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Design and Construction of A Variable Air-Core Inductor for Lightning Impulse Current Test on Surge Arresters

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***Abstract*—This paper presents the design and construction of a variable air-core inductor for lightning impulse current test on surge arresters. The designed inductance value of the developed air core inductor is in the range of 6.4 µH to 50 µH. To confirm the inductor design, it is employed in the impulse current generation circuit. In the experiment, the impulse currents were generated in the short-circuit condition and were injected to an arrester. The generated waveforms are compared with the simulation. Good agreement is observed. From the comparison of experimental and simulated results, it can be confirmed that the developed air core inductor can be used to adjust impulse current waveform to that according to the standard requirement efficiently.**

Keywords : impulse current; over-voltage; surge arrester; variable air-core inductor

I. Introduction

Conventional lightning impulse current generation circuit comprises of charging capacitor, inductor and resistor. To generate lightning impulse current of which waveform is according to IEC standard requirement [1-4], the value of circuit parameters, charging capacitor, inductor and resistor of the lightning impulse current generation circuit must be adjusted. But, due to the physical configuration, capacitance value of the charging capacitor is quite difficult to be adjusted, so the value of other two parameters must be adjusted instead.

When impulse current test of lightning arrester is performed, the front time and the time to half of lightning impulse current waveform generated by lightning impulse current generator are often deviated from the standard requirement due to the non-linear characteristic of the lightning arrester. In the real practice, the resistance in the generation circuit is set to be fixed and the inductance in the circuit must be adjusted to obtain the waveform as the standard requirement. Therefore, there are many inductors required to obtain the standard waveform in the laboratory test, and sometimes the inductor is made for each lightning arrester under test. It will be advantageous for test engineers, if the high-voltage variable inductor is available in the testing laboratory.

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In this paper, the design and construction of the variable air core inductor for impulse current test is represented. The aim of the developed variable air core inductor is to reduce the number of the inductors used to adjust the impulse current waveform. In this paper, 8/20 µs lightning impulse current was used to verify the performance of the developed air core inductor.

II. Theory

A. Standard Lightning Impulse Current

The IEC standard 62475 [1] defines time parameters and tolerance of the lightning impulse current waveform as Table 1. The front time of the waveform can be calculated by multiplying 1.25 to the period of time which is measured from the time at 10% of the peak of the lightning impulse current to the time at 90% of the peak of the lightning impulse current, and the time to half is the time which is measured from the virtual start point of the waveform to the time at 50% of the peak of the lightning impulse current.

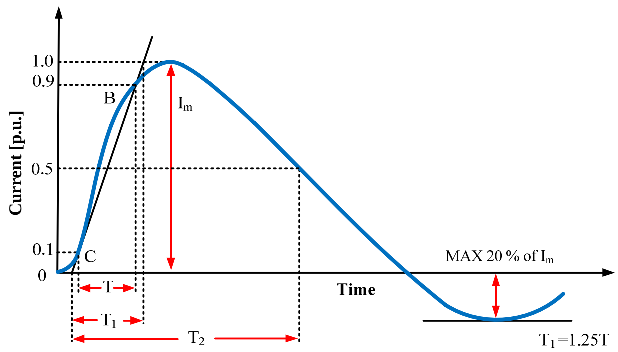

Fig. 1. Standard lightning impulse current waveform.

TABLE I. Time Parameters and Tolerance of the Standard Lightning Impulse Current Waveform According to the IEC Standard

Standard waveform	8/20 µs
Front time	8±10%
Time to half	20±10%
Error	±10%
Undershoot	< 20%I_m

B. Design and Construction of a Variable Air – Core inductor

The design of variable air core inductor is based on adjustment of magnetic flux using sliding aluminum tube as shown in Fig. 2. The winding is constructed from copper wire of 2x5 mm^2. on insulating sheet of which thickness is 0.3 mm. The number of turns is 39 and 2 mm gap between each turn is inserted with a pice of insulating sheet. The resin casting is performed to increase machanical strength of the developed variabel air core inductor. The inductance value of the developed air core inductor can be calculated by eqs. (1) and (2).

$$L_0 = \frac{N^2 r^2}{9r + 10l} . \quad (1)$$

$$L = L_0 (1 - k) . \quad (2)$$

where, L is inductance in unit of μH, N is the number of turns, r is radius of coil in unit of inch, l is length of inductor in unit of inch, and k is adjusting factor being in the range from 0.1 to 1.

The winding has the inner diameter of 102.3 mm, the outer diameter of 132 mm, the thickness of 14.8 mm and the height of 400 mm. The aluminum tube with inner diameter of 95.6 mm and outer diameter of 101.6 mm is inserted into the center of the developed air core inductor winding, so the inductance value can be adjusted by moving aluminum tube through the air core inductor winding. The distance between outer surface of aluminum tube and inner surface of the air core inductor winding is 0.35 mm. When the aluminum tube is inserted fully into the air core inductor winding, the inductance value of the developed air core inductor is minimum 6.4 μH which is the minimum inductance value of the developed air core inductor, and when the aluminum tube is pulled out of the developed air core inductor winding, the inductance value of the developed air core inductor will be 50 μH which is the maximum inductance of the developed air core inductor. The developed air core inductor is illustrated in Fig. 2.

TABLE II. THE DIMENSION DETAIL OF THE DEVELOPED VARIABLE AIR CORE INDUCTOR

Size of copper wire	2x5 mm^2
Distance between two turns	2 mm
Inner diameter of winding	102.3 mm
Outer diameter of winding	132 mm
Inner diameter of aluminum tube	95.6 mm
Outer diameter of aluminum tube	101.6 mm
Length	330 mm
Number of turns	39 turn
Inductance value	6.4-50 μH

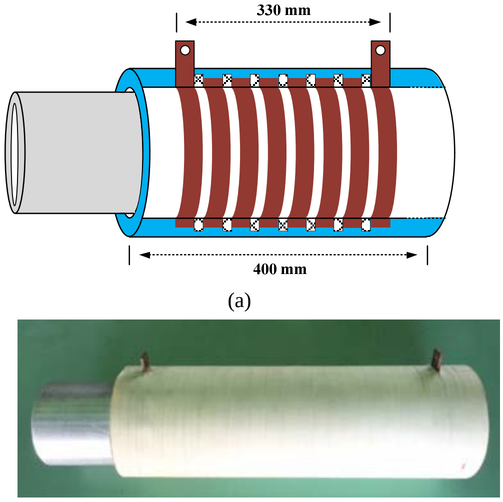

Fig. 2. The developed variable air core inductor; (a) Model of the developed variable air core inductor and (b) The developed variable air core inductor.

To confirm the designed inductor, the inductance of the developed air core inductor was measured by impedance analyzer HP4194A shown in Fig. 3 at the frequency of 10 kHz. The inductances with various adjusting lengths are given in Fig. 4.

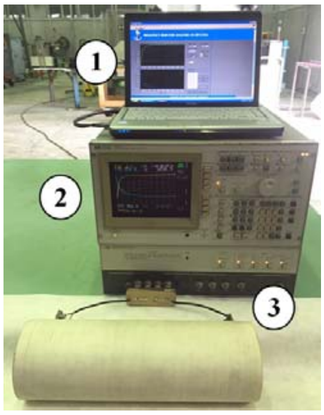

Fig. 3. Variable air-core inductor and Instrument under experiment, (1) Recording instrument (2) Spectrum analyzer and (3) Variable air- core inductor.

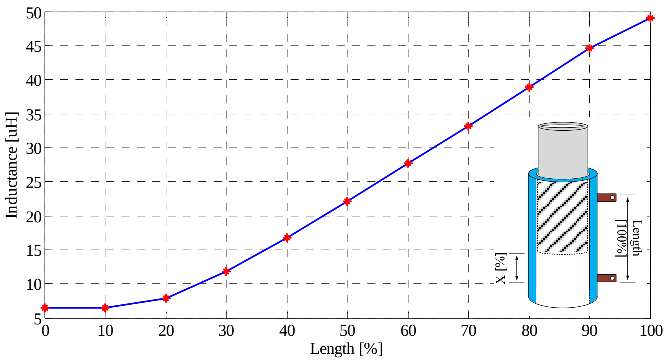

Fig. 4. Frequency response analysis results of the developed variable air core inductor.

III. EXPERIMENT

A. Impulse Current Test with The Developed Variable Air-Core Inductor in The Short-Circuit Condition

To verify the performance of the developed air core inductor, the developed air core inductor was installed as the inductor of the conventional lightning impulse current generator in impulse current test, and the short circuit test was performed. The capacitance value of the charging capacitor is 4 μF, and the resistance value of the resistor is 2 Ω. In the experiment, the inductance values of the developed air core inductor were varied to be 6.4 μH, 12.6 μH, 28.5 μH and 50.5 μH to observe the current waveforms. The current generation circuit simulated by ATP/EMTP is illustrated in Fig. 5. The same parameters were employed in the simulation. Good agreement between experimental and simulated results in Fig. 6 is observed.

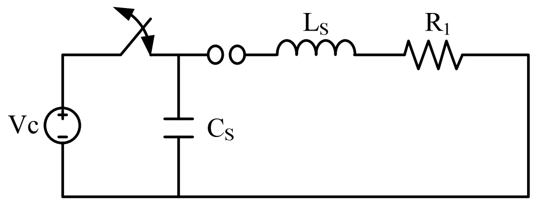

Fig. 5. Lightning impulse current generation circuit with short-circuit condition.

B. Impulse Current Test with A Surge Arrester

To verify the performance of the developed air core inductor in the practical condition, the lightning impulse current generator with the developed air core inductor was used to generate the lightning impulse current to a 5-kA lightning arrester for the impulse current test. The charging capacitance and the resistance of the lightning impulse generator are 4 μF and 0.6 Ω, respectively. In the experiment, the inductance values of the developed air core inductor were varied to be 6.4 μH, 10.8 μH, 28.8 μH and 50.5 μH to observe the current waveforms. To confirm the experimental results, the lightning impulse current generator with the developed air core inductor and the lightning arrester was simulated by ATP/EMTP, and the experimental results were compared to the simulation results. The simulation of the impulse current generator with the developed air core inductor and the lightning arrester is illustrated in Fig. 7. Impulse current test circuit with the developed air core inductor and the lightning arrester is shown in Fig. 8 [5]. Good agreement is observed between the experimental and simulated results as shown in Fig. 9.

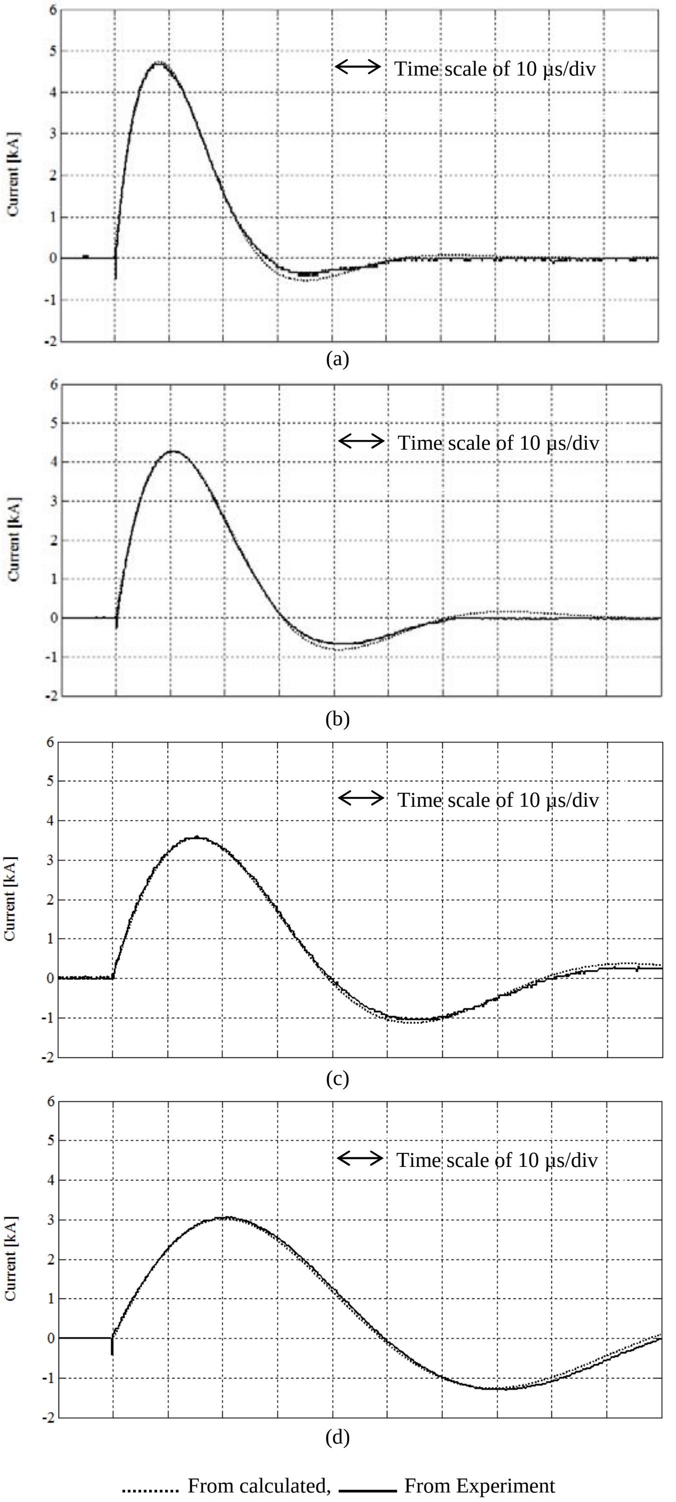

Fig. 6. Experimental and simulated results; (a) L = 6.4 μH, (b) = 12.6 μH, (c) L = 28.5 μH, and (d) L = 50.5 μH.

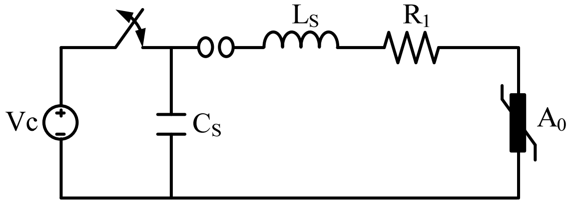

Fig. 7. Equivalent circuit of impulse current test with the lightning surge arrester.

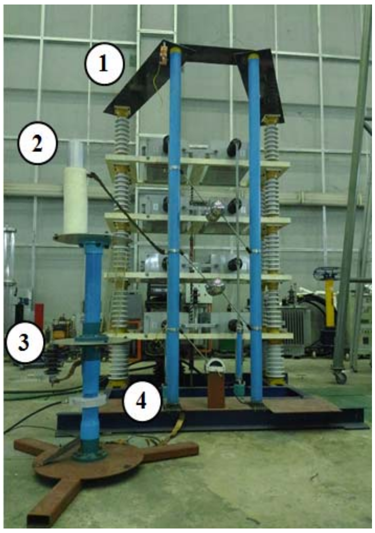

Fig. 8. Lightning impulse current test circuit on the lightning arrester; (1) Lightning impulse current generator, (2) The variable air core inductor (3) The lightning arrester, and (4) Rogowski coil.

From the test results in Figs. 6 and 9, the variable inductor can be used to adjust the current waveform according to the standard requirement for the residual voltage test of the lightning arrester.

Conclusion

In this paper, the design and construction of the variable air-core inductor has been presented. From the design and construction, the inductance value of the variable air core inductor can be varied from 6.4 µH to 50 µH. The inductor is employed to generate impulse current waveform. The generated waveforms are compared with the simulation. Good agreement is observed. From simulated and experimental results, the developed air core inductor can be used for impulse current waveform adjustment to obtain the waveform according to the standard requirement in the short-circuit condition and in condition with a surge arrester installed in the generation circuit.

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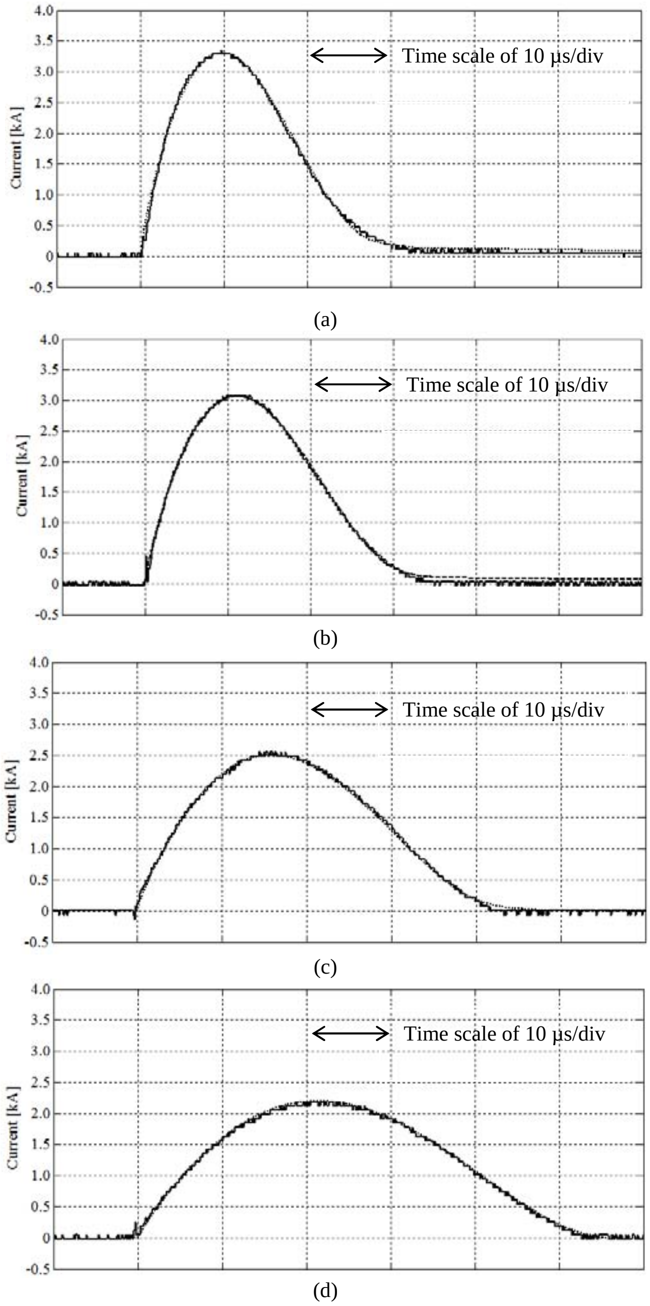

.... From calculated, ——— From Experiment

Fig. 9. Experiment result and simulation result; (a) L = 6.4 µH, (b) L = 10.8 µH, (c) L = 28.5 µH, and (d) L = 50.5 µH.

Reference

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[2] *IEC 61641-1, Low-voltage surge protective devices – Part 1.*

[3] *IEC 60099-4: Surge arresters.Part 4:Metal-oxide surge arresters without gaps for a.c. system, 2001.*

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