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A Method of Automatic Washing for Salt Contaminated Insulators

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Described in this paper is a method of automatic washing for salt contaminated insulators. An average value of leakage current through the surface of the pilot insulator in a duration is measured, for this is a function of the quantity of salt adhered and its moisture content. In each cycle, the program signals give one by one the instructions on a start and an end of the integration of leakage current, a detection of the integrated value, a stop of the washing device and a reset of the integrator. The integrator consists of *RC* circuit and the main detecting part consists of the thyristor whose firing gate voltage is used as a reference value. If the integrator output rises above the firing gate voltage, the pulse signals are made in the signal conversion part at the same time that the thyristor turns on, which are distributed to the pump motor or the electromagnetic valve. Then the insulators on hot-line are washed all together in the appointed duration. Finally, by the various experiments this method was proved to have enough accuracy and reliability in practical use. The conclusions are summarized as follows.

(1) An average value of leakage current is justified to be the detecting variable.
(2) The *RC* circuit used as the integrator is proved to be easy in maintenance.
(3) Because of the fairly short duration of the detecting action, the integrator is kept in a sufficiently safe condition under expected environment.

§ 1. Introduction

The subject of salt contaminated insulator is a very important one at the present time and includes a large variety of disturbances. If such insulators are put in a fine rain or a humid atomosphere, flash-over may occur at ordinary use voltages. As an unit capacity of power plant, during the last few years, has been increased, the whole service interruptions give the disturbances not only to the power plant but also to the power transmission systems. Therefore the routine washing for the insulators has been carried out for the protection against the above mentioned troubles, but the washing can be carried out more effectively by making it automatic in operation. In the case of the automatic washing, a detecting variable should be determined. Because of the fact that the leakage current–*i.e.* the current passing through the surface of the insulator increases with the quantity of salt adhered and its moisture content, the leakage current is able to be used as the detecting variable which shows the need of the washing. If the voltage corresponded to the maximum allowable current is designed to be equal to the firing gate voltage of any thyristor (*SCR*), the firing gate voltage can be utilized as the reference value for the washing. The authors produced the automatic washing device by way of experiment. It consists of the detector, the signal conversion part and the program timer which gives the sequence of detection and operation, etc. in each cycle.

§ 2. Construction of the detector and its considerations

As above the leakage current was adopted as a detecting variable, but in practice the average value of the leakage current in the appointed duration is used. According to the experiments, the growing of flash-over depends not so much on the peak value of the current as on the frequence of the current above a certain value. The several examples of the experiments which decide the reference value are as follows.

Photo. 1 shows the oscillogram of the leakage current of the salt contaminated insulator under the conditions of Table 1. It is observed that the average value of the current was maintained within 20 (mA) during about 40 (sec) and thereafter the excessive current began to flow. Under

Table 1 Test conditions

Component	Specification	
Insulator	Grooved insulator JEM 1144	
	Surface area	1040 (cm^2)
	Nominal voltage	20 (kV)
	Commercial frequency proof voltage	50 (kV)
	Dry flash-over voltage	86 (kV)
Pump	Centrifugal pump	30 (HP)
Motor	Three phase induction motor	25 (kVA)
Nozzle	Nippon Grinnell Sprinkler K. K.	No. 99
Fog room	Corrugated wall made of galvanished iron (forced water cooling)	
	Distributed vaporizer by electric heater	
	Dimension	250×200×300 (cm^3)
	Temperature	31 (°C)
	Humidity	96 (%)
Contamination	Artificial contamination (Painting)	
	Salt	0.5 (mg/cm^2)
	Kaolin	10 (mg/cm^2)
Water	Resistivity	8000 (Ωcm)
Other conditions	Insulator painted dirt is dry up and put in fog room during 15 min.	
	Applied voltage	24 (kV)

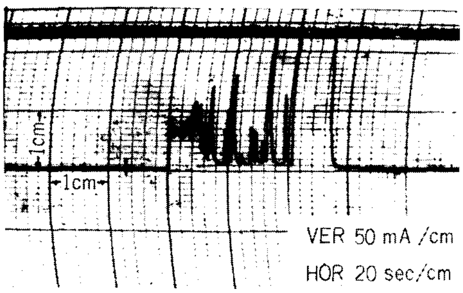

Photo. 1 Oscillogram of leakage current of salt contaminated insulator under conditions of Table 1

these conditions, the average value 20 (mA) during 30 (sec) will be safety and suitable as the reference value for the washing. And in the detector this value is corresponded to the firing gate voltage of the thyristor.

Fig. 1 shows the block diagram of the detector. The voltage across the potentiometer v is proportional to the instantaneous leakage current i, and the voltage v is integrated during t (sec) in the integrator. The output of the integrator v is given by

$$V = \frac{K_1}{t_1}\int_0^{t_1} v dt + V_0 \qquad (1)$$

where

V_0 = initial voltage of V at $t=0$

K_1 = constant determined by potentiometer

Let V_0 then be zero.

$$V \propto I \qquad (2)$$

where

I = average value of leakage current during t_1 (sec)

If the value E is the maximum allowable value of the voltage V, the thyristor of which the firing gate voltage is E may be used as the main detecting part.

Then, if

$$V \geqq E \qquad (3)$$

The thyristor turns on and the signal is sent to the signal conversion part.

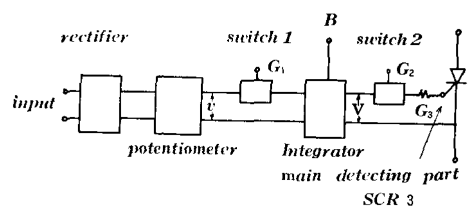

Fig. 1 Block diagram of detector

§ 3. Principle and characteristics of the device

Fig. 2 shows the program signals of automatic washing sent from the program timer and Fig. 3 shows the connections of the control circuits in

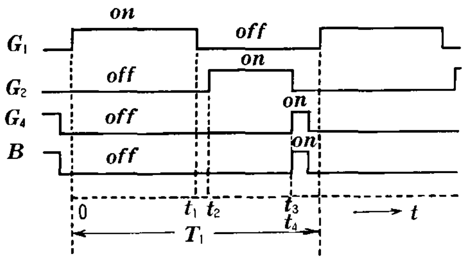

Fig. 2 Signals of automatic washing

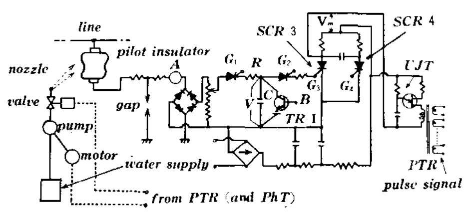

Fig. 3 Connections of control circuits

the device. In a cycle- *i. e.* the duration between $t=0$ and $t=T$, -the detection, the operation, the washing and the reset are proceeded by program signals, and thereafter the same processes are repeated periodically.

Now applying the positive voltage to the gate G_1 of the thyristor *SCR1* at $t=0$, the *SCR1* turns on, the voltage v is integrated in the *RC* circuit. Removing the above gate voltage at $t=t_1$, the *SCR1* turns off at the same time that the full-wave rectifier current through the *SCR1* becomes zero. Then applying the positive to the gate G_2 of the *SCR* 2 turns on and the voltage V (across the carpacitor C) is proportional to the average curent I is applied to the gate G_3 of the *SCR3*. The voltage V is compared with the reference value E.

Then, if

$$V \geqq E$$

As above the *SCR3* turns on. Thus the voltage V_m is applied to the uni-junction transistor *UJT* and the operation pulses are distributed from the pulse transformer *PTR* to the pump motor or the electromagnetic valve.

In the case of $V<E$, the *SCR3* turns off and the signal conversion part does not work. Removing the voltage across the gate G_2 at $t=t_3$, the *SCR2* turns off. Applying the pulse voltage to the gate G_4 of the *SCR4* at $t=t_4$, the *SCR4* turns on and the *SCR3* turns off at the same time. Also the other pulse voltage is applied to the base B of transistor *TR1* at $t=t_4$ and the capacitor C is discharged. Thus the voltage V_0 -*i. e.* the initial voltage of the voltage V at $t=0$ -becomes zero. Turning off the *SCR3*, the motor or the valve stops and the first cycle is at an end.

The program timer which sends the program signals consists of the synchronous motor and the signal plate combined the photo-transistors *PhT*. As shown Fig. 4 the signal plate has pro-

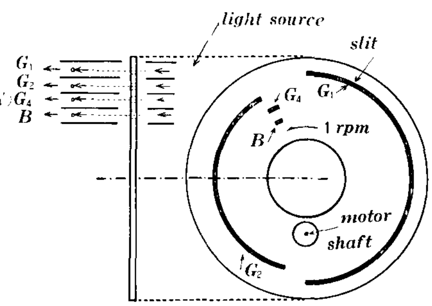

Fig. 4 Signal plate of automatic washing

grammed slits, and the voltage signals are taken out by the photo-transistors. The *RC* circuits together with its characteristics are given in Fig. 5. *RC* circuit is the most simplest

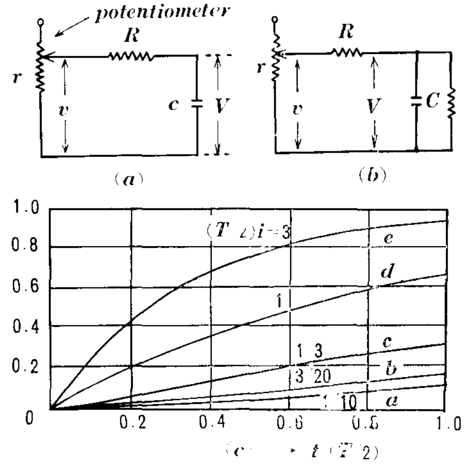

Fig. 5 Charging characteristics of RC circuit

integrator, but for the practical use the integrated characteristics must be examined. The relation between V and v is given by

$$V = v\,[1-\varepsilon^{-(t/RC)}] \tag{4}$$

Then, if the input impedance of the recorder R' can not be neglected and has the dimension of resistance

$$V = \frac{R}{R+R'}\,v\,[1-\varepsilon^{-(t/\frac{RR'}{R+R'}c)}] \tag{5}$$

and Eq. (5) can be written

$$V/v' = 1-\varepsilon^{-\frac{(T/2)}{\tau'}\cdot\frac{t}{(T/2)}} \tag{6}$$

where

$$v' = \frac{R'}{R+R'}v, \quad \tau' = \frac{RR'}{R+R'}C$$

The graphs of V/v' *vs.* $t/(T/2)$ for different parameters $(T/2)/\tau'$ are shown in Fig. 5 (c).

As an numerical example, let

$R=5$ (MΩ), $R'=2$ (MΩ), $C=140$ (pF)

Then

$v'/v=2/7$, $\tau'=200$ (sec), $T/2=30$ (sec), $(T/2)/\tau'=3/20$

The graph b of Fig. 5 (c) corresponds to the above numerical example. It has the linearity sufficient to be used in the practical use.

Let

r = value of resistance of potentiometer 2.84 (KΩ)

i = value of current flowing in potentiometer 20 (mA)

Then

v = value of voltage drop in potentiometer 56.7 (V)

Similarly, let

$r=2.84\,n$ (KΩ), $i/n=20$ (mA)

Then

$v=66.7$ (V)

In these case, the output of the integrator V becomes 2.43 (V) during 30 (sec). In general the value of the firing gate voltage of a form of thyristor is fixed, but the value of the current corresponding to it can be determined freely by the potentiometer. But in practice the voltage v is a full-wave rectifier form and its mean value is always fluctuating. Since if it is lower than the voltage V across the capacitor no charging current may flow. It is necessary to compensate the error in V arising from the above, but the discharging current never flow for the backward re istance of the *SCR1*. At $t=\delta$, dividing v into two parts- *i.e.* v_1 and v_2- , V is written by

$$V=\frac{K_1}{\delta}\int_0^{\delta} v_1 dt+\frac{K_1}{t_1-\delta}\int_{\delta}^{t_1} v_2 dt \quad (\delta<t_1) \tag{7}$$

Now if

$$\frac{K_1}{\delta}\int_0^{\delta} v_1\, dt \geqq v_2 \tag{8}$$

Then C is not charged nor discharged, and the second term in equation (7) becomes zero.

Considering the maximum c mpensation $\triangle E$, it is given by

$$\triangle E = \frac{K_I}{t_1}\int_0^{t_1} Edt \tag{9}$$

Hence the compensated reference value is written by

$$E' = E-\triangle E \tag{10}$$

where

E = reference value without compensation

In the case of the above example, $\triangle E$ is wthin 3 (%) of E.

In the next, Fig. 6 shows the actuating circuits

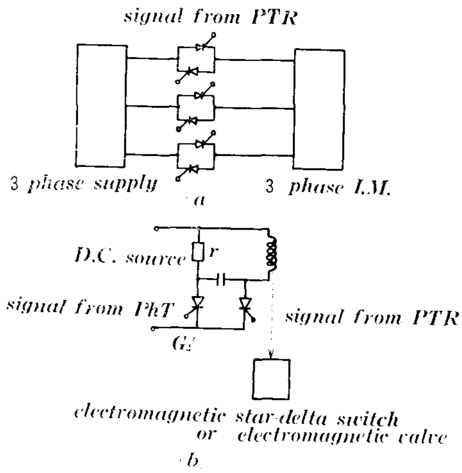

Fig. 6 Actuating circuits of motor or valve

of the pump motor or electromagnetic valve. The three phase induction motor is started directly or by the use of auxiliary circuits, and both the motor and the electromagnetic valve are actuated by the thyristor. Using the pulse transformer, the signals applied to the gates of every thyristor are each independent.

Also the dynamic characteristics of the device are as follows.

Let

$t_1=30$ (sec), $t_2=32$ (sec), $t_3=t_4=58$ (sec)
$E=2.43$ (v)

In case that in the first cycle the value of the input current is 20 (mA) and in the second one it is 19.7 (mA), then the oscillograms in the appointed places are as shown in Photo. 2. That is, each of No. 1, No. 2 and No. 3 shows the input current filtered in the recorder, the voltage across the capacitor, and the pilot voltage for the switching of the *SCR3*. Also Table 2 shows the digital voltmeter readings for the

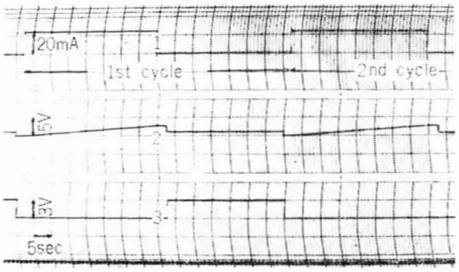

Photo. 2 Experimental results

Table 2 Digital voltmeter readings for voltage across capacitor C

1st cycle	2nd cycle
0.00	0.00
0.13	0.12
0.32	0.31
0.50	0.48
0.68	0.66
0.85	0.83
1.02	1.01
1.19	1.18
1.35	1.34
1.52	1.50
1.67	1.66
1.83	1.81
1.98	1.96
2.13	2.11
2.28	2.26
2.43	2.40
2.43	2.40
0.96	0.65
0.96	0.65
0.96	0.65
0.96	0.65
0.96	0.65
0.96	0.65
0.96	0.65
0.96	0.65
0.96	0.65
0.96	0.65
0.96	0.65
0.96	0.65
0.96	0.65
0.00	0.00

voltage across the capacitor.

Here it is observed that the $SCR3$ worked accurately at $t=32$ (sec) and the control processes also went on well in accordance with the program. Although the value of the input current is constant in this example, this device will work similarly for the sake of the linearity of its integrator even if the current pulsates.

§ 4. Tests for practical use and their discussions

The tests of which the conditions are given in Table 1 are carried out. Photo. 3 shows the testing sets.

In these tests, the conditions requiring the washing are given by

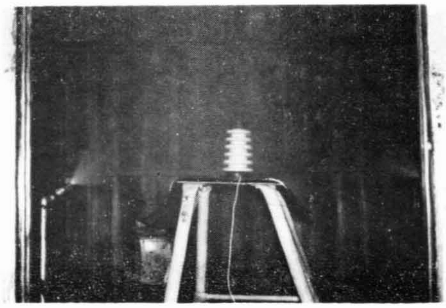

Photo. 3 Testing sets

I_r = value of average leakage current requiring washing 20 (mA),

$t_1=30$ (sec), $t_2=32$ (sec), $t_3=t_4=58$ (sec)

Observing the oscillogram of Photo. 4 (a), it is shown that the average current flowed over 20 (mA) and the washing was carried out in the appointed duration. After the washing, no current flowed.

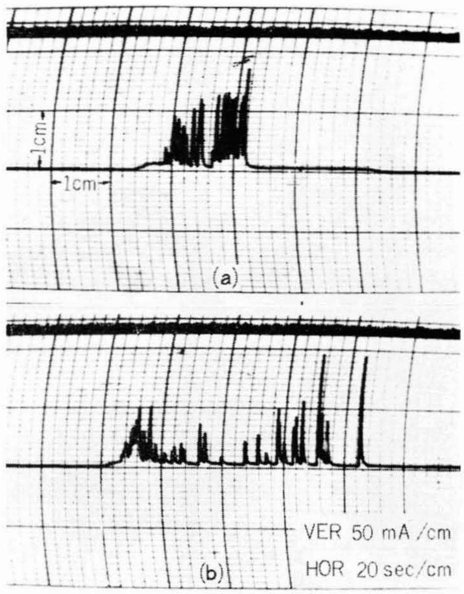

Photo. 4 Testing results of automatic washing

Let the humidity be 87 (%) and before the second cycle-*i. e.* at any time between $t=32$ (sec) and $t=60$ (sec)-the value of I_r be reduced to 10 (mA) by manual operation. Then Photo. 4 (b) shows that in the first cycle the washing did not be carried out and in the second one it was done. By these results it is illustrated that the leakage current decreased with decreasing humidity.

Let the first conditions be used and the fog room be opened rapidly at $t=0$. Opening the

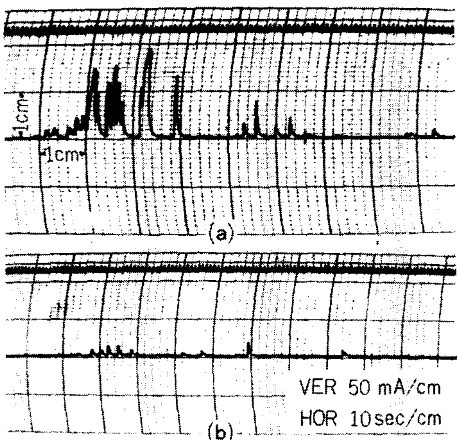

Photo. 5 Oscillograms of leakage current of salt contaminated insulator

frg room, the humidity will decrease with the time. The result is shown in Photo. 5 (a).

Let the quantity of salt only be a quarter of that in the first conditions. The result is shown in Photo. 5 (b). The quantity of salt upon the surface has a simular effect to that of moisture content. Any moisture which may exist in the humid atomosphere tends to be combined with salt. An average value of leakage current is justified to be the detecting variable.

Although the resistivity of the water fcr the washing was about 8000 (Ωcm), it is de ired to be kept the value more than 8000 (Ωcm). Thus usually the value must be measured. Unless the value is suitable, the washing must be stopped.

The accuracy of this device is sufficient to use in most practical cases.

§ 5. Conclusions

The conditions requiring the washing- i. e. the reference value for the washing must be decided in accordance with the meteorological statistics and the various experiments. Here the several methods deciding such conditions, and a method of automatic washing have been illustrated. The conclusions are summarized as follows.

(1) An average value of leakage current is justified to be the detecting variable.
(2) The *RC* circuit used as the integrator is proved to be easy in maintenance.
(3) Because cf the fairly short period of the detecting action, the insulator is kept in a sufficiently safe condition under expected environment.

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