Paper

Investigation of DC Leakage-current Waveform of Contaminated Insulators

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Leakage currents on various kinds of porcelain insulators were measured under DC voltage application in artificial contamination tests by using powerful DC power source which practically gives no voltage drop against leakage current during the test. Magnitude, duration and waveform of leakage currents were analyzed in relation to kinds of insulators and test procedures.

Key words: Leakage current, DC, Contaminated insulators, Voltage source

1. Introduction

Compared with AC transmission, DC transmission has advantages of higher stability, more economical for longer transmission distances, smaller size and so on. DC transmission lines have been constructed in some countries like U.S.A., Canada, Brazil and so on. In Japan, a DC ±250kV transmission line is under operation between Honshu and Hokkaido. The number of DC transmission systems is expected to increase all over the world.

Contamination of DC insulators is a principal factor in its insulation design. Thus, a full-scale artificial contamination test is indispensable for research and development of DC insulators and bushings. Investigations so far have proved that the performance of DC insulators is considerably different from that of AC insulators due to different arcing behaviors reported in References 1, 2, etc. Under such a condition, an international study was made and artificial contamination test method on DC insulators has been standardized[3].

DC power source is an important factor in artificial contamination test. During a DC contamination test, a large leakage current flows on the contaminated insulator. If the power source causes a large drop in the output voltage, apparently higher withstand voltage may be obtained. A very stiff power source is required for such an artificial contamination test[1,4].

A large leakage current is observed with relatively long duration in an artificial test using contaminated snow[5]. CIGRE discussed specifications of power source for DC artificial contamination test of insulators[6] and recommended the requirement for maximum and mean voltage drops and ripple content to IEC who accepted them for substantial inclusion in the IEC Technical Report[7]. They are mostly based on the withstand voltages of line insulators obtained in artificial contamination tests. In practice, however, flashover voltage has to be obtained in artificial contamination tests. To select an appropriate power source for contamination tests, information on magnitude and duration of leakage currents on various kinds of insulators is indispensable. DC leakage current waveforms on a disc insulator have been analyzed in relation to the DC test source requirements for contamination tests[8]. However, no systematic study on DC leakage current waveform has been carried out. Besides, using a weak voltage source seems to result in a large voltage drop against large current[6]. Thus, it is necessary to make a study on DC leakage current by using a reasonably powerful DC voltage source.

This paper reports on measured results of leakage current on various kinds of porcelain insulators obtained in artificial contamination tests using a stiff DC power source that practically eliminates voltage drop. Effects of applied voltage, type of insulator and contamination method on leakage current waveform are discussed.

2. Experimental Procedure

2.1 DC Power Source

Requirements for a voltage source for artificial contamination test of DC insulators are described in IEC Technical Report as follows[7]:

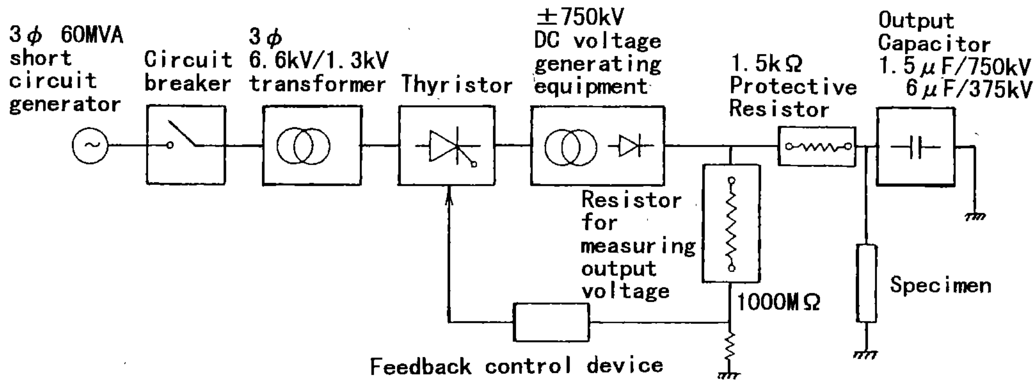

Fig. 1 Block diagram of DC ±750kV power source (Thyrister-controlled feedback system).

(1) The ripple factor of the test voltage demonstrated in a suitable way, shall be ≦3% for a current of 100mA with a resistive load.
(2) The relative voltage drop occurring during individual tests resulting in withstand shall not exceed 10%.
(3) The relative voltage overshoot, usually due to load-release caused by extinction of electrical discharges on the insulator surface, shall not exceed 10%.

In the present study, a DC power source was used which satisfy the above requirements. The power source is composed of the following components: ±750-kV DC voltage generating equipment, 1.5-μF output capacitor, 60-MVA short circuit generator and thyristor feedback control unit[9].

The output capacitor suppresses the ripple of the output voltage and instantaneous voltage variation at the time of sudden change of load, and stabilizes the feedback system of voltage drop compensation. The feedback control unit quickly detects the subsequent drop of the output voltage and compensates it by operating the thyristors equipped on the AC side of the ±750-kV DC voltage generating equipment. By using the thyristor control unit with the rapid response time, a compact design of the testing equipment was realized.

The specifications of the power supply are summarized in Table 1 with the block diagram of the power source shown in Fig. 1. The voltage drop in the range of output voltage of ±200 to ±750kV is less than 5% against leakage current of 2.5A. Figure 2 shows typical oscillograms of output voltage and leakage current at the time of flashover event when a 12-m contaminated bushing shell was tested at SDD of 0.03mg/cm^2 using the described equipment. The test was carried out by the clean fog procedure prescribed in IEC Publication 61245 Section 4[7]. With a leakage current of 2.5A, the maximum drop of output voltage was about 3.5%, which satisfied the requirement mentioned above. Before the flashover occurred, current was clipped by a ZnO varistor. The residual voltage appeared after the flashover event by recharging the output capacitor until the complete disconnection of the AC circuit. It is considered that a highly reliable artificial contamination test is possible up to UHV range.

2.2 Measurement of Leakage Current

Artificial contamination withstand (WS) and flashover (FO) voltage tests were conducted in the large fog chamber of dimension of 30m×25m×30m. A properly selected constant voltage was applied to a specimen in order to investigate whether it can withstand the voltage for an hour or not. The applied voltage was increased by 5% if the specimen could withstand the applied voltage. Conversely, the applied voltage was reduced by the same 5% if there was a flashover. This procedure was repeated until the maximum voltage which gives four withstands and no flashover. This voltage was defined as withstand voltage.

Leakage current waveforms were obtained by measuring the voltage across a 0.5Ω shunt resistance. The

Table 1 Specifications of DC power source.

Item	Specification
Output voltage and output current	DC±750kV: 1A (continuous) 2.5A (1 min.) 15A (10 cycles)
Input voltage	6kV, 60Hz, 3 phases (Power source: 60-MVA short circuit generator)
Rectification method	cascaded three phase full-wave rectification
Voltage control method	Thyristor control
Output capacitor	1.5μF/±750kV 6μF/±375kV
Voltage drop	Less than 5% / 200-750kV, 2.5A
Ripple rate of output voltage	Less than 2% / 200-750kV, 2.5A
Overshoot at load-release	Less than 5% / 200-750kV, 2.5A

Table 2 Specimen insulators and test conditions for clean fog procedure.

Specimen insulators					Clean fog procedure		Figure No.
		Dimensions					
Type of insulator	Number of Units	Effective length, mm	Shed diameter, mm	Leakage Distance, mm	Applied voltage, kV	SDD, mg/cm^2	
DC Fog disc	15	-	320	545 (8175)*	-320	0.02	3
Station post	4	3780	225 (average)	12800	-465	0.02	4
					-345	0.05	6
Bushing shell	1	9228	955 (average)	39700	-750	0.03	5
					-425	0.12	7
Long-rod	4	1011 (4044)*	127 (average)	2970 (11880)*	-300	0.05	8

Note: * Dimensions of an insulator string. NSDD was 0.1 mg/cm^2 for all samples.

Table 3 Specimen insulator and test condition for salt fog procedure.

Specimen insulator					Salt fog procedure		Figure No.
		Dimensions					
Type of Insulator	Number of Units	Effective length, mm	Shed diameter, mm	Leakage distance, mm	Applied voltage, kV	Salinity, g/liter	
Station post	2	3517	275 (average)	13970	-240	40	9

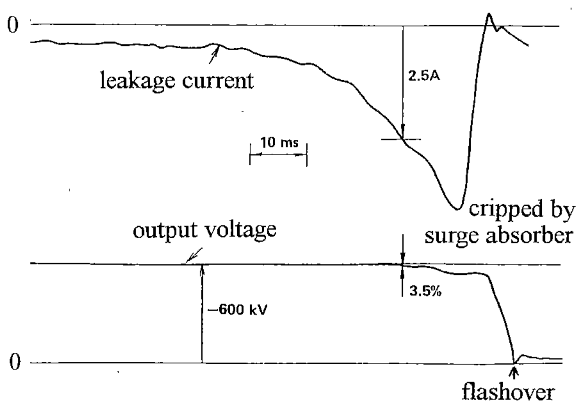

Fig.2 An example of observed wave shapes of voltage and current.

negative polarity of applied DC voltage was selected, because it generally gives lower contamination withstand voltage. Tests were carried out by both the clean fog and the salt fog procedures according to IEC publication 61245 [7].

2.3 Specimen Insulators

Various kinds of porcelain insulators were used as specimen insulators. Dimensions of the test specimen insulators and test conditions are shown in Tables 2 and 3, respectively.

3. Results and Discussion

Typical leakage current waveforms of porcelain disc and station post insulators and bushing shells are shown in Figs.3, 4 and 5, respectively, which were obtained in the clean fog procedure. In all specimens, a leakage current tends to increase gradually at the beginning and to decrease relatively faster after the peak value. The waveforms show triangular-pulse like patterns. Duration of leakage current on disc and post insulators was mostly in the range of 0.5-1 sec. That on bushing shell is longer than 1 sec. in most cases.

Figures 6 and 7 show typical leakage current waveforms on station post insulator and bushing shell, respectively, and were obtained under higher degree of contamination compared with Figs. 4 and 5.

Figure 8 shows a typical leakage current waveform on porcelain long-rod insulator. The leakage current waveform was very similar to that of porcelain station post.

Figure 9 shows typical waveforms of leakage current on the station post insulator in the salt fog procedure. The waveform is similar to a half cycle of sinusoidal wave. Duration of the leakage current is mostly shorter than 0.5 sec.

Relation between magnitude of leakage current and its duration of station post insulators is shown in Fig. 10. The clean fog test was carried out under salt deposit density (SDD) of 0.02-0.1 mg/cm^2 and non-soluble material deposit density (NSDD) of 0.1 mg/cm^2. The range of the applied voltage was –325 to –510kV. In the salt fog procedure, the salinity was 40g/liter and voltage from –200 to –300kV was applied. In the clean fog procedure, the magnitude of leakage current at a given SDD is larger with higher voltage. However, the duration of leakage current does not depend on the magnitude of applied voltage or SDD in the range of the present experiment. The results obtained by the salt fog test show that applying higher voltage leads to larger magnitude of leakage current at a given SDD. There seems to be no significant relation between applied voltage and duration of leakage current in the salt fog procedure. Comparing the two test methods, the duration is longer for the clean fog procedure than that for the salt fog. Magnitude of leakage current is almost the same in the two procedures.

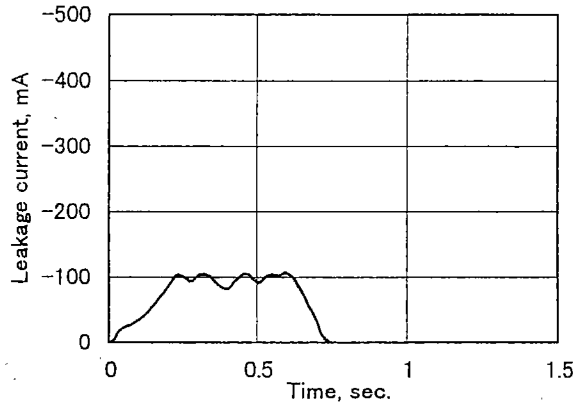

Fig. 3 Leakage current waveform on disc insulator. Clean fog procedure. SDD: 0.02 mg/cm^2. Applied voltage: −320kV.

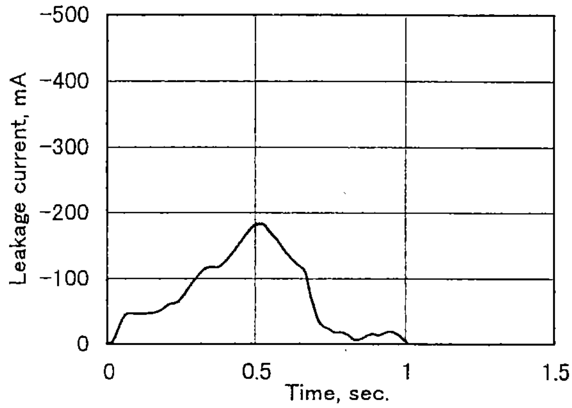

Fig.4 Leakage current waveform on station post insulator. Clean fog procedure. SDD : 0.02 mg/cm^2. Applied voltage: −465kV.

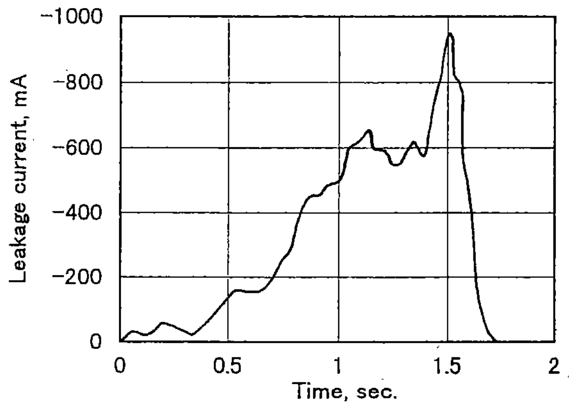

Fig. 5 Leakage current waveform on bushing shell. Clean fog procedure. ESDD : 0.03mg/cm^2. Applied voltage: −750kV.

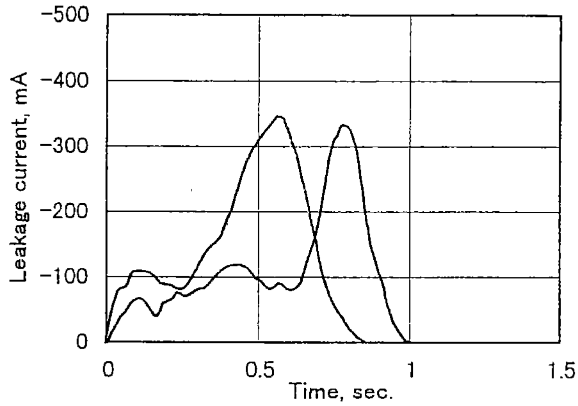

Fig. 6 Leakage current waveform on station post insulator. Clean fog procedure. SDD: 0.05 mg/cm^2. Applied voltage: −325kV.

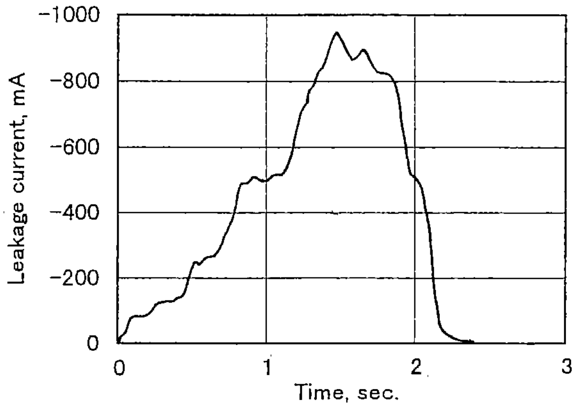

Fig. 7 Leakage current waveform on bushing shell. Clean fog procedure. SDD : 0.12mg/cm^2. Applied voltage: −425kV.

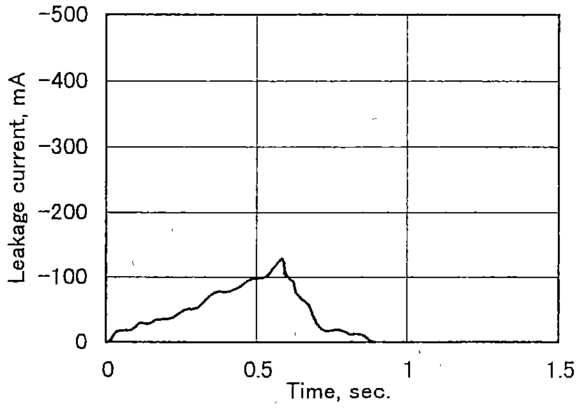

Fig. 8 Leakage current waveform on long-rod insulator. Clean fog procedure. SDD : 0.05 mg/cm^2. Applied voltage: −300kV.

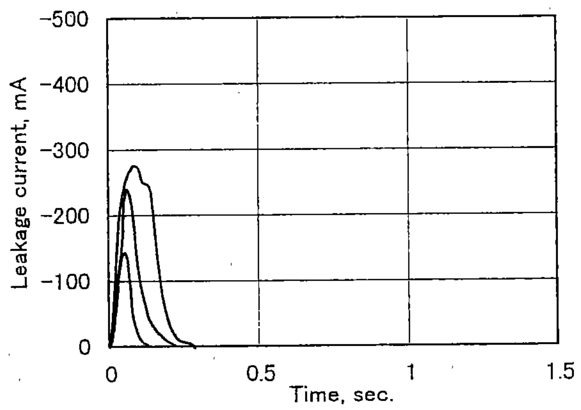

Fig.9 Leakage current waveform on station post insulator. Salt fog procedure. Salinity : 40g/liter. Applied voltage: −240kV.

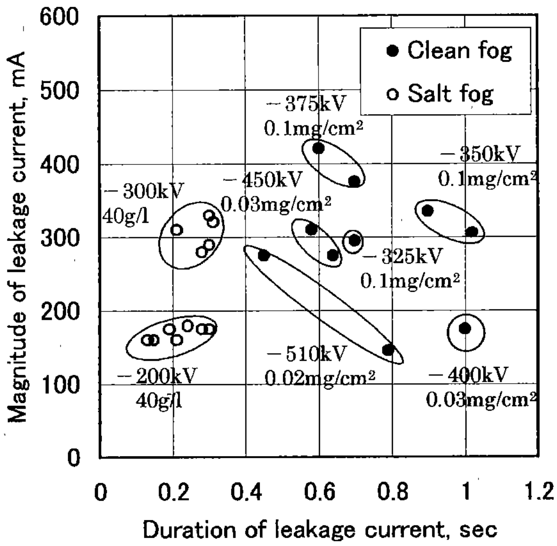

Fig.10 Relation between magnitude of leakage current and its duration of station post insulator.

Figure 11 shows relation between magnitude of leakage current and its duration of DC fog disc, station post , and bushing shell specimens, which were obtained by the clean fog procedure. Test conditions are summarized in Table 4. In these samples, the applied voltage does not seem to affect the magnitude and duration of leakage current. There seems to be no significant relation between SDD and magnitude or duration of leakage current. It is, however, clear that leakage current of longer duration and higher magnitude is observed for a larger size of the sample.

Tests were repeated on a post insulator stack. The range of applied voltage was from –325 to –510kV. SDD and NSDD were 0.02-0.1 and 0.1mg/cm², respectively. Current pulses during the tests were grouped into cases of flashover and withstand. The occurrence probability of pulses was arranged in statistical order as shown in Fig.12. Occurrence probability of leakage current pulse of larger magnitude is higher in the flashover test compared with that of the withstand.

Table 4 Test conditions.

Specimen	Applied voltage (kV)	SDD (mg/cm^2)	NSDD (mg/cm^2)
DC fog disc	-315 ~ -510	0.02~0.05	0.1
Station post	-325 ~ -510	0.02~0.10	
Bushing	-325 ~ -750	0.01~0.12	

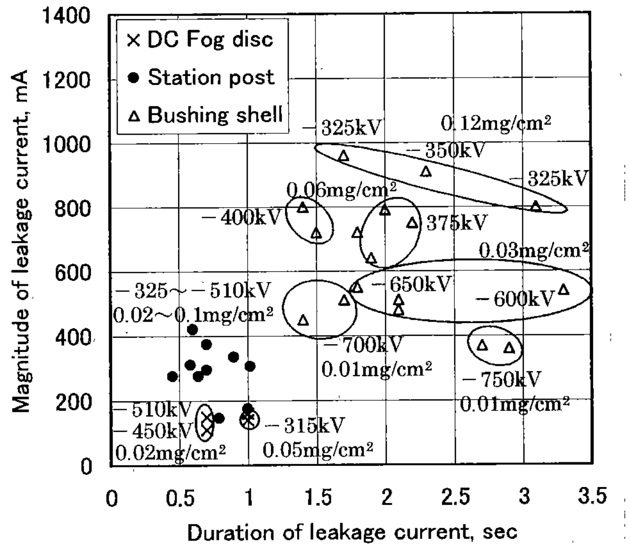

Fig.11 Relation between magnitude of leakage current and its duration obtained by the clean fog procedure.

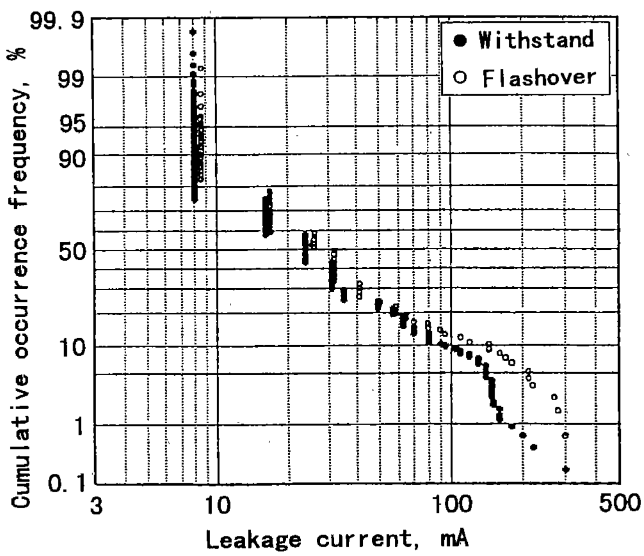

Fig.12 Cumulative occurrence frequency of leakage on station post insulators.

4. Conclusions

Leakage current waveforms on disc and station post insulators and bushing shells were measured using DC voltage in artificial contamination tests with a stiff DC power source that practically eliminates voltage drop against leakage current during the test. Magnitude and duration of leakage currents obtained by the clean fog procedure were different from those by the salt fog one. The main results obtained by the clean fog procedure, which are based on a lot of data, are as follows:

(1) The magnitude of leakage current reached ranged from 200 to 400mA and the duration was less than 1 sec. for post insulators.

(2) The magnitude of leakage current is larger in flashover tests compared with withstand ones.

(3) In the contamination test of a large-sized sample like bushing shell, the magnitude and duration of leakage current were 400-1000mA and 1.5-3sec., respectively. It is considered that a stiff power source is required for such a test.

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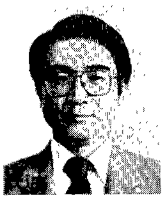

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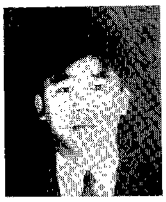

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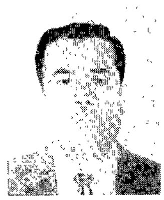

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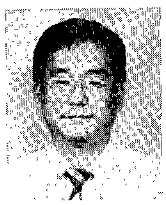

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