RESIDUAL MAGNETIC FLUX AT TRANSMISSION ACCIDENT FOR THREE PHASE TRANSFORMER

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ABSTRACT

When a transformer is being energized, a large magnetizing inrush current flows depending upon the closing phase of circuit breakers and the residual magnetic flux in the iron core. One of the suppressing the magnetizing inrush current method is controlling closing phase of the circuit breaker. For the controlled switching, to grasp condition of residual magnetic flux in the iron core is essential. Ample studies demonstrate that residual magnetic flux for no-load transformers. The residual magnetic flux for three-phase three-leg transformer had been investigated. However, little is known about residual magnetic flux after fault current interruption.

In this paper, the residual magnetic fluxes after interruption at one line ground (1LG) and two lines short-circuited (2LS) faults in isolated neutral system were investigated with experiments and calculations.

INTRODUCTION

Residual magnetic flux remains in iron core of the transformer when the transformer is disconnected from transmission system. When the transformer is being energized again, a large magnetic inrush current may flow due to residual magnetic flux and closing phase of circuit breakers. This large magnetic inrush current may cause voltage fluctuation of the transmission system and malfunction of the protection relay.

One of the methods for suppressing the magnetic inrush current is controlled switching. For the controlled switching, condition of the residual magnetic flux in the transformer's iron core is essential. Residual magnetic flux has been widely studied on no-load transformer, and the residual magnetic flux on loaded transformer and three-phase three-leg iron core type transformer also have been studied [1][2][3][4].

On the other hand, the transformer may be disconnected along with the faults such as one line ground (1LG) or two lines short-circuited (2LS) faults. In these cases, magnetic inrush current may also flows when the transformer is being energized again. However, there are few literatures discussing residual magnetic flux of these case.

In this paper, the residual magnetic flux of transformer after interruption at 1LG and 2LS faults in isolated neutral system are investigated with experiments and calculations.

MEASUREMENT AND CALCULATION OF RESIDUAL MAGNETIC FLUX

Measurement of residual magnetic flux

Figure 1 shows the measurement circuit for residual magnetic flux. The three phases transformer is constructed by three single phase transformers with 200V-200V-1kVA. The winding connection is Y-delta. In this measurements, the transformer has no load condition. The neutral point of primary side of the transformer is grounded for voltage measurement as shown in figure 1. The three phase magnetizing currents are interrupted at same time by circuit breaker with current chopping. The magnetic fluxes are calculated by integrating measured primary phase voltages.

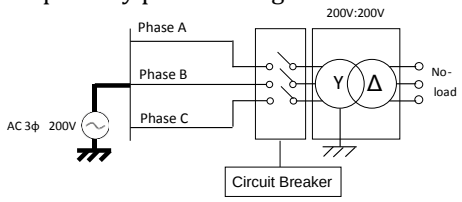

Fig.1 Measurement circuit of residual magnetic flux (Neutral point grounded)

Figure 2 shows the measured waveforms of three phase residual magnetic fluxes at current interrupted 45 electrical degrees. As shown in figure 2, residual magnetic fluxes were remained near the steady state flux at interrupting instant. The sum of the three phases residual magnetic fluxes is about zero because this transformer has delta connection in secondary winding.

Figure 3 shows the residual magnetic fluxes and steady state fluxes at each interrupted electric degrees. The residual magnetic fluxes remain along the steady state fluxes at each interrupted electric degrees.

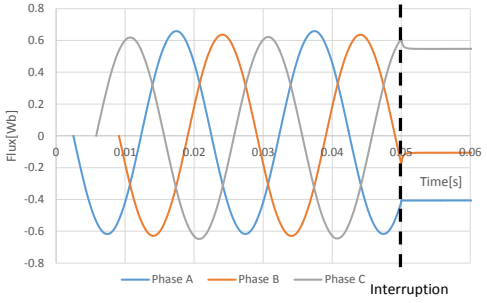

Fig.2 Flux waveforms (interruption 45 electric degrees)

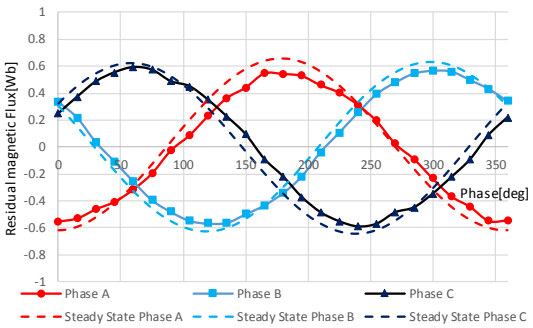

Fig.3 Residual magnetic fluxes at interruption from 0 to 360 electric degrees

Calculation of residual magnetic flux

Figure 4 shows calculation circuit on ATP-EMTP. The residual magnetic fluxes of various interruption electric degrees were calculated. The magnetizing hysteresis characteristics using these calculations were measured separately and adapted to the calculation.

Figure 5 shows the calculated residual magnetic fluxes. To compare the figure 3 and figure 5, the calculated residual magnetic fluxes has good agreement with the measurement.

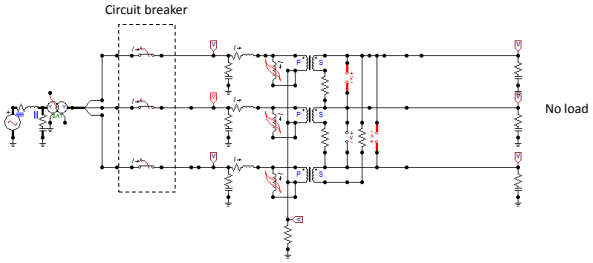

Fig.4 Calculation circuit for ATP-EMTP

RESIDUAL MAGNETIC FLUX AT ONE LINE GROUND FAULT INTERRUPTION

Fault condition

Figure 6 shows the one line fault (1LG) conditions. As shown in figure 6, the calculations were carried out under three fault conditions. One is fault occurring at upstream circuit breaker. Second is fault occurring at between circuit breaker and transformer and third is downstream of transformer. The transformer has Y-delta connections and the neutral point isolated.

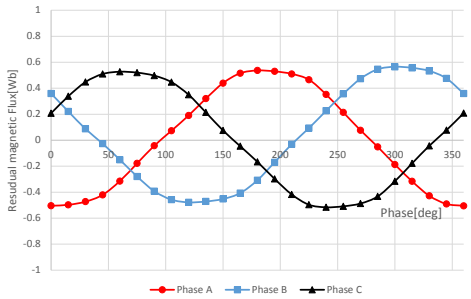

Fig.5 Calculated residual magnetic fluxes by EMTP at interruption 0 to 360 degrees

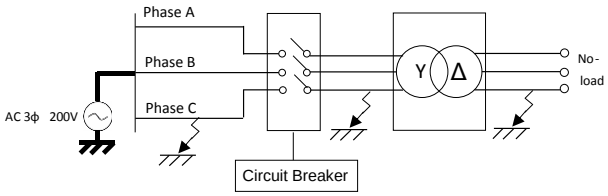

Fig.6 Calculation circuit at one line ground fault

Fault in upstream of circuit breaker

Voltage and magnetic flux when the 1LG occurred at upstream of the circuit breaker were calculated. Fault phase is C-phase and fault occurring is 45 electrical degree. Figure 7 shows voltage waveforms at phase-A, phase-B, phase-C and neutral point. Figure 8 shows the fluxes.

As shown in figure 7, the neutral point voltage fluctuates with 1 p. u. after 1LG fault occurs. So, the winding voltages of each phases are changing with 1p.u. As shown in figure 8, the magnetic fluxes after fault occurring do not change with before fault occurring.

Fault in between breakers and transformer

Voltage and magnetic flux of 1LG fault between the circuit breaker and transformer were calculated. In this case, large current does not flow through the circuit breaker. The circuit breaker is interrupted the current with current chopping. Faulted phase, timing and interruption phase are same as that of the previous chapter.

Figure 9 shows voltages at phase-A, phase-B, phase-C, and neutral point. Figure 10 shows their fluxes.

As shown in figure 9, the voltages after 1LG are same as figure 7. As shown in figure 10, fluxes are also same as figure 8.

Fault in secondary of transformer

Voltage and magnetic flux when the 1LG fault occurred in secondary of the transformer were calculated. This fault condition is commonly called as Transformer Limited Fault (TLF). Faulted phase, timing and interruption phase are the same as in the previous chapter.

Figure 11 shows voltages of phase-A, phase-B, phase-C, and neutral point. Figure 12 shows their fluxes. As shown in figure 11, voltages are not change after 1LG, therefore fluxes are also kept. Residual magnetic flux is decided from interruption phase of circuit breakers.

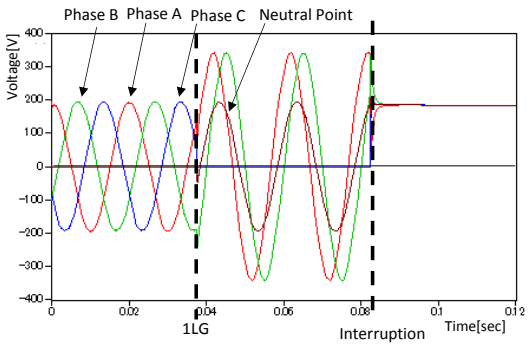

Fig.7 Voltages at 1LG in upstream of circuit breakers

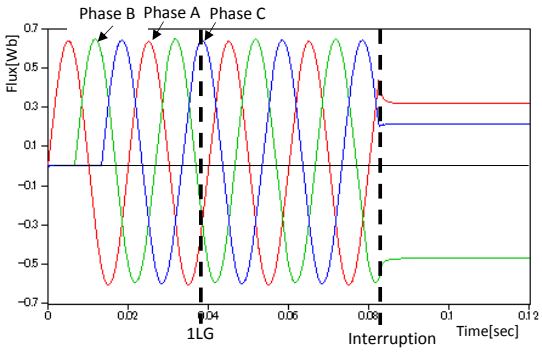

Fig.8 Fluxes at 1LG in upstream of circuit breakers

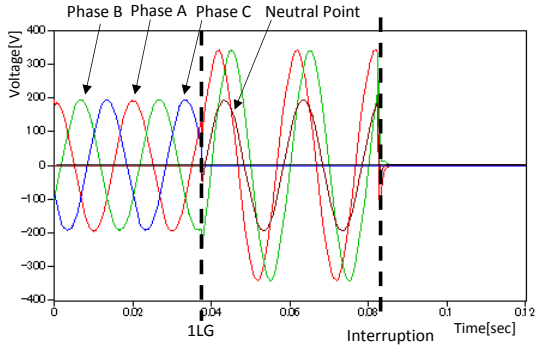

Fig.9 Voltages at 1LG between breakers and transformer

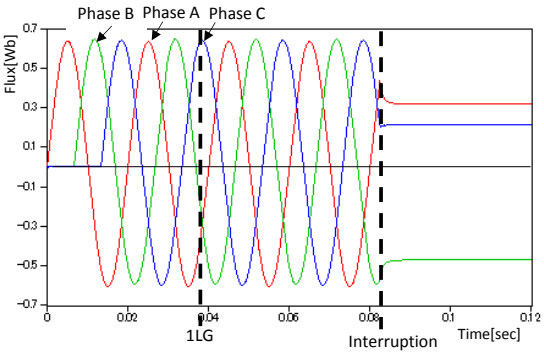

Fig.10 Fluxes at 1LG between breakers and transformer

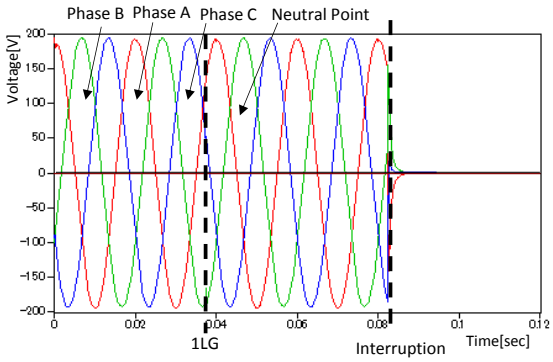

Fig.11 Voltages at 1LG in secondary of transformer

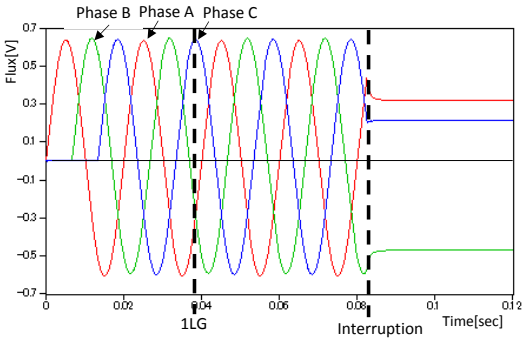

Fig.12 Fluxes at 1LG in secondary of transformer

Conclusion for one line ground

As shown in figures from 7 to 12, the residual magnetic fluxes on 1 LG depend on the interruption electric phase of the circuit breaker same as no-load transformer. In addition, the residual magnetic fluxes do not depend on the point of the fault.

RESIDUAL MAGNETIC FLUX AT TWO LINE SHORT-CIRCUIT FAULT INTERRUPTION

Fault condition

Figure 13 shows the two lines short-circuited (2LS) fault condition. As shown in figure 13, the calculations were carried out under such three fault conditions as upstream circuit breaker, between circuit breaker and transformer, and downstream of transformer.

The transformer has Y-delta connections and the neutral point isolated same as figure 6.

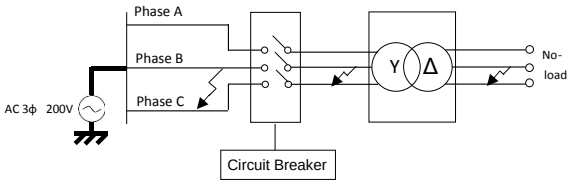

Fig.13 Calculation circuit at 2LS

Fault in upstream of circuit breaker

Voltage and magnetic flux when the 2LS fault occurred in upstream of the circuit breaker were calculated. Faulted phases are between B and C-phase, and fault occurs at 45 electric degree. Figure 14 shows voltages of phase-A, phase-B, phase-C, and neutral point. Figure 15 shows the magnetic fluxes.

As shown in figure 14, faulted phase voltages fluctuate with 0.5p.u. In this case, neutral point voltage is zero. Therefore, winding voltages of the faulted phases fluctuate 0.5p.u. As shown in figure 15, the magnetic fluxes on faulted phases fluctuate 0.5 p.u. after 2LS occurred. Due to the fact, the fault occurrence electric phase is considered to be related to the residual magnetic flux. Figure 16 shows fluxes waveforms at 2LS occurred in different electric

phase as figure 14 (345°). Current interruption phase of the circuit breaker is the same as figure14. As shown in figure 16, residual magnetic fluxes were different when the fault phases are different even if interruption phases are same.

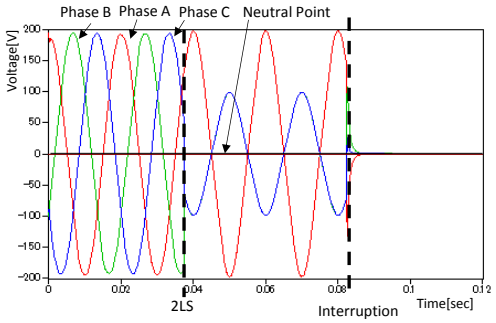

Fig.14 Voltages at 2LS in upstream of circuit breaker

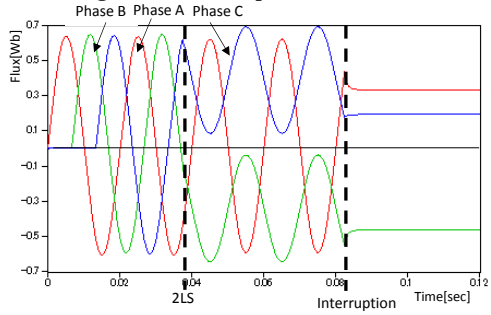

Fig.15 Fluxes at 2LS in upstream of circuit breaker

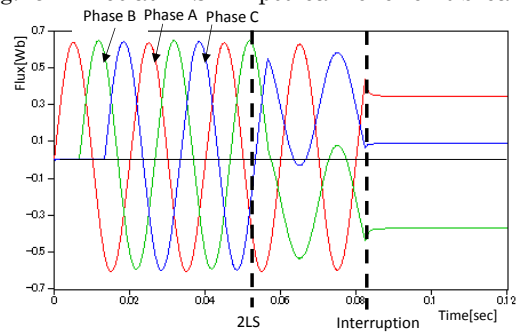

Fig.16 Fluxes at 2LS in upstream of circuit breaker
: Interruption 345°

Fault in between breaker and transformer

Voltage and magnetic flux when 2LS fault occurred between the circuit breaker and the transformer were calculated. In this case, large fault current flows through the circuit breaker at the faulted phase, and these following cases can be considered.

A) The currents of all phases included large fault current are interrupted at current zero point for each phases.

B) The large fault current flows, and the faulted phase current is interrupted at current zero point. But current of the sound phase is interrupted by current chopping.

Therefore, voltages and magnetic fluxes under these conditions were calculated.

Figure 17 and 18 show the voltages and magnetic fluxes of case A. Figure 19 and 20 show the voltages and magnetic fluxes of case B. When comparing Case A and Case B, the order of interruption phase is different. In addition, the residual magnetic flux also changes.

Fault in secondary of transformer

Voltage and magnetic flux when 2LS occurred in secondary side of the transformer were calculated. Also in this case, case A and case B are conceivable as in the previous section. Figure 21 and 22 show the voltage and magnetic flux of case A. Figure 23 and 24 show the voltage and magnetic flux of case B.

When comparing case A and case B, the order of interruption phases and the residual magnetic fluxes are also different.

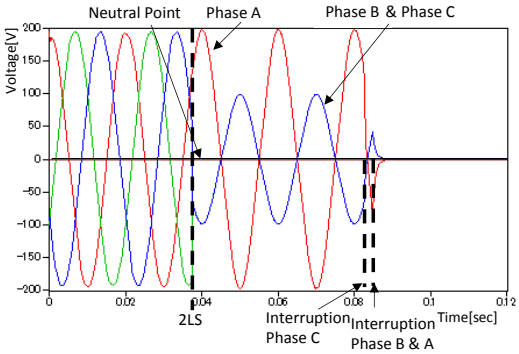

Fig.17 Voltages at 2LS in upstream of circuit breaker
: each phase currents are interrupted at current zero

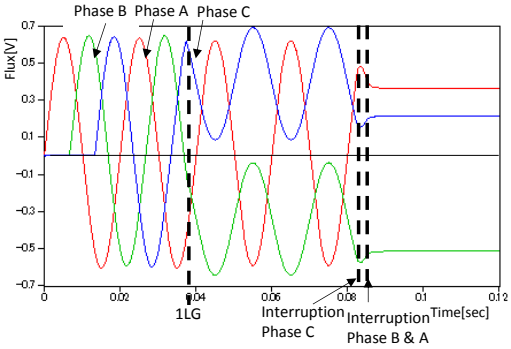

Fig.18 Fluxes at 2LS in upstream of circuit breakers
: each phase currents are interrupted at current zero

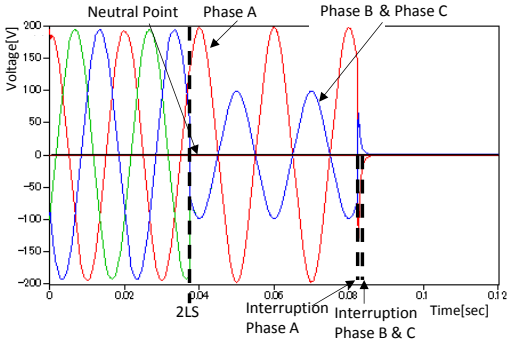

Fig.19 Voltages at 2LS in upstream of circuit breakers
: phase A current is interrupted by chopping

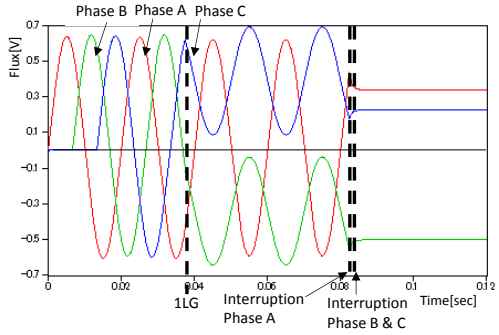

Fig.20 Fluxes at 2LS in upstream of circuit breaker: phase A current is interrupted by chopping

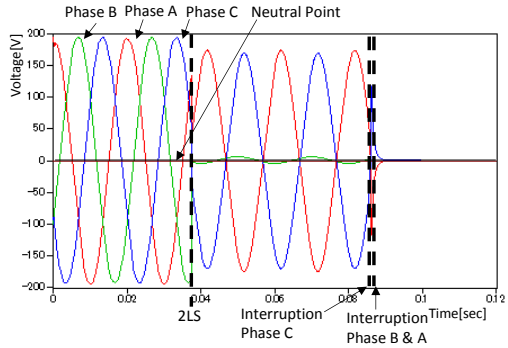

Fig.21 Voltages at 2LS in downstream of transformer: each phase currents are interrupted at current zero

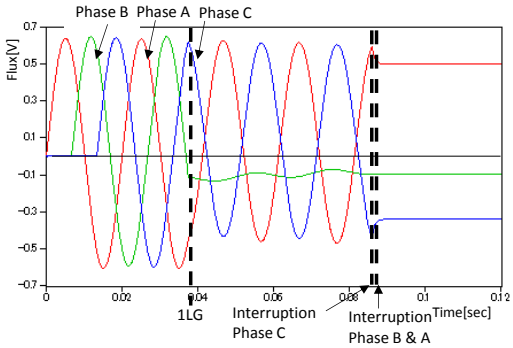

Fig.22 Fluxes at 2LS in downstream of transformer: each phase current are interrupted at current zero

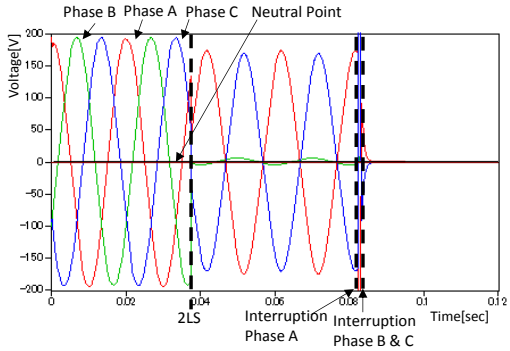

Fig.23 Voltage waveform at 2LS in upstream of circuit breaker: phase A current is interrupted by chopping

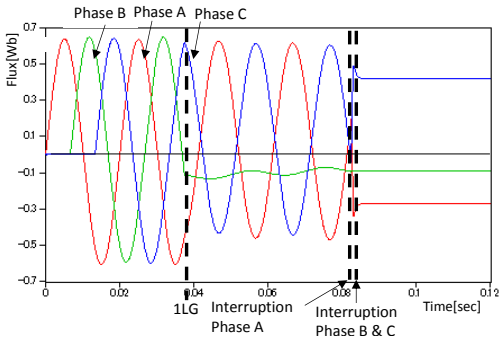

Fig.24 Fluxes at 2LS in upstream of circuit breakers: phase A current is interrupted by chopping

Conclusion for two line short

As shown in figures 13 to 22, the residual magnetic flux when 2LS depends upon the fault occurrence electric phase and current interruption condition.

CONCLUSION

In this paper, the residual magnetic flux for transformer under fault current interruption of 1 LG and 2 LS in isolate neutral system were investigated.

A) In case of 1LG, the voltages of the sound phases rise up to 1.73 p.u. However, since a voltage appears at the neutral point, the winding voltages of each phases are 1 p.u. Therefore, the residual magnetic fluxes have no influences of accident.

B) The residual magnetic fluxes at the 1LG does not depend on the faulted place.

C) In case of 2LS, the voltages of the accident phases are 0.5 p.u. The residual magnetic fluxes are not determined only the time of interruption of circuit breaker, but it depends on the occurrence time of the fault.

D) The residual magnetic fluxes in the 2LS fault greatly depend on the faulted point.

E) The residual magnetic fluxes of the 2LS also depend on interrupting condition of the circuit breakers.

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