The Simulation of High Speed Grounding Switches for the Rapid Secondary Arc Extinction on 765 kV Transmission Lines

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Abstract - **A critical aspect of reclosing operation is the extinction of the secondary arc because it must extinguish before successful reclosure can occur. Until now, two technologies of quenching secondary arcs for high speed reclosing on UHV lines were suggested. One is installing special 4-legged reactive compensation, the other is connecting high speed grounding switches(HSGS) to ground at each end of a transmission line in parallel.**

This paper presents characteristics of the secondary arc extinction by HSGS simulation on Korean 765 kV transmission lines using EMTP. In addition, results of auto-extinction simulation are compared with that of installing HSGS. Also, total operating timings of switches like circuit breaker, HSGS, reclosure are evaluated by empirical studies, which are applied to this present work.

Keywords: HSGS, Secondary Arc, EMTP, Reclosure, 765 kV Transmission Lines.

I. INTRODUCTION

In many countries including Korea, in order to transmit the more electric power, the higher transmission line voltage is inevitable. So, a rapid reclosing scheme is important for UHV transmission lines to ensure requirements for high reliability of main lines. But, because of high voltage and long span of UHV lines, the secondary arc current, which is chiefly due to capacitive and inductive coupling with other energized phases, flows across the fault point even after the interruption of fault current[1-5]. Successful reclosing switching can be accomplished through some combination of these two means:

1) Prevent reclosing until the secondary arc gradually self extinguishes.
2) Adopt a proper method to reduce the secondary arc extinction time, thereby ensuring its rapid reclosing.

From research papers for UHV lines given out in America and Japan, 4-legged reactor and High Speed Grounding Switches are known to suppress the secondary arc. 4-legged shunt reactor is widely used in America, but BPA 500 kV lines adopt HSGS since 1985. In Japan, HSGS were tested on 220 kV and 550 kV AC transmission lines with favorable results [6-9].

Korea 765 kV transmission lines are scheduled to operate from the year of 2002. And through some special research report, it is desirable to adopt HSGS. But, until now, there was no field test in Korean 765 kV transmission lines, so it is necessary to simulate HSGS accurately [10-12].

In this paper, HSGS simulation is performed by EMTP on Korean 765 kV transmission lines. And various waveforms of simulation results are presented. Then, the auto-extinction time of secondary arcs is compared with the forced-extinction time by HSGS. Besides, switching-cycles of circuit breaker, HSGS, reclosure are applied to this EMTP simulation.

II. RECLOSING STRATEGY

A. Operating Sequences of Reclosure

Fig. 1 shows operating sequences of equipments such as protective relay, circuit breaker, reclosing relay from fault inception to reclosure.

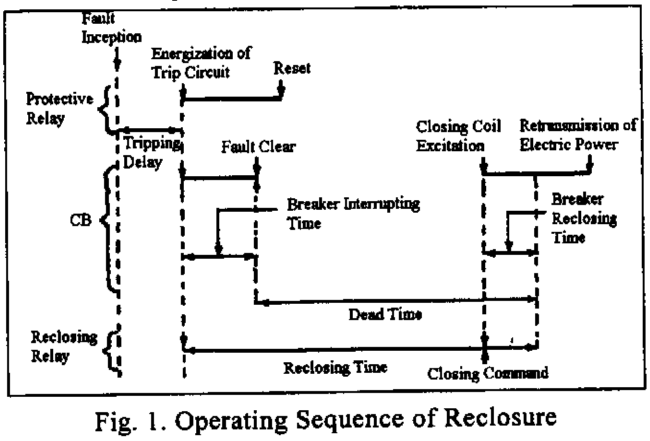

Fig. 1. Operating Sequence of Reclosure

Circuit breakers are excited by energization of trip coil in protective relay. After breakers trip, deionization time is required to reclose circuit breakers. During this time, the secondary arc should be extinguished. Dead time is defined as interval between two events. One is opening of breakers, the other is reclosing of breakers for retransmit electric power. This can be evaluated from (1) suggested by many experiments[13].

$$t = 10.5 + \frac{kV}{34.5} \quad \text{[cycles]} \qquad (1)$$

Where kV is a rated voltage of power system.

In general, it is necessary to reduce dead time and to reclose breakers as fast as possible for improving reliability of power system, but, if reclosure be made so rapidly, there can be possibility of arc reignition. Therefore, extinction of arc should be checked before reclosing operation.

B. Reclosing Strategy on 765 kV Lines

According to investigation about UHV technology of CIGRE, single-phase reclosing scheme is planned for one circuit transmission line and multi-phase reclosing scheme for double circuit transmission line in most countries. In Korea, the 765 kV transmission lines is scheduled to operate from the year of 2002 to meet increasing power demand, and it is supposed to play a major role in future systems. So, route faults should always be avoided in all cases. Therefore, to ensure the reliable operation of the power system, it is desirable to adopt high speed multi-phase reclosing scheme.

From calculation of (1) in 765 kV lines, dead time is about 33 cycles, i.e. 0.5 second. But, (1) is applied in three-phase reclosure method, which trips all three-phase. In case of single-phase or multi-phase reclosure mode, only a faulted phase is interrupted and other phases remain sound. Therefore, it can be concluded that dead time of the latter is twice as long as that of the former, 66 cycles, nearly 1 second, although it varies according to line length and circuit configuration. Actually it is reported that the secondary arc sustains from 0.9 to 5 seconds in technical report, which researched on Japanese 1000 kV, AEP 765 kV, USSR 750 kV lines[6-11].

Therefore, for the purpose of dead time less than 1 second, arc suppression method should be considered. In this paper, HSGS is adopted to EMTP simulation and applied to 765 kV lines. So, the effect of high speed grounding switches is analyzed.

III. HIGH SPEED GROUNDING SWITCHES

Now HSGS are installed on certain existing 500 kV lines of the BPA. The main disadvantage of HSGS was the high cost of additional circuit breakers which would serve as grounding switches. But the switching technology of today has made the use of HSGS economically feasible[8]. The grounding switches at both ends of fault lines are connected to ground after fault current is interrupted. As a result, the secondary arc is extinguished because the impedance of grounding switches is smaller than that of the secondary arc. Fig. 2 shows an operating sequence of HSGS;

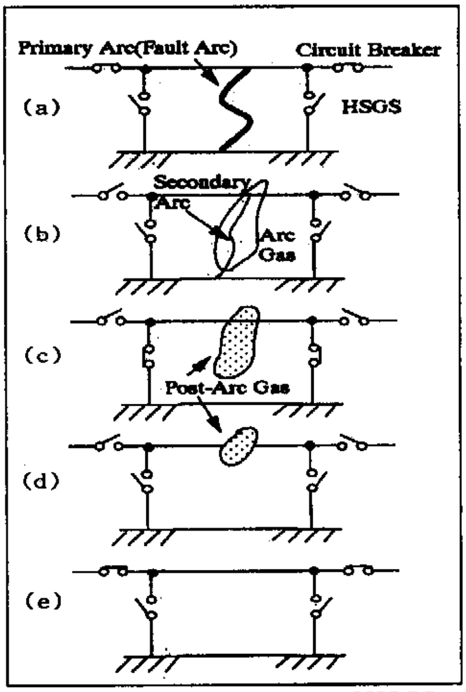

Fig. 2. Operating Sequence of HSGS

(a) The primary arc is generated at the fault point when a fault occurs.
(b) The secondary arc current caused by sound phases flows at the fault point, though fault current is interrupted by circuit breakers.
(c) HSGS are closed, then the secondary arc is extinguished.
(d) HSGS are opened.
(e) Circuit breakers are closed after the insulation strength at the fault point has recovered.

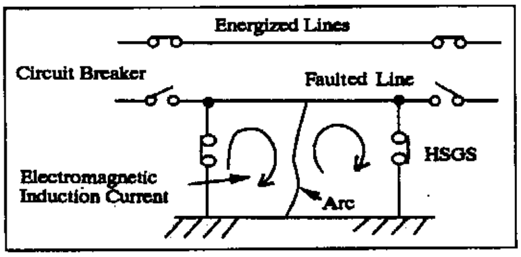

Fig. 3. Electromagnetic Induction Current

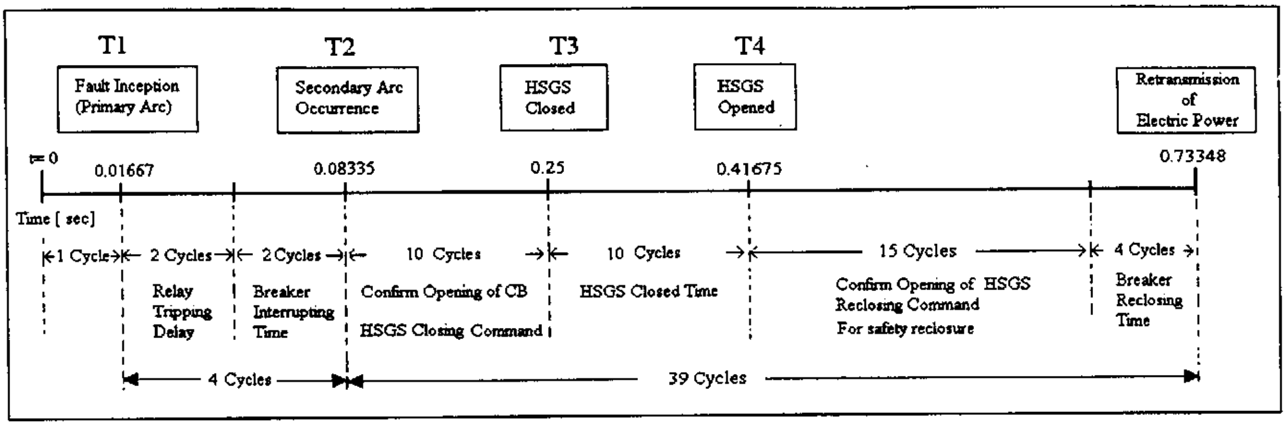

Fig. 6. Operating Timings of Total Simulation

Fig. 3 shows the current generated when HSGS are closed. With one grounding switch closed, a closed circuit is formed through the arc path and current flows by electromagnetic induction due to the other energized phases. When the other grounding switch is closed, the electromagnetic induction current in the arc path is canceled.

IV. SIMULATION RESULTS AND DISCUSSION

A. Modeling Technique for Arc

Fig. 4 shows the total diagram for simulating arcing faults.

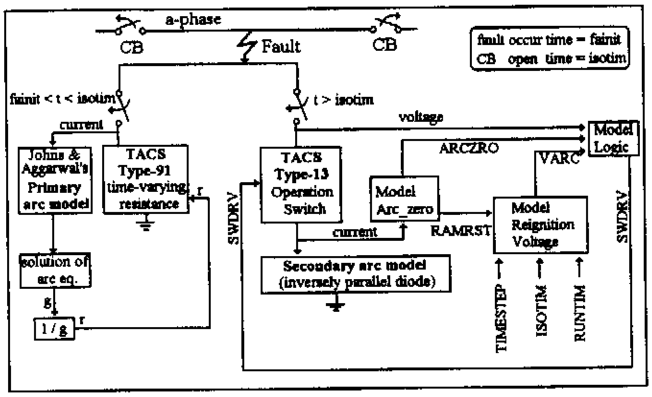

Fig. 4. Total Diagram of Arcing Faults Modeling

When fault occurs, Johns and Aggarwal's primary arc model[2] is applied to first process, which express primary arc characteristics. In each time step, arc conductance can be obtained by solving arc equation. Then inverse value of arc conductance is used for time-varying arc resistance in TACS Type-91.

After circuit breaker open, the simulation process of the secondary arc model begins. Characteristics of secondary arcs are so dynamic and complicated that it is difficult to simulate secondary arcs. Thus simulation technique in ref. [4] and inversely paralleled double diode circuit[5] are adopted to our simulation, including characteristics of reignition voltage.

All simulations of arcing faults are implemented by EMTP as well as MODELS for the purpose of interfacing switch and submodels with model system.

B. Simulation Method

In the present work, the transmission system modeled is the Korean 765 kV system as shown in fig.5, which is scheduled to operate from the year of 2002. Electrical constants are simulated by line constant routine of EMTP. S.M(Synchronous Machine) card ana TACS are used for ULCHIN nuclear power plant including governor and excitation system. Loads are assumed to be maximum based on the power flow calculation in the year of 2006. The simulation assumes a-phase to ground fault at mid-point of 765 kV lines.

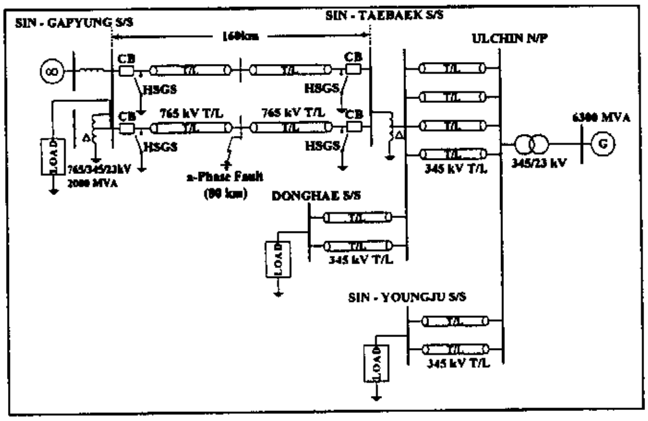

Fig. 5. Simulation Model of 765 kV System

Operating timings of total simulation are depicted in fig. 6. In order to maintain a transient stability of power system, fault clearing time must less than 4 cycles which are the sum of main protective relay operation time(2 cycles) and circuit breaker interrupting time(2 cycles). For confirming opening of CB, 10 cycles are

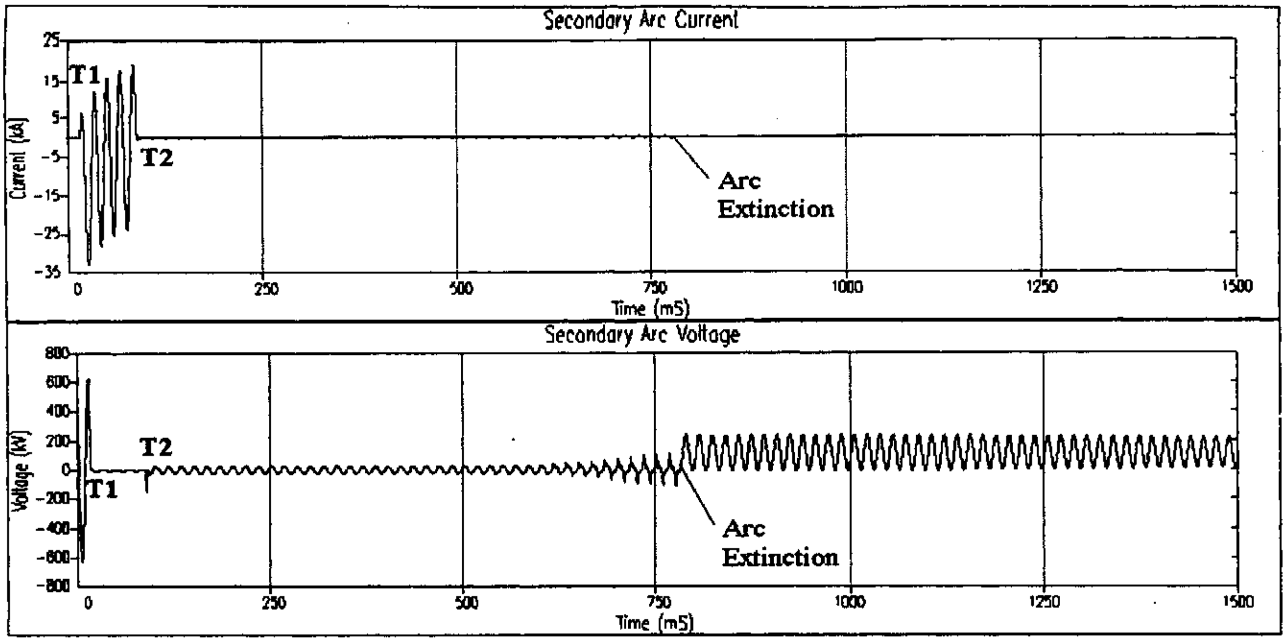

Fig. 8. Waveforms of Current and Voltage at the Fault Point (In Case of Auto-Extinction)

required. HSGS should remain closed for 10-15 cycles to recover the insulation strength. Before circuit breakers are closed, duration time of 10-15 cycles is recommended to check opening of HSGS and to excite reclosing coil in the safety aspect. After that, breaker reclosing time is 4 cycles. Consequently duration time of 35-45 cycles should be needed from closure of HSGS to reclosure operation.

B. Simulation Results

1) In Case of Auto-Extinction:

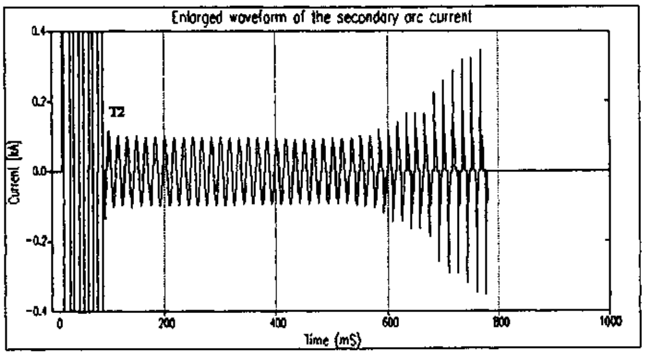

Fig. 7. Enlarged Waveform of the Secondary Arc

In fig. 7, it can be evaluated that the secondary arc extinguishes at nearly 0.8 second. Fig. 8 shows waveforms of current and voltage at the fault point in the case of auto-extinction. From simulation results, if deionization time and reclosing operation time are considered, it is difficult to make a high-speed reclosure within less than 1 second. So, the method of arc suppression should be required.

2) In Case of Installing HSGS

Fig. 9 on next page shows waveforms of current and voltage at the fault point in the case of installing HSGS. In fig. 9, reclosure can be made after T4 point, but as stated in fig. 6, at least 15 cycles are recommended in the safety aspect. Fig. 10 shows electromagnetic induction current at each end of a transmission line when HSGS are closed. As depicted in fig. 3, one waveform is reverse to the other. Finally it is canceled through arc path in closed circuit.

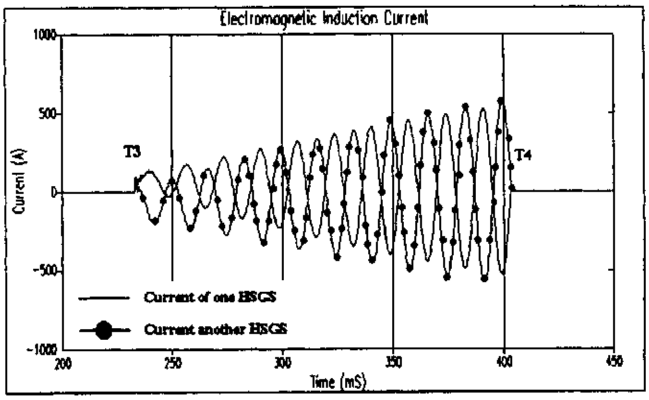

Fig. 10. Electromagnetic Induction Current

V. CONCLUSION

In this paper, High Speed Grounding Switches are taken into consideration as arc suppression method, and this scheme is included to EMTP simulation of Korean 765 kV transmission lines. For improving accuracy of

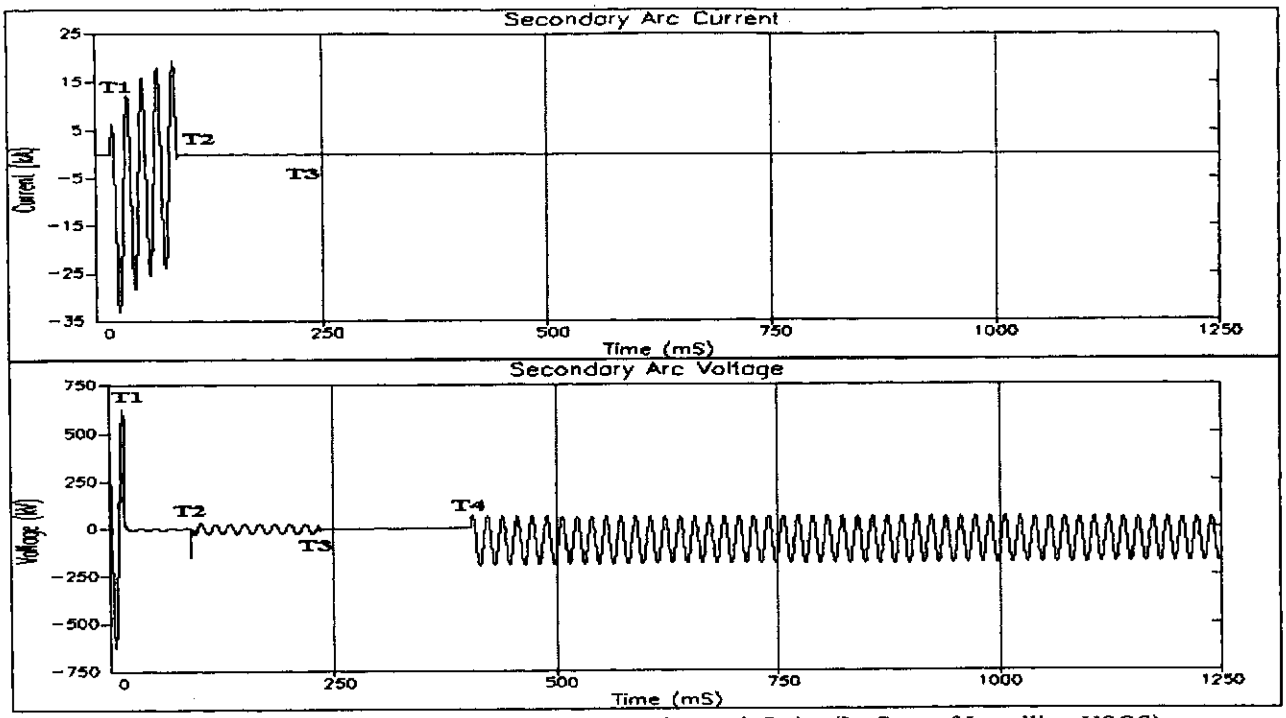

Fig. 9. Waveforms of Current and Voltage at the Fault Point (In Case of Installing HSGS)

simulation, total operating timings are suggested.

The simulation of HSGS is performed well, so we can understand the role of HSGS in comparison with auto-extinction case through our simulated results. Additionally when HSGS are closed, cancellation of electromagnetic induction current at each end of a transmission line is evaluated.

Now, HSGS and multi-phase reclosing scheme will be installed to Korean 765 kV transmission lines. Therefore, various simulation results should be suggested for determining operating and interrupting duties. And, our simulation results will contribute to improve reclosing strategy.

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