain insulator



(b) DC electric field distribution curves of composed insulator

Fig.3 DC electric field distribution curves

As Fig.3 (a) shows: the practical DC electric field distribution curve shape of porcelain insulators significantly differed from the result of theory calculation, the distribution curves were disorderly and unsystematic. It couldn't judge Whether the porcelain insulators were health or faulty by the electric field distribution curves,becasue the curve faulty insulator was similar to that of healty insuator. Research shows that the porcelain insulators can be equal to one pure resistance as Fig.4 showed under DC operation.



R_b-Resistances of insulator;
R_g- Air resistances between insulator metals and ground;
R_I—Air resistances between insulator metals and circuit line

Fig.4 The equivalent circuit of porcelain insulator string under DC voltage

The electrical potential Φ distribution is determined by three kinds of resistance parameters, one is the air resistance between insulator metals and ground, one is the own resistance of insulators, and the other is the air resistance between insulator metals and transmission line. Research also found that the equivalent parameters of porcelain insulators were influenced by many factors such as insulators own resistance, air humidity, temperature, space charge, etc[9]. As Table1 showed , the voltage distribution value of six pieces of porcelain insulators were measured under different humidity in laboratory.

Table1 Distribution Voltage under different humidity

Insulator No.	Distribution Voltage (kV)		
Humidity (%)	52	70	83
1	**10.2**	**12.1**	11.3
2	**7.0**	**7.0**	5.9
3	**9.0**	**11.1**	14.3
4	**9.8**	**10.0**	9.2
5	**13.1**	**11.4**	12.5
6	**20.9**	**18.4**	16.8

We can clearly see that the voltage value changed and the distribution curves were irregular as showed in Fig.5.

Beacaus the relationship between electrical field strength and the electrical potential is satisfied with: $E = -\Delta\Phi$, it determined that actual DC electric field distribution of porcelain insulators was irregular and uncertainty. Therefore DC electric field distribution was not suitable for live detecting DC porcelain insulators in field.

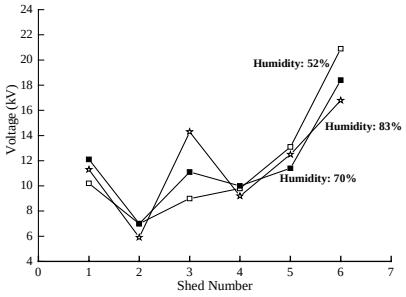
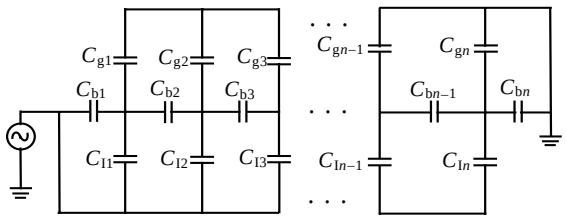


Fig.5 Volatge distribution curves under different humidity

As Fig.3 (b) showed: the practical DC electric field distribution curve shape of composite insulators was basically accord to the result of theory calculation. The DC electric field distribution curve shape of the 1st insulators (faulty insulators) distorted obviously in the defect position. The DC electric field distribution curve shape of the 2th insulators (health insulators) was continuous and smooth. According to the DC electric field distribution curve shape, it is very easy to judge whether the insulators was health or faulty. Composite insulators on high voltage line can be considered as a continuous elongated piece of insulating material placed between two conductive electrodes, the skirts can be neglected because they have almost negligible effect on the overall electric distribution. Aforementioned factors have small influence on electric field distribution. Electric field distribution was mainly decided by the quality of the continuous insulating material of insulators[12,13]. So the DC electric field distribution method can be used to on-site detect composite insulators.

4.2 Detecting harmonic E-field of insulator

Research indicated the porcelain insualtor string is qual to one pure capacitance as Fig.6 showed under AC operation. The electrical potential Φ distribution is determined by three kinds of capacitance parameters, one is the air capacitance between insulator metals and ground, one is the own capacitance of insulators, and the other is the air capacitance between insulator metals and transmission line.



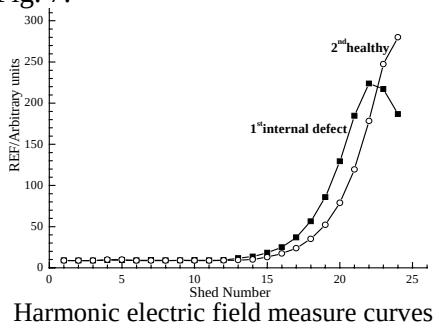
C_b-the capacitance of insulator;
C_g-the air capacitance between insulator metals and ground

C_n-the air capacitance between insulator metals and transmission line

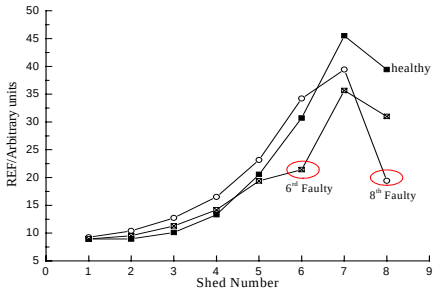
Fig.6 Equivalent circuit of porcelain insulator under AC voltage operation

Different from DC voltage operation, the distribution of electric field of porcelain insulator string under AC operation was lightly influenced by external factors such as temperature, space charge, wind direction and so on, the AC electric field of porcelain insulator bunch distributed more steady. The distribution curve of electric field of good insulator was obviously different from defect insulator's, it had been proved by practice that feasibility of AC electric field method detect AC insulators. But in the DC transmitting system, because the harmonic electric field was smaller, it need to be tested whether the harmonic electric field could detect insulators and sensitively reflect the defect of the insulators.

In laboratory, harmonic Electric field of same spicemen insulators was measured by adopting Similar experimental circuit illustrated in Fig. 2 under 770V harmonic Volatge, respectively. Testing voltage selects 770V , because the tested insulators length is about 1/5 of actual DC insulator length. Author calculated the harmonic voltage value on the model of Ge ZhouBa to Hainan bridge ±500kV DC transmission line , the result of calculation indicates there are abundant harmonic weight in the DC transmission line. The total virtual value of harmonic voltage has reached 3.36kV [17]. The test results show inFig. 7.



(a) Harmonic electric field measure curves of composed insulator



(b) Harmonic electric field curves of Porcelain insulators

Fig.7 Harmonic electric field test results

From the harmonic electric field distribution curves in figure 7 (a), the practical harmonic electric field distribution curve of composite insulators was basically according with the result of theory calculation. The harmonic electric field distribution curve shape of the 1st insulators (faulty insulators) distorted obviously in the defect position. From the curve, we can conclude there was defect of short on the high voltage end of 1st insulator;The harmonic electric field distribution curve shape of the 2th insulators (health insulators) was continuous and smooth, the 2nd insulator was healthy. According to the harmonic electric field distribution curve shape, it is very easy to judge whether the insulators was health or faulty. The results indicated that harmonic could be used to on-line detect composed insulators and It can reflect defect of inner conduction of the composed insulators, especially this method can seek the position of faulty.

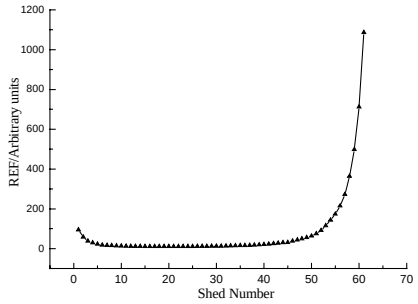
In the experiment, we measured the distribution of harmnic electric field by changing the position of the faulty porcelain insulator. The test results were showed in Fig. 7 (b). The faulty insulator was on the 8th, 6th position , respectively. The harmnic electric field distribution curve of healty porcelain insulators is similar to the curve of healthy composed insulator, except the value of the first insulator is smaller than the value of the second insulator, which is the result of the apparatus only measured vertical electric field, and the diameter of porcelain insulators are much large than the diameter of composed insulators, so the electric field relied mainly along the radial of the insulator, the vertical weight is relatively weak. The second insulator already had some distances with the high-pressure electrode, the electric field of this insulator border takes vertical weight as the core, which is similar to the electric field distribution of composed insulators, so the result shown in Fig.7 (b) was produced. When faulty porcelain insulator exited in the insulator bunch, obvious distortion had all taken place in the wave of electric harmony field in the corresponding position.

When porcelain insulator exites in insulator bunch, the harmonic electric field distribution curve would geberates distortion in the corresponding position. The results of the test indicated the harmonic electric field can on-line detect the faulty DC porcelain insulator.

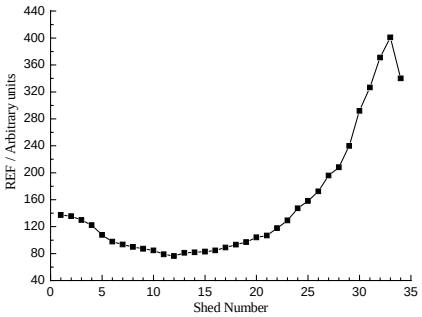
5 E-Field Method Detecting in Field

We carried out the online detection to the insulators of No.1585 tower and No.1598 tower in ±500kV Tianguang DC transmission line. The No.1585 tower was a straight-line tower, its straight-line bunch was composite insulators, 45 pieces of skirts in equal diameter of 170mm and average-voltage rings in the

double terminals. The No.1598 tower was a strain tower; its straight-line bunch was porcelain insulators, 34 pieces in all, diameter of 320mm and with average-voltage rings in the double terminals.The experimental result was showed in Fig.8.



(a)harmonic electric field distribution curve of composite insulator of the No.1585 tower



(b) harmonic electric field distribution curve of porcelain insulator of the No.1598 tower

Fig.8 harmonic electric field detection curves in field

Every curve of field detection result was fully agreed with the detection datum of health insulators in the lab. The harmonic electric field of porcelain insulators was smaller than that of composite insulator under same voltage operation. The local experiment result has proved that harmonic electric field distribution method could be used to online detect DC composite insulator and porcelain insulators. But it was regret to un-find out faulty insulator in local for the reason of limited time, it should be done in future.

6 Conclusion

DC transmission line has abundant harmonic components volatge besides steady DC component volatge,so the DC insulator string electric field has DC component electric field and harmonic component electric field. Laboratory research and field measure indicated that the DC electric field distribution curves were disorderly and unsystematic, and it couldn't judge Whether the porcelain insulators were health or faulty by the DC electric field distribution curves, becasue the curve faulty insulator was similar to that of healty insuator. Harmonic electric field distribution is stabler and smaller influenced by outside factor, it can effectively find out the internal short circuit defect in composed insulat and faulty porcelain insulator. we can use harmonic component electric field to on-line detect DC insulator.But because the time is limited, the field test has not been able to find out faulty insulator, usability of the method still need more research.

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