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Detection Methods of the Faulty Porcelain Insulators

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Abstract: The present on-line detection methods of the porcelain insulator are reviewed in this paper. A new synthetic method, which includes three new methods, is introduced in detail. The first method is the sensitive insulator method that is based on 110kV and 220kV power line. In this method it is proved that the fourth insulator numbered from the earth side is generally the sensitive insulator. Only via measuring its distribution voltage can we know whether there is a faulty insulator in the string or not. The second method is called pulse current method. This method points to the condition that the faulty insulator has a discharge track, but can still afford high distribution voltage. The discharge pulse can be extracted from the noises effectively by wavelet. The third method is called string current method. It is proved that for 110kV line, the string current will increase when there is a faulty insulator in the string. With this synthetic method, the correction ratio of the judgment will be enhanced and the workload of measurement will be decreased greatly.

Key words: sensitive insulator   relative difference   distribution voltage   pulse current   string current

1 INTRODUCTION

Since the power industry's early days, the distance over which electrical power is transmitted has been continuously increasing along with system voltage levels. This has led to a significant increase in the number of suspension insulators in use on power lines. Since the service life of the individual insulator making up these strings is difficult to predict, they must be tested periodically to maintain adequate line reliability at all times. Every porcelain insulator on our lines would get tested thus permitting to replace faulty ones before they could cause problems. Hence the use of tremendous numbers of suspension porcelain insulators increases the load of the measurement.

The faulty porcelain insulator can not be found easily from the outward appearance. In order to detect it, the operation condition of the faulty insulator has to be held. The difference must be distinguished between the fine insulator and the faulty one under the natural condition.

The characteristic of the faulty insulator can be concluded as follows:

1) When there is a little crack in the faulty insulator, the partial discharge may occur, and cause pulse discharge current. The insulation medium of the crack is not porcelain but air. Before the crack is run through by discharge, air is still a good kind of insulation medium. So under this condition, the faulty insulator still can afford quite high distribution voltage.

2) The PD of the faulty insulator can emit out EM wave and sound wave.

3) The minute current on the surface of the faulty insulator can hold heat, which cause the uneven temperature of the faulty insulator surface. The temperature of the current area is higher than that of other part.

4) The faulty insulator is too faulty to afford the same value of distribution voltage as usual.

5) The insulation resistance of the faulty insulator decreases, and the power leakage current increases correspondingly.

Over the years, many testing methods pointing to the characteristics of the faulty insulator have been used to detect the faulty insulator. Until now there are non-electrical methods, represented by ultrasonic method, laser Doppler vibration and infrared imaging method; and electrical methods, represented by distribution voltage method, insulation resistance method and pulse current method. However the non-electrical methods still remain on the stage of theoretical analysis and experiment. The insulation resistance method and the pulse current method still have some software and hardware problems to be resolved. The distribution voltage method is widely used[1][2].

2 ON-LINE METHODS

2.1 Non-electrical Method

With the problems such as coupling, attenuation and the performance of the ultra-sonic transducer, testing the insulator by ultra-sonic is only in laboratory for studying[3][4]. The laser Doppler vibration equipment is too large, heavy, expensive and complex in maintenance[5]. It is important for the testing apparatus to be light and sample for on-site measurement. So these two methods are too difficult to be used on site under the present condition. Infrared image equipment is only effective to the insulators with semiconductor, because the temperature of the normal surface is several degrees lower than that of the faulty surface. But as to the glass insulator and the insulator with common glaze, there is only a bit of difference between the normal surface and the faulty surface, infrared image equipment is not feasible[6]. And the price of the infrared image equipment is very high to most of the customers.

2.2 Electrical Method

The insulation resistance can be obtained via measuring the leakage current. But the leakage current is influenced by the change of the transmission line voltage. The change of the current caused by the fluctuation of the voltage is theoretically equal to that caused by one or two faulty insulators[7]. The leakage current is also determined by the contamination degree [8]~[10], tower structure [11], aging of the insulator [12], the shape of insulator[13], the ambient environment and the weather [14] [15], even the time. Therefore the criterion is too difficult to be made.

The pulse current method is to judge the status of the insulator via recording the number of the corona pulse. The bigger the number of the recorded corona pulse is, the worse the condition of the insulator is. The corona pulse current may exist at any time, and the number will change with the fluctuation of the running voltage. And the measurement result of the corona pulse current will be influenced by the weather condition[16]. The criterion is also difficult to be made.

The measurement of the distribution voltage is a conventional on-site method that is widely used. This method is to detect the potential across an insulator called as distribution voltage, which is not considered to be a very refined method but has proven to be very useful especially for long insulator strings[17]~[19]. There are almost several ten thousand insulators installed in a 300km-long 220kV line. It will take a line-operator one or two months to finish the measurement of the distribution voltage. But the faulty ratio of the porcelain insulator is very small. The result of the measurement is that only a few faulty insulators would be obtained. This low-efficiency method is facing improvement.

However, in fact, even when the insulator is destroyed, the PD may not take place, the power leakage current may not increase distinctly, and the distribution voltage is not lower than the fine insulator obviously. So judging the faulty insulator by only one method is not correct. The method introduced in this paper is based on the distribution voltage method, and considered the characteristics a) and e) presented in the introduction. A new judgement of the faulty insulator is also developed, which is considered the possible condition of the faulty insulator synthetically. This new method can not only decrease the ratio of the missing-detection and error-detection, but also reduce the labor load.

3 SENSITIVE INSULATOR

3.1 Principle

The distribution voltage across every insulator is called SDV (standard distribution voltage) when every insulator of the strings is fine. If there is a faulty insulator in the string, a difference will occur between the measured result and the standard distribution voltage, because the distribution voltage afforded by the faulty insulator decreases greatly. The difference will change with the place and the faulty degree of the insulator in the string. Under the condition that the overall voltage is unchanged, the distribution voltage that should afford by the faulty insulator transfers to the other fine insulators, which makes those of the latter increase.

As to the 110kV line and 220kV line, when there is a faulty insulator in the string, there is a special insulator, of which the relative difference is always obvious, no matter the place of the faulty insulator is. This special insulator is called as sensitive insulator. Only via measuring the voltage across this sensitive insulator, can we judge whether there is a faulty insulator or not. If the measured voltage of the sensitive insulator is higher than its standard value exceeding the limitation, it can be confirmed that a fault insulator is in the string. If the measured voltage is smaller than its standard value in excess of the criterion rule, the sensitive insulator must be the fault insulator.

In the simulation experiment, the condition can be controlled not to change obviously, so the standard distribution voltage is the average of multiple measurement values. It is defined as LSDV(laboratory standard distribution voltage). As to the field measurement, the condition is decided by the natural condition, so the standard distribution voltage is different from that got in the laboratory. Comparing to the large quantity of the porcelain insulator serving in the power line, the occurrence ratio of the faulty insulator is too minute. The probability of two faulty insulators in different phase on the same tower is near to zero. So it can be presumed that there is only one faulty insulator in one phase on one tower, which has almost no effect on the relevance ratio. Under the normal situation, the measurement results got from the same place of the three-phase insulator string in the same tower are approximate because of the similar electrical condition. But if there is a faulty insulator in one phase, the measurement results of that phase are different from that of the other two phases. So considering the average of the two nearer values as the field standard distribution voltage is feasible. It is defined as FSDV (field standard distribution voltage).

After finding out the occurrence of the faulty insulator, the distribution voltage of every insulator is just measured in order to find the actual place of the faulty insulator. Because of the minute ratio of the faulty insulator, the measurement load decreases greatly.

3.2 Testing setting and steps

In order to prove the deduction, many experiments have been done in the laboratory. The testing voltage levels are 110kV line and 220kV line. The experiment model is displayed in Fig.1. The fine insulator paralleled with the resistors with different resistance is used to simulate the insulator with different faulty degree. The measurement apparatus is the faulty insulator tester, which is widely used in the power utilities all over China. The measurement error of this apparatus is ±3%.The experiments were done according to the following steps.

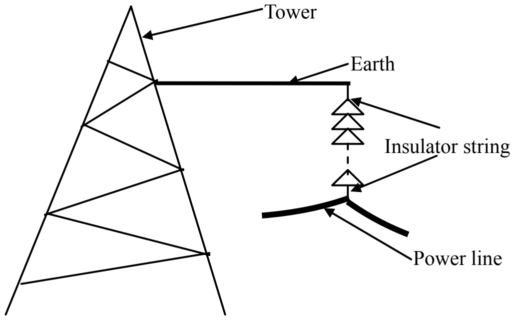


Fig. 1 Schematic figure of the measurement system

3.2.1 Experiment 1-- 110kV Line

The prepared experimental conditions are that the power voltage is 64kV, nine fine insulators are selected and numbered from No.1 to No.9 respectively from the earth to the power line.

First step, Measure groups of the distribution voltage, and calculate the average of the values with the same number as the standard value marked down as ΔU_j^s, s represents the word standard, j is the position of the measurement in the string. The standard value is not relevant to the position of the faulty insulator. So only one footnote j is enough.

Second step, the faulty insulator with different faulty degree is put into the string replacing every good insulator. When the faulty insulator replaces the No.i insulator, measure the distribution voltage of every insulator, marked as $\Delta U_{i,j}^m$ （i, j=1,…9）; m represents measurement, i is the position of the faulty insulator in the string, j is the measurement position.

Finally, calculate the relative differenceδ and make the curve j. The letter j represents the place of the faulty insulator.

3.2.2 Experiment 2--220kV Line

This experiment is similar to the experiment 1, the differences are that the experimental voltage is 128kV, the number of the insulators is 14. The insulators are numbered from No.1 to No.14 respectively from the earth to the power line.

3.2.3 Results of the Experiments

The data of the experiment are shown in from Fig.2 to Fig.5. The X-axis is the insulator number, and the Y-axis is the relative difference. From Fig.2 to Fig.5, the insulation performance of the faulty insulator is better. In the same figure, the place of the faulty insulator is differently marked, and (a) and (b) are the results of simulated 110kV line and 220kV line. The number with different signal represents the measurement position

$$\delta_{i,j} = \left|\Delta U_{i,j}^m - \Delta U_j^s\right| / \Delta U_j^s \cdot 100\% \quad (i,j=1,\ldots 9) \tag{1}$$

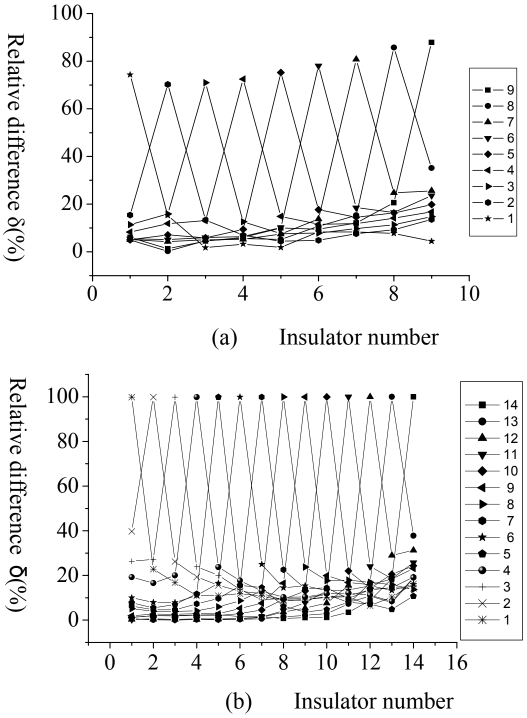


Fig.2 Relative difference with the zero-value insulator at different place in the string

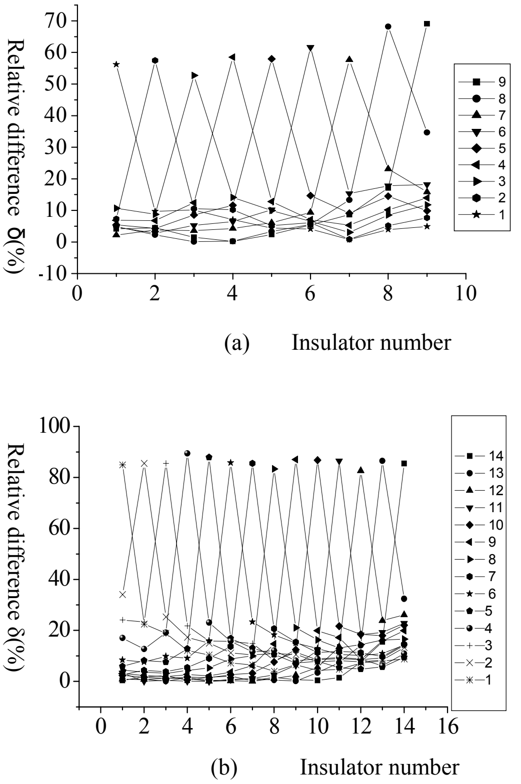


Fig.3 Relative difference with the faulty insulator (10MΩ)at different place in the string

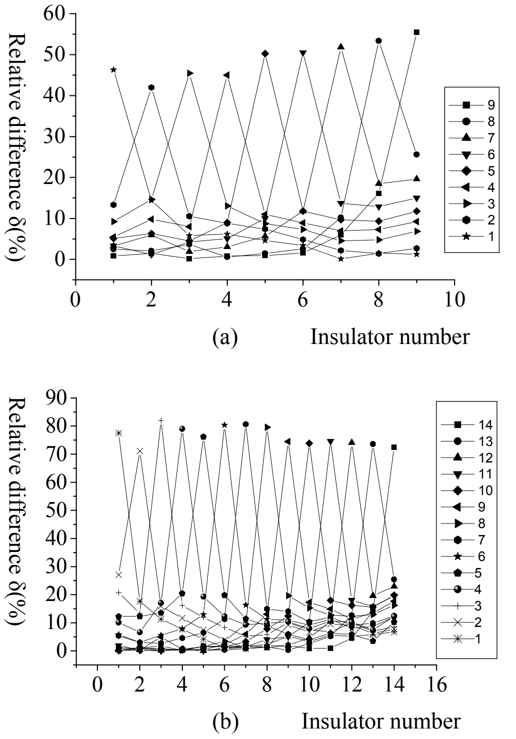


Fig.4 Relative difference with the faulty insulator (20MΩ)at different place in the string

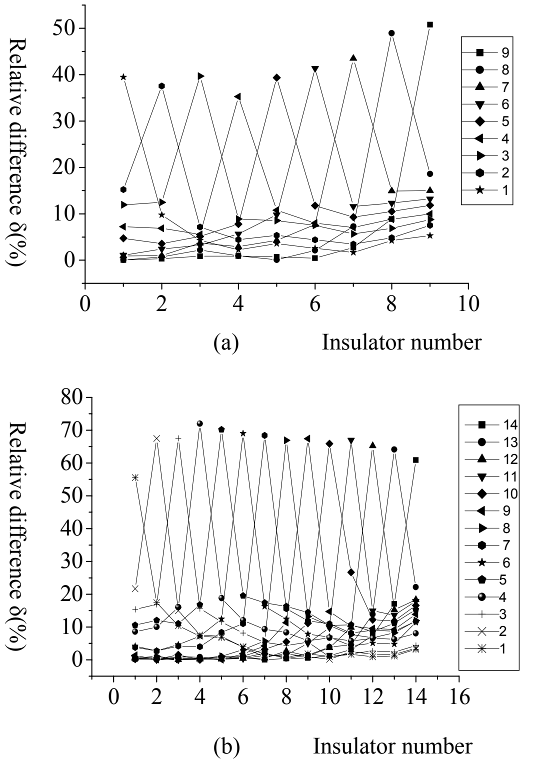


Fig.5 Relative difference with the faulty insulator (30MΩ)at different place in the string

3.2.4 Field Data

The field data are got from the 110kV line of Yantai power company of Shandong province in China. The three phase data are listed in TABLE.1(unit: kV).

TABLE 1 The field data of 110kV line in Yantai

	9	8	7	6	5	4	3	2	1
A	11.5	9.4	7.7	7.1	6.0	5.5	5.5	5.6	5.7
B	12.5	10.3	1.2	8.5	6.7	6.1	6.2	5.8	6.5
C	12.4	9.2	7.9	6.5	5.6	5.4	5.3	5.3	6.3

From the TABLE 1, it can be seen that the No.7 insulator in B-phase is faulty, of which the distribution voltage is much lower than it should affords. But the distribution voltages of the others all increase.

3.2.5 Analysis of the Data

1) From the figures above, it can be seen that the relative difference δ of the faulty insulator itself is the largest one, then are that of the insulators near the faulty one.

2) The bigger the parallel resistance is, the lighter the faulty degree of the insulator is, and the smaller the effect of the faulty insulator on the others is. Under this condition, judging whether there is a faulty insulator or not only by measuring the distribution voltage of the sensitive insulator is inaccurate. It is confirmed that the resolution is the parallel resistance is smaller than 30MΩwhich represents that capacitive reactance of the insulator is smaller than 30MΩin this paper. Under this condition the faulty insulator can not afford 3kV voltage.

3) The shape of the distribution voltage curve is like asymmetrical letter “U”, the bottom of the curve is not exact in the middle but near to the earth terminate. In the experiment, the distribution voltage of No.9 insulator is much higher than that of No.1 insulator. Therefore, when the place of the faulty insulator is near the power line, the distribution voltage of most of the other insulators will apparently increase. But if the place of the faulty insulator is near the earth or the bottom of the “U” curve, the transferred voltage is very small, which has little effect on the other insulator. The distribution voltage of most of the other insulators will increase a bit. However, that of the insulator near the power line doesn't change at all. The insulators near the earth are sensitive to the voltage-change of the insulator near the power line, but the latter are not sensitive to that of the frontier. By this analysis the sensitive insulator could not be in the middle or near the line, it must be a bit near the earth. Synthetically considered, No.4 insulator is the sensitive insulator proved by many experiments. Measuring the distribution voltage of the No.4 insulator can determine whether there is a faulty insulator in the string or not.

3.2.6 Criterion of the Judgement of the Sensitive Insulator

In TABLE 1 and TABLE 2, the data, which represent the relative difference of No.4 insulator when there is a faulty insulator in the string, are listed. In the national standard of China, the insulator that can afford more than 3kV voltage is not classified as the faulty insulator. That condition is equal to the insulator paralleled with more than 30MΩ resistor in this paper. So the criterion of the judgement is to find out, within the tolerance, the faulty insulator, of which the capacitive resistance is smaller than 30MΩ.

TABLE 2 RELATIVE DIFFERENCE OF THE 4th INSULATOR WITH DIFFERENT DEGREE FAULTY INSULATOR IN THE 110kV STRING

δ R (MΩ)	$\delta_{9,4}$	$\delta_{8,4}$	$\delta_{7,4}$	$\delta_{6,4}$	$\delta_{5,4}$	$\delta_{4,4}$	$\delta_{3,4}$	$\delta_{2,4}$	$\delta_{1,4}$
0	16.75	14.10	11.82	11.55	14.83	72.45	13.06	11.85	8.32
10	13.95	10.13	5.32	7.09	12.80	58.51	12.41	6.79	6.90
20	9.23	7.27	6.97	8.92	10.98	45.00	7.99	9.80	5.46
30	9.97	8.84	7.03	8.00	10.78	35.26	5.56	6.88	7.22

TABLE 3 RELATIVE DIFFERENCE OF THE 4th INSULATOR WITH DIFFERENT DEGREE FAULTY INSULATOR IN THE 220kV STRING

δ R(MΩ)	$\delta_{14,4}$	$\delta_{13,4}$	$\delta_{12,4}$	$\delta_{11,4}$	$\delta_{10,4}$	$\delta_{9,4}$	$\delta_{8,4}$
0	18.99	8.41	11.21	12.14	11.90	10.37	10.29
10	10.88	6.14	8.84	9.39	8.84	8.18	12.06
20	12.21	7.42	10.22	10.66	7.91	10.33	9.85
30	8.08	6.27	6.58	5.74	6.72	5.83	8.31

δ R(MΩ)	$\delta_{7,4}$	$\delta_{6,4}$	$\delta_{5,4}$	$\delta_{4,4}$	$\delta_{3,4}$	$\delta_{2,4}$	$\delta_{1,4}$
0	13.03	17.64	23.74	99.83	20.02	16.56	19.23
10	11.55	15.85	23.05	89.41	19.11	12.69	17.04
20	9.29	12.25	19.28	79.02	17.01	6.63	10.13
30	9.30	12.03	18.79	71.93	16.00	9.97	8.53

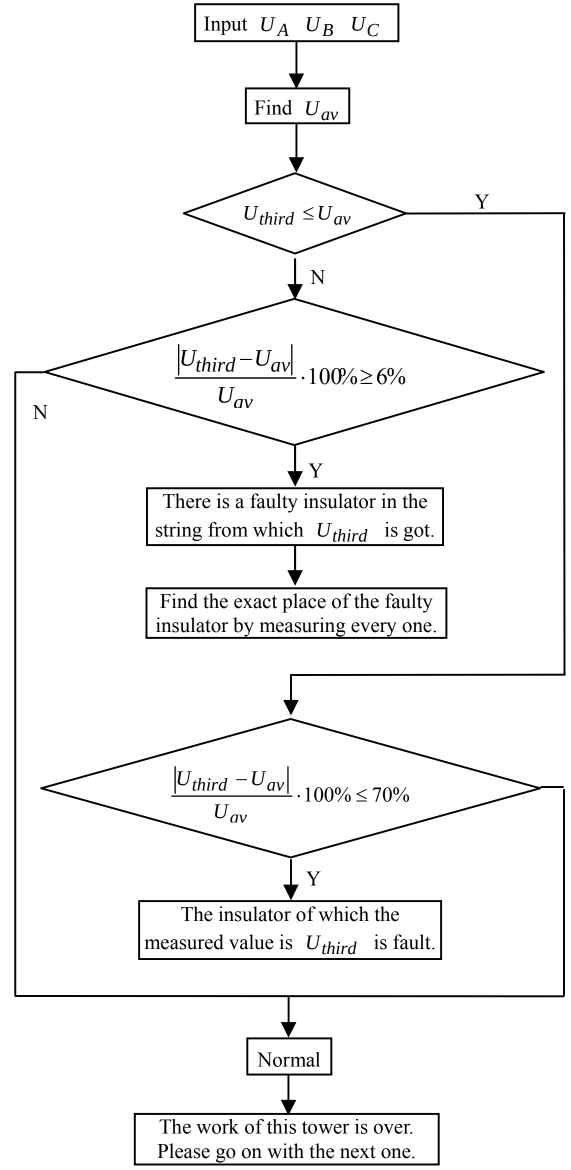


Fig. 6. Flow diagram of the judgment software

Considering the dispersity of the experiments and the measurement error of the apparatus, the threshold of the relative difference is 6%. If the distribution voltage of No.4 insulator is more than 6% higher than its standard distribution voltage, it can be predicted that a faulty insulator may be in the string, the omission factor is less than 10%. The zero-value insulator can be found out almost at 100%.

Compared with the FSDV, a special program is designed to judge the situation of the insulator. The flow diagram of the judgment software is shown in Fig.6.

In the flow diagram, U_{av} is the FSDV, the average of the two nearer values of the three phases, of NO.4 insulator. The constant 70% is got from the operation standard of Shandong Power Company in China.

1) Measuring the distribution voltage of NO.4 insulator in three phases;

2) Finding the FSDV, marked as U_{av} . If the three values are arithmetic progression, the two values in similar EM field are averaged as the FSDV.

3) Compare U_{third} with U_{av} according to the criterion, and give the conclusion.

Applied this program to the field data in TABLE.I, the average voltage is

$$U_{av} = (U_A + U_C)/2 = (5.5 + 5.4)/2 = 5.45$$

Then the relative difference is

$$\delta = (U_B - U_{av})/U_{av} \cdot 100\% = (6.1 - 5.45)/5.45 \cdot 100\% = 11.93\%$$

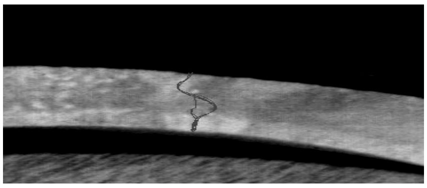
Obviously, the relative difference 11.93% is much larger than the threshold 6%, so there must be a faulty insulator in the string.

The method using of sensitive insulator has been proven not only in the laboratory but also in the field. The application of this method will decrease the workload of the measurement greatly.

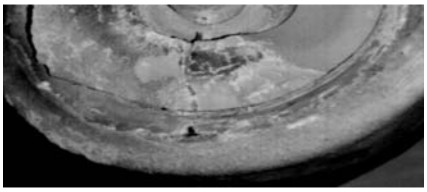
4 THE PD OF THE INSULATOR

The insulators may be damaged by either electrical or mechanical force. Internal cracks or discharge tracks may take place. Under this condition, the insulator is possible to have the characteristic a). The insulator can still afford quite high distribution voltage. In fact it is very dangerous, because with the discharge tracks the insulator may become faulty suddenly. However by the sensitive insulator method, even by the conventional distribution voltage method, this kind of faulty insulator is difficult to be found.

The discharge tracks often occur in the insulator shed and the edge of the cap and pin. Both possibilities have all been found in the laboratory, which are shown in Fig.7 respectively.



(a)



(b)

Fig. 7 Discharge tracks and cracks

Fig. 8 shows the testing system. The string current of the faulty insulator includes the surface leakage current and the body current. The surface leakage current is often influenced by the environment, which is considered as the interference signal. When measuring the pulse current of the string, we short circuit the surface leakage current. Then the string current only includes the body current.

The pulse is contained in the string current. The wave of the partial discharge has been recorded by the 300MHz oscilloscope in the laboratory, and is shown in Fig.9. This wave is based on power frequency and mixed with all kinds of noise. But the PD pulse is still prominent.

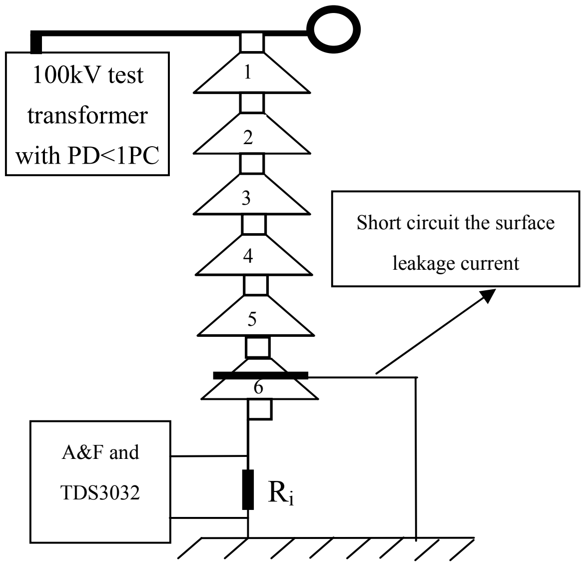


Fig. 8 Testing system R_i is the sampling resistance

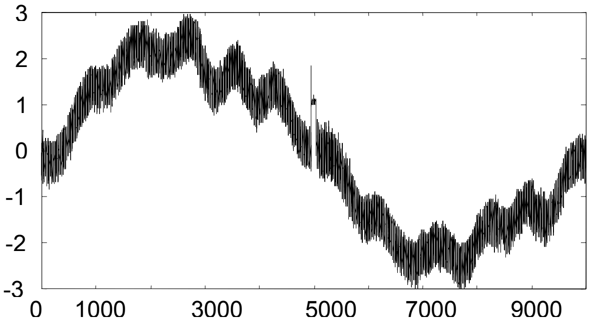


Fig. 9 Discharge wave with noise

Wavelets are functions that are excellent in analyzing non-stationary signals. Essentially wavelets are short waves that decay to zero quickly (compact support) and also exhibit oscillatory behavior. Because of this localization property, wavelets are quite good in isolating singularities and irregular structures in signals. The partial discharge pulse is a kind of typical exponential waveform that is wide in frequency domain but narrow in time domain. Using wavelet transform, the pulse signal can be extracted.

If there is no faulty insulator in the string judging from the sensitive insulator criterion and the PD pulse could not be caught either, it can be assured that the insulators on that tower are all operating well.

Our conclusion is based on the case that the distributed voltage of the faulty insulator can lead to discharge. But in other cases, especially for a badly damaged insulator, the internal discharge of faulty insulator does not occur at all because of its low distributed voltage. Therefore the new method can not be available.

5 ANALYSIS OF THE STRING CURRENT

Under the condition of AC power system, the surface leakage resistance is much bigger than the body resistance. Then the surface leakage current is much smaller than the body current. In the experiment, the surface leakage current is also short circuit. The testing system is also shown as Fig.8. Because there is no the effect of the surface leakage current in the measurement result, the value of the body resistance influences the string current directly. When there is a faulty insulator in the string, the measured string current will change.

Since the distribution voltage of the whole insulator string is asymmetrical “U”, the place of the faulty insulator is important, it will have effect on the measurement of the string current. When the faulty insulator is at both ends of the string, the afforded voltage is higher. With the same faulty degree, the string current is higher than that the faulty insulator in the middle of the string.

Under the laboratory condition, six insulators are used to prove the deduction above. Because the experiments are done in the high voltage laboratory, the experimental conditions are similar, such as the temperature, the humidity, and some factors that may have great effects on the measurement.

First step: select six fine insulators and measure the string current of the string, the average value of many times is 132μA. This is the standard string current of six insulators, marked down as I^s

Second step: put the zero-value faulty insulator in the different place in the string, and measure the string current, the average data are listed in TABLE.IV, marked down as $I_i^m(i=1......6)$, i is the place of the faulty insulator. The relative value is defined as

$$\delta_i = (I_i^m - I^s)/I^s \cdot 100\% \qquad (2)$$

Short-circuit a fine insulator is similar to a zero value faulty insulator.

TABLE 4 STRING CURRENTS OF THE WHOLE STRING WITH A ZERO-VALUE FAULTY INSULATOR

Place of the faulty insulator	1	2	3	4	5	6
String current □μA□	172.0	158.0	154.0	159.0	162.0	187.0
Relative value (%)	30.3	19.7	16.7	20.5	22.7	41.7

Third step: Parallel the fine insulator with a 50MΩ resistor, measure the string current, the average data are listed in TABLE 5.

TABLE 5 STRING CURRENT OF THE WHOLE STRING WITH A LIGHT FAULTY INSULATOR

Place of the faulty insulator	1	2	3	4	5	6
String current □μA□	155.0	144.0	137.0	138.0	146.0	156.0
Relative value (%)	17.4	9.1	3.8	4.5	10.6	18.2

From TABLE 4 and TABLE 5, it can be seen that the string current increases because of the faulty insulator. The string current is influenced directly by the faulty degree and the place of the insulator. Under the same condition, the leakage current measured with zero-value faulty insulator is bigger than that measured with light faulty insulator. The string current measured with the faulty insulator at both ends is bigger than that measured with the faulty insulator at the middle.

6 CONCLUSION

The analysis and conclusion in this paper is based on the experiment of the 110kV line and 220kV line. The relative difference is 6%, which makes the omission error is no more than 10%. As to the higher voltage level, such as the 500kV line, the insulator string is so long that only one sensitive insulator can not determine whether there is a faulty insulator or not. In this situation the insulator string has to be divided into more than one section, a sensitive insulator can be found in each section. The sensitive insulator will be confirmed by experiment.

Under such condition that the faulty insulator can afford normal distribution voltage but the PD pulse has occurred, the capacitive current can be caught and de-noised by wavelet. If there are some pulses in the de-noised wave, there is a faulty insulator in the string.

Under normal condition, the three-phase leakage currents are approximate. If one of them is much bigger than the other two, there is a faulty insulator in the string.

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