Development of Leakage Current Monitoring Device for Arrester

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***Abstract* – In order to determine the deterioration of an arrester used in bullet train electricity feeding, it is effective to capture changes in the current of the resistance in the leakage current that flows through the grounding cable of the arrester. However, it is difficult to measure current of the resistance directly. In this research, we devised a principle for the detection of changes in current of the resistance by obtaining a leakage current that can be measured using the grounding cable of an arrester at an arbitrary date and time, and by calculating the difference with a reference leakage current. We have also developed a leakage current monitoring device for arrester by applying this principle to measure the current of the resistance at a bullet train substation.**

***Keywords* – electric railway, arrester, zinc oxide element, deterioration management, leakage current, current of the resistance**

I. Introduction

An arrester, which is connected between a feeding circuit and the ground, functions to suppress overvoltage of the feeding circuit by discharging excessive lightning surge voltage entering the feeding circuit, therefore preventing the breakdown of devices. One method for managing the deterioration of an arrester uses the all leakage current (I_0) of the arrester. The effective technique for determining the deterioration of an arrester is to detect the changes in the current of the resistance (I_R),which is a part of the all leakage current (I_0) caused by the deterioration of zinc oxide elements. However, in the all leakage current (I_0), the current that flows to fill the stray capacitance of the arrester is dominant and, when a train is running, the waveform of the all leakage current (I_0) contains harmonics generated by the train. This makes it extremely difficult to detect the variation in the current of the resistance (I_R) from the all leakage current (I_0) of the arrester. In this study, we have focused on the fact that the changes in the current of the resistance (I_R) in the all leakage current (I_0) appears in limited phases.

Also, we developed a leakage current monitoring device for arrester to obtain the changes in the current of the resistance (I_R) of an arrester by subtracting a reference all leakage current (I_0) from the all leakage current (I_0) obtained at an arbitrary date and time.

II. Measurement of Current of the resistance (I_R)

This section reports the technique we have devised to obtain the current of the resistance (I_R) from the all leakage current (I_0) that flows through the grounding cable of an arrester.

A. All leakage current of arrester (I_0)

Fig. 1 shows an equivalent circuit of an arrester. An arrester can be equivalently represented by a parallel circuit of a zinc oxide element resistor (R) and stray capacitance (C). The resistance value of the zinc oxide element resistor (R) changes due to the applied voltage and deterioration of the element. The all leakage current (I_0) that can be measured with the grounding cable of an arrester is a result of combining the stray current of the capacitance (I_C) and the current of the resistance (I_R). Generally, the all leakage current flows through the grounding cable of an arrester due to the steady-state circuit voltage. Also a discharge current may flow due to the surge voltage generated by the action of a circuit breaker.

Fig. 2 shows the all leakage current waveform of an arrester for a feeding circuit measured at a bullet train substation. The all leakage current (I_0) has almost 90 degree leading phase against the applied voltage, which shows that the current of the capacitance (I_C) is dominant.

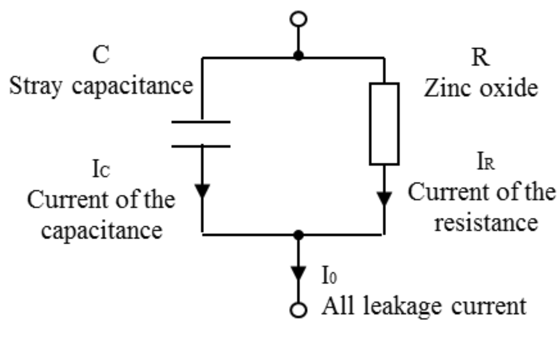

Fig. 1 Equivalent circuit of an arrester

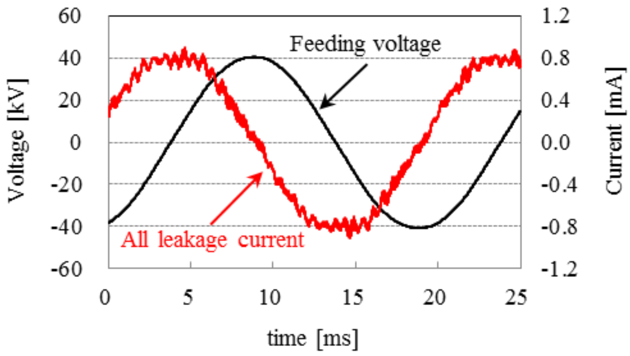

Fig. 2 All leakage current waveform of an arrester in a bullet train feeding circuit

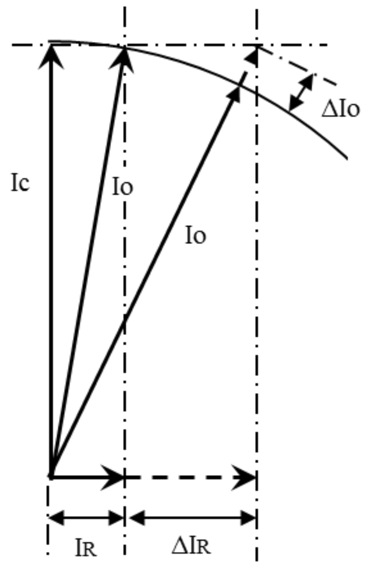

Fig. 3 Change in all leakage current due to element deterioration

As the zinc oxide element deteriorates, the resistance R of the element decreases and the current of the resistance (I_R) increases. As a result, the all leakage current (I_0), which is the combined value of the current of the resistance (I_R) and current of the capacitance (I_C), increases. Fig. 3 shows how the all leakage current (I_0) changes as the element deteriorates. The current of the capacitance (I_C) is dominant in the all leakage current (I_0) and the increment (ΔI_0) of the all leakage current (I_0) is small compared to the increment (ΔI_R) of the current of the resistance (I_R). Consequently, it is difficult to detect the increment (ΔI_R) of the current of the resistance (I_R) using the increment (ΔI_0) of the all leakage current (I_0).

B. Principle of measurement of current of the resistance (I_R)

The current of the resistance (I_R) can be determined by synchronized measurement of the all leakage current (I_0) and the voltage applied to the arrester, and using Equation (1):

$$i_R = i_O - C\frac{dv}{dt} \quad (1)$$

As the second term of the right side of Equation (1) corresponds to the current of the capacitance (I_C), the current of the resistance (I_R) can be obtained by subtracting the current of the capacitance (I_C) from the all leakage current (I_0). It has been reported that this method can accurately detect the current of the resistance (I_R) [1]. However, the output signal of an instrument transformer is required to obtain the voltage applied to the arrester and the current of the resistance (I_R) cannot be detected with a leakage current meter alone.

To address this problem, we adopted a method to the present device by first recording the all leakage current of the arrester in its normal state in advance as the reference waveform. Next, we obtain a comparison waveform at an arbitrary time and subtract the reference waveform to detect the changes in the current of the resistance (I_R). This has made it possible to detect the current of the resistance (I_R) with only the present device without using an instrument transformer. The detected value of the current of the resistance (I_R) indicates the changes from the initial value obtained when the reference waveform is captured.

C. Detection procedure

Fig. 4 outlines the procedure for detection of the current of the resistance (I_R) using the present device. The reference and comparison waveforms have high-order harmonics but they are eliminated by applying a moving average process. For phase adjustment, the phase in which the difference between the reference and comparison waveforms at its minimum is considered as the same phase. Because the amplitude of the all leakage current changes according to the feed voltage changed by the effect of the load current, the amplitudes of the reference and comparison waveforms may differ. Therefore, we match the amplitude of the reference waveform to that of the comparison waveform and adjust the amplitude of the reference waveform so that the difference between them is minimized.

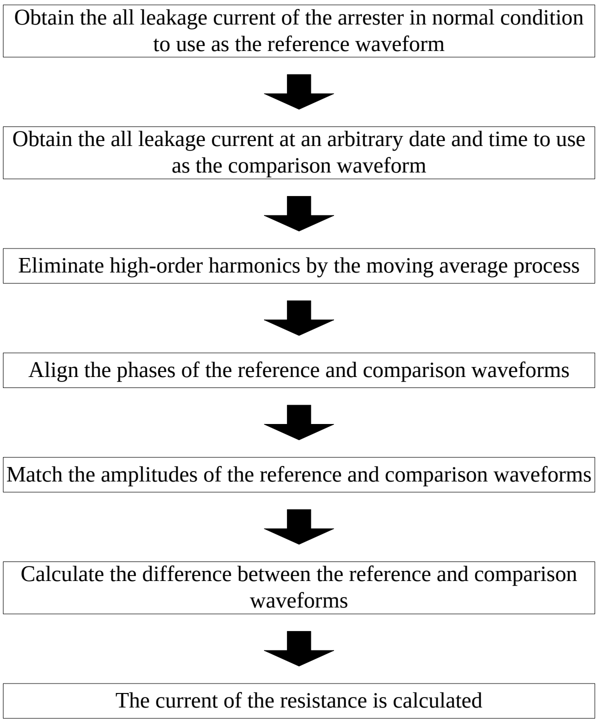

Fig. 4 Procedure for detection of current of the resistance (I_R)

III. Results of Measurement

We used this device for measurement on a circuit that simulates an arrester and actual measurement at a substation. This section reports the results.

A. Verification by arrester simulation circuit

Fig. 5 shows a diagram of an arrester simulation circuit. This simulation circuit was used to confirm that the current of the resistance (I_R) could be properly detected.

The capacitor C simulates the stray capacitance of the arrester and the varistor simulates the arrester element. A varistor is an element similar to the zinc oxide element used as the element of an arrester. A voltage at or below the varistor starting voltage is applied to simulate a waveform in the normal state of the arrester, which is used as the reference waveform. Applying an overvoltage a few percent higher than the operating voltage to the varistor allows simulation of the current of the resistance (I_R) to flow. This simulates a state in which an arrester deteriorates, which is used as the comparison waveform. Fig. 6 shows the reference and comparison waveforms obtained using the simulation circuit. Fig. 7 shows the waveform of the current of the resistance (I_R) calculated from the reference and comparison waveforms obtained using the simulation circuit. It can be confirmed from Fig. 7 that the current of the resistance (I_R) is properly detected from the all leakage current. It also shows that the current of the resistance (I_R) is generated only in crossings of the reference waveform in the vicinity of zero.

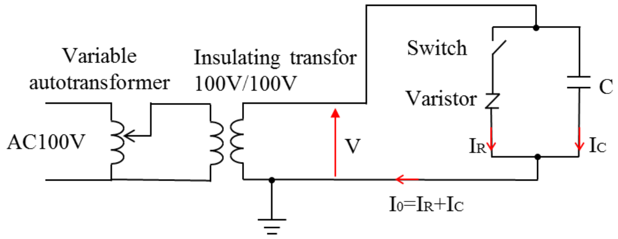

Fig. 5 Arrester simulation circuit

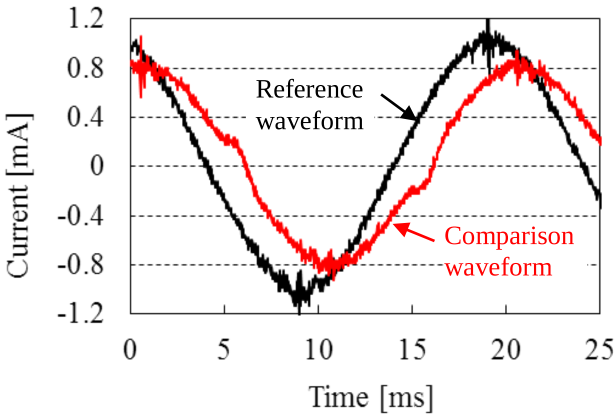

Fig. 6 Reference and comparison waveforms obtained using a simulation circuit

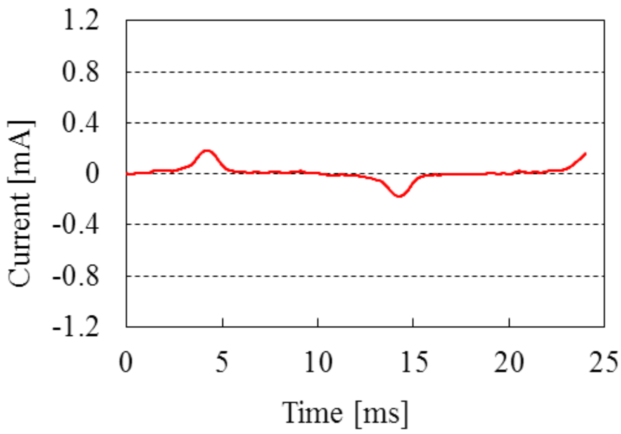

Fig. 7 Waveform of current of the resistance (I_R) detected using a simulation circuit

B. Testing with a temporary device at a substation

The simulation circuit showed that the waveform of the current of the resistance (I_R) was properly detected by the present device so we built a prototype of the present device temporarily at a substation on the Tohoku bullet train line.

Fig. 8 shows the reference and comparison waveforms actually measured at the substation. The reference waveform was obtained when no train was in the feeder section immediately after the start of feeding. The comparison waveform was obtained when a train was running in the feeder section. Fig. 9 shows the waveform of the current of the resistance (I_R) calculated from the reference and comparison waveforms actually measured. It can be confirmed from Fig. 9 that the current of the resistance (I_R) shows no variation with a normal arrester.

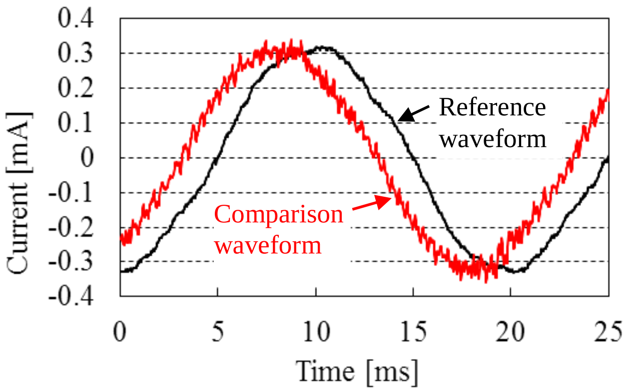

Fig. 8 Measured reference and comparison waveforms

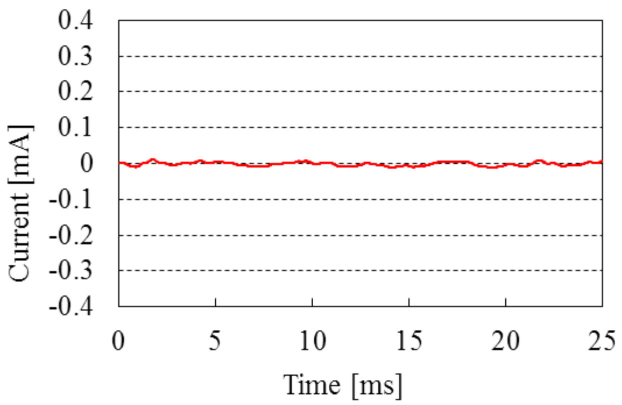

Fig. 9 Measured waveform of current of the resistance (I_R)

IV. Summary

Capturing variation in the current of the resistance (I_R) is effective for determining the state of deterioration of arrester. While the current of the resistance (I_R) cannot be measured directly, the principle we have devised has made it possible to obtain the variation in the current of the resistance (I_R). We intend to apply the current of the resistance (I_R) that can be obtained using this principle to gain an understanding of its change over time and apply it to the diagnosis of deterioration of arrester.

Furthermore, combining this with the surge current measurement function already developed [2] [3] may lead to the discovery of the relationship between the electric energy applied to an arrester and deterioration of the zinc oxide elements. We consider this a possible foundation for the construction of new techniques in the management of deterioration of arrester.

References

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