The Adequacy Analysis for Installation of High Speed Grounding Switches on the Korean 765kV Single Transmission Line

Sang-Pil Ahn†, Chul-Hwan Kim, Nam-Ok Park*, Hyung-Jun Ju*** and Eung-Bo Shim*****

Abstract - This paper analyzes arc phenomena including the secondary arc's elongation in the Korean 765kV single transmission line (79km) between Sin-Ansung S/S and Sin-Gapyeong S/S, which will be installed in Korea in June 2006. In particular, both frequency independent and frequency dependent line models are compared to make our final decisions. As well, the significant simulation results are investigated by the EMTP program. As a result, there is no need of HSGS in the Korean 765kV single transmission line from both a practical and an economical point of view.

Keywords: EMTP, High speed grounding switches (HSGS), Secondary arc, Ultra high voltage transmission line

1. Introduction

In many countries, including Korea, in order to transmit more electric power, 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 the high voltage and long span of UHV lines, the secondary arc current flows across the fault point even after the interruption of the fault current. Namely a critical aspect of reclosing operation is the extinction of the secondary arc since it must be extinguished before successful reclosure can occur [1-9].

Successful reclosing switching can be accomplished through some combinations of these two means:

(a) Prevent reclosing until the secondary arc gradually being self-extinguished.

(b) 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 (HSGS) are known to suppress the secondary arc [2].

In the 765kV transmission lines in Korea, high speed grounding switches have already been applied to 765kV double transmission lines since that was part of the first stage of the 765kV implementation. The 765kV single transmission line (79km) between Sin-Ansung S/S and Sin-Gapyeong S/S is scheduled to be energized in June 2006 [1-3].

This paper analyzes characteristics of the secondary arc extinction on a 765kV single transmission line using the EMTP program. Also, both frequency independent and frequency dependent line models using the EMTP program are compared to make our final decisions [10, 11].

According to these simulation results, consulting reports are suggested to KEPCO (Korea Electric Power Corporation) for constructing a 765kV single transmission line and future works.

2. Overview of Korean UHV Transmission Lines

2.1 Korean 765kV Power Systems

Since 1991, the necessity of UHV transmission lines has been consistently brought up because the increasing rate of the peak demand is more than 10% annually. As such, KEPCO launched the 765kV Project Team in 1992. For this 765kV project, KEPCO and KEPRI (Korea Electric Power Research Institute) have researched various fields of the UHV power system such as facilities (transmission line, substation, etc.) design, load flow, stability, failure analysis, and project profitability. Their ten long years of exertion made a commencement of the 765kV system operation with completion of the 765kV Sin-Ansung and Sin-Seosan substations. Thus, the 765kV power system has played the important role of direct connection with bulk power plants and the nation's capital region, providing a large and stable power supply to the heart of the nation's capital and becoming the backbone of the transmission system.

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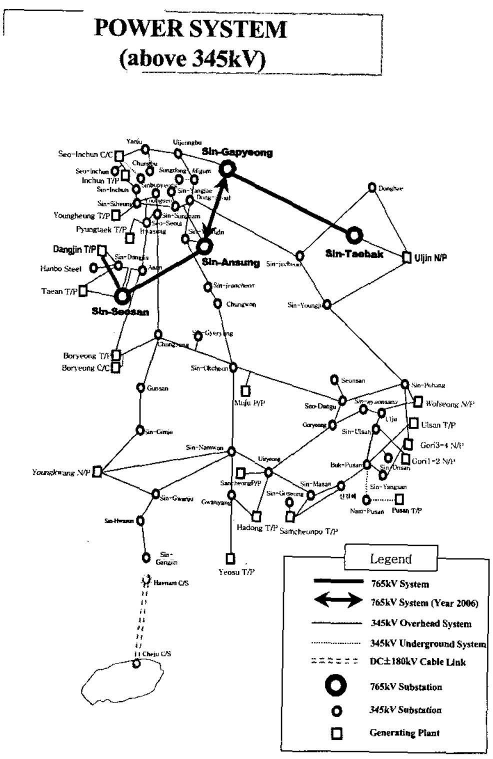


Fig. 1. Korean Power System Lines

Table 1. Detailed Information of Korean 765kV Power System

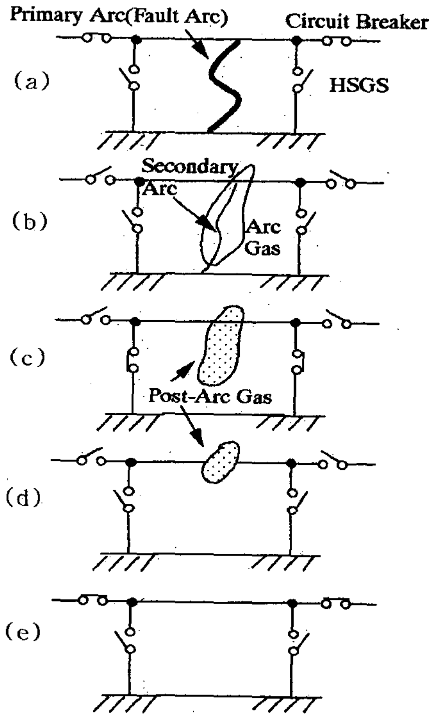
Construction Year	Transmission line	Length [C-km]	Support [EA]
1999	Dangjin T/P ~ Sin-Seosan S/S	78 (double)	90
2000	Sin-Seosan S/S ~ Sin-Ansung S/S	274 (double)	259
	Sin-Taebaek S/S ~ Sin-Gapyeong S/S	310 (double)	317
2005	Uljin N/P ~ Sin-Taebaek S/S	96 (double)	81
2006	Sin-Ansung S/S ~ Sin-Gapyeong S/S	79 (single)	159

Year	Substation	Bank [EA]	Capacity [MVA]
2002	Sin-Seosan	2	2,000
	Sin-Ansung	2	4,000
	Dangjin T/P	1	1,100
2004	Sin-Gapyeong	3	6,000
	Sin-Taebaek	3	6,000

The second 765kV transmission lines were energized between Sin-Gapyeong S/S and Sin-Taebaek S/S in 2004. The 765kV single transmission line between Sin-Ansung S/S and Sin-Gapyeong S/S is scheduled to be energized in June 2006. Fig. 1 shows Korean power system lines and Table 1 shows the detailed present state of Korean 765kV project plans [3].

2.2 High Speed Grounding Switches (HSGS)

The main disadvantage of HSGS has been the high cost of additional circuit breakers, which would serve as grounding switches. However, the switching technology of today has made the use of HSGS economically feasible. The grounding switches at both ends of fault lines are connected to the ground after a 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 presents the 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, and 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. 2. Operating Sequence of HSGS

Fig. 3 presents the current generated when HSGS are closed. With one grounding switch closed, a closed circuit is formed through the arc path and the 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.

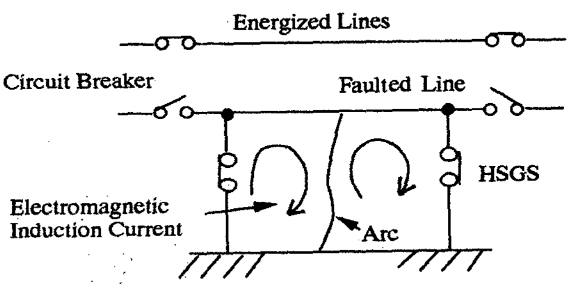


Fig. 3. Electromagnetic Induction Current

The Korean 765kV power system mainly consists of double transmission lines. So route faults should always be avoided in all cases. To ensure the reliable operation of the power system, it is desirable to adopt a high-speed multi-phase reclosing scheme. For this purpose, the secondary arc should be quenched rapidly.

Therefore, HSGS has already been adopted on the Sin-Seosan S/S ~ Sin-Ansung S/S (137km) line and the Sin-Taebaek S/S ~ Sin-Gapyeong S/S line (155km). The section between Sin-Ansung S/S and Sin-Gapyeong S/S scheduled to be energized in 2006 is a short-length, single transmission line. But because the line voltage is of the UHV class, the necessity of the adaptation of HSGS should be considered by a simulation program.

For the reference, ratings of 765kV outdoor full GIS including HSGS are as follows.

(a) Rated voltage: 800kV
(b) Rate current: 8,000A
(c) Lightning impulse voltage: 2,250kV_{peak}
(d) Switching impulse voltage: 1,425kV_{peak}
(e) Power frequency withstand voltage: 830kV_{rms}

3. Arc Simulation Studies

3.1 Modeling Technique for Arc Phenomena

Recently modeling techniques for arc phenomena are improved with field experiments to simulate dynamic characteristics [6, 7]. In Korea, there has been no field measurement of arc phenomena to set up dynamic parameters until now. Thus, the linearized modeling technique used for our study is as follows.

Fig. 4 shows the complete diagram for simulating arcing faults. When a fault occurs, Johns and Aggarwal's primary arc model [4] is applied to the first process, which expresses primary arc characteristics. In each time step, arc conductance can be obtained by solving the arc equation. Then inverse value of arc conductance is used for time-varying arc resistance in TACS Type-91.

Once the circuit breaker is opened, 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 S. Goldberg's computer model of inversely paralleled double diode [5] and linearized modeling simulation techniques in [2] are adapted to our simulation, including characteristics of re-ignition voltage. The detailed parameters and assumptions are noted in [9]

In respect of the secondary arc simulation, even if the arc current becomes zero, a re-ignition of arcs can occur so long as the arc energy voltage at fault point is larger than the re-ignition voltage of the power system. So, MODEL logic (AND-gate) is applied to the simulation for satisfying the two conditions of the arc extinction.

This paper implements not only a dynamic conducting characteristic but also the re-ignition voltage characteristic, which has the variation of the arc length using MODELS routine within the EMTP data card. Namely, each mathematical model is programmed by the submodel routine. And all simulations of arcing faults are implemented by EMTP as well as MODELS and TACS for the purpose of interfacing switch and submodels with the model system.

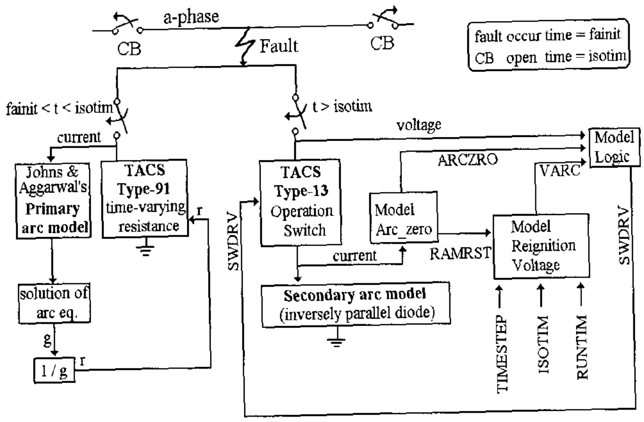


Fig. 4. Total Diagram of Arcing Faults Modeling

3.2 Simulation Method

In the present work, the transmission system studied is a 765kV single transmission line between Sin-Ansung S/S and Sin-Gapyeong S/S, which will be energized in June 2006 in Korea as depicted in Fig. 1.

The total line length is 79km and the nominal power frequency is 60 Hz. Electrical line constants are punched by both K.C.LEE (frequency independency) model and JMARTI Setup (frequency dependency) of EMTP. For the purpose of simplicity, the model system is reduced equivalently to two electric power sources on both sides of a single transmission line.

The simulation assumes a-phase to ground fault at four points, which are located 16, 32, 48, and 64km from Sin-Ansung S/S. Fault inception occurs after 1 cycle (0.01667 sec., A-point) from simulation starting. In order to maintain the transient stability of a power system, fault clearing time must be less than 4 cycles, which is the sum of main protective relay operation time (2 cycles) and circuit breaker interrupting time (2 cycles). After these 4 cycles (0.08335 sec, B-point), circuit breakers on both sides are opened, then the secondary arcs are ignited. In order to compare the auto-extinction time of the secondary arcs on various fault points and study transient phenomena, simulations are carried out without HSGS.

3.3 Arc Simulation Results

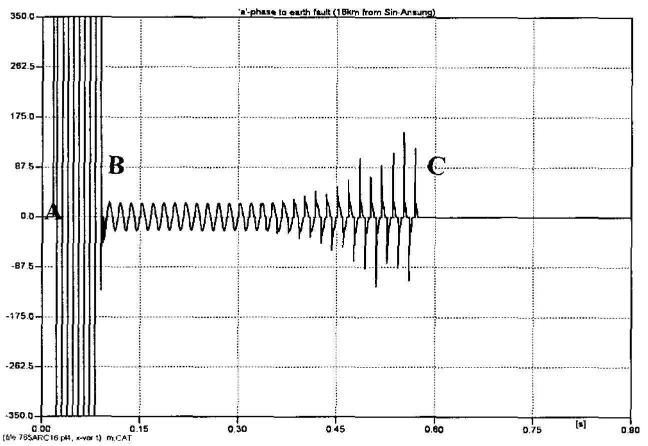


Fig. 5. Enlarged current waveform at 16km fault point

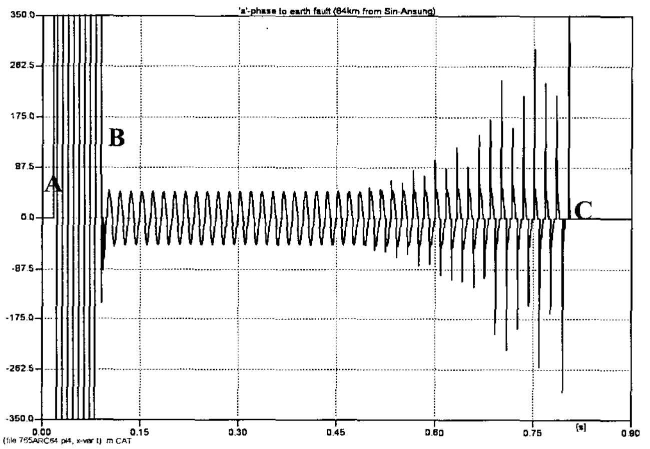


Fig. 6. Enlarged current waveform at 64km fault point

Fig. 5 shows a current waveform at fault point in the case of a fault at 16km from Sin-Ansung S/S. At the point marked A on the waveform in Fig. 5, a fault develops on the ground line. So there is a heavy fault current to the earth. The protection system detects the fault and opens the circuit breakers at point B. The secondary arc is then established and this can be seen to have extinction and re-striking characteristics. Finally, the arc is extinguished completely at point C. Thus, it can be evaluated that the secondary arc is extinguished at nearly 0.57 sec. and the magnitude of the secondary arc current is $18A_{rms}$ $(25A_{peak})$.

A current waveform at the 64km fault point is depicted in Fig. 6, which is plotted by the same scale of X-Y axes.

Both the magnitude and the extinction time of the secondary arc current are especially proportional to the fault location from Sin-Ansung S/S as stated in Table 2.

Table 2. Major Values attained from Simulation Results

Fault location	16km	32km	48km	64km
Magnitude of current [A_{rms}]	18	21	24	30
Extinction time [sec]	0.57	0.64	0.74	0.8
Arc energy voltage [$\lvert kV_p \rvert$]	136	177	210	260

In Figs. 7 and 8, there is a small (compared to 765kV) system voltage component on the line after point C, which is due to electrostatic coupling between the faulted phase and the two healthy phases. This voltage is actually the arc energy voltage of the secondary arc at fault point.

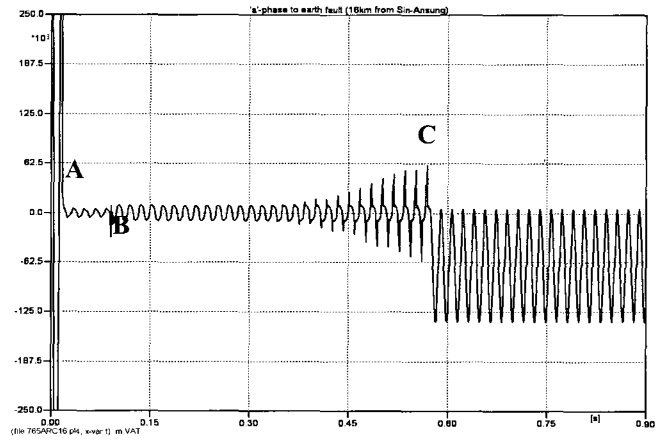


Fig. 7. Voltage waveform at 16km fault point

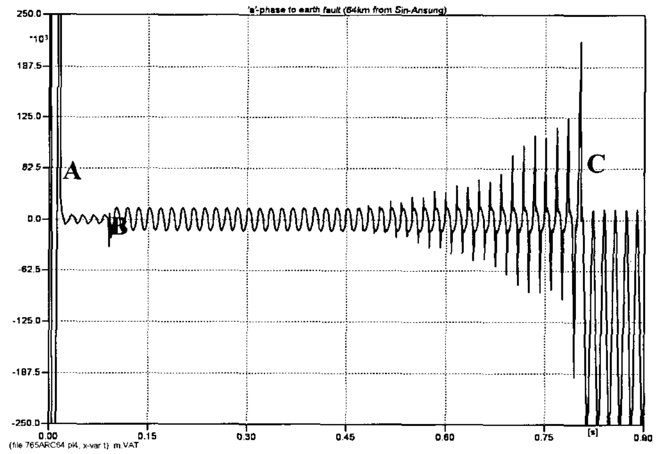


Fig. 8. Voltage waveform at 64km fault point

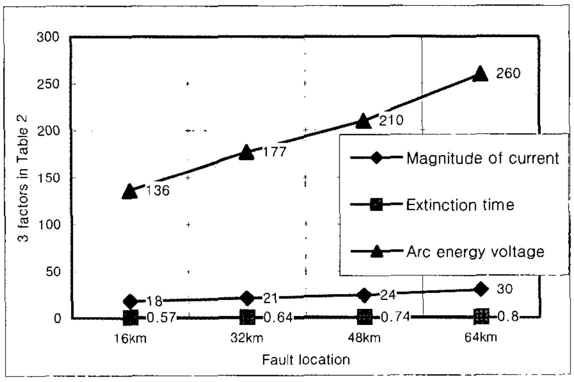


Fig. 9. Relation between fault location and 3 factors in Table 2

The re-ignition voltage (withstand voltage) has the complex characteristics of the secondary arc as stated in [5]. The secondary arc can be re-ignited if a sustaining arc energy voltage supplied by the power system is larger than the re-ignition voltage. So in order to achieve the arc extinction, the arc energy voltage must always not exceed the re-ignition voltage.

Our simulation results show that the magnitude of arc energy voltage is similarly proportional to the auto-extinction time of the secondary arc, the magnitude of the secondary arc current and also the fault location from Sin-Ansung S/S with increase, as shown in Table 2 and Fig. 9.

4. HSGS Simulation Studies

4.1 HSGS of Frequency-Independent Line Model (K.C.LEE)

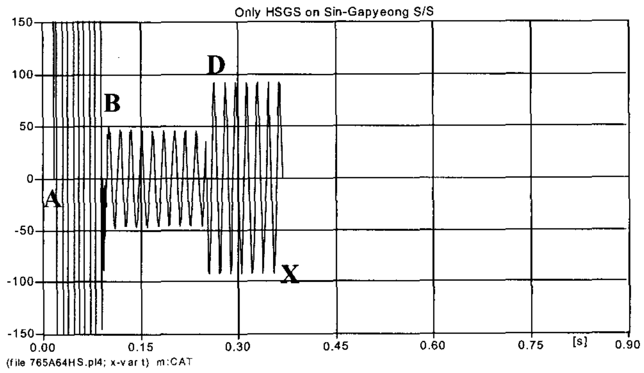
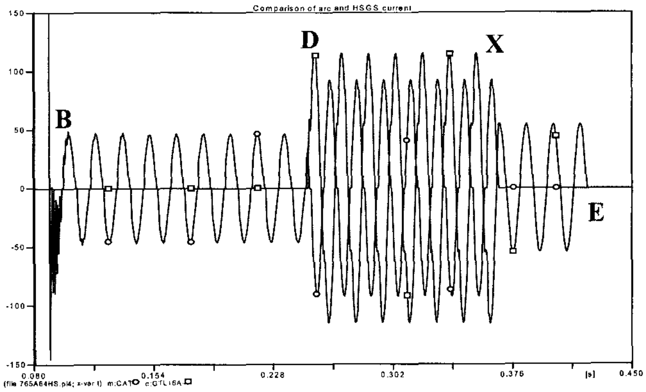


Fig. 10. Enlarged current waveform at 64km fault point in the case of HSGS on one side (Sin-Gapyeong S/S) of a single line [K.C.LEE]

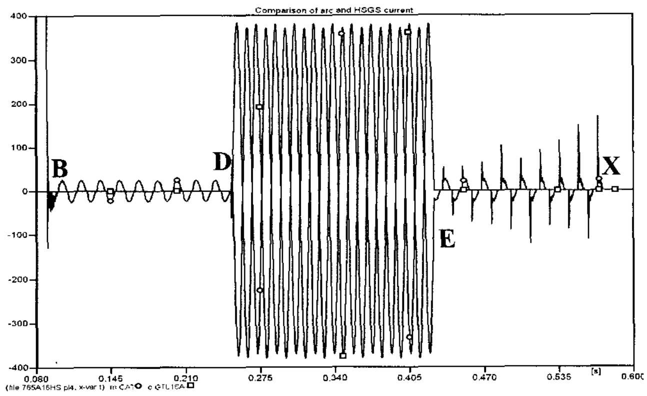
First of all, it is decided that HSGS may be installed on either side, especially at Sin-Gapyeong S/S, because the auto-extinction time of the secondary arc is longer at the closer fault point to Sin-Gapyeong S/S and this UHV line is not much longer compared to other lines.

Thus, new simulation cases are implemented, which have only one HSGS on the Sin-Gapyeong S/S. Total simulation timing is the same as stated in Section 3.2 section that HSGS is closed after 10 cycles (0.25 sec., D-point) from fault clearing in order to confirm operation of circuit breakers and remain closed for 10 cycles (until 0.42 sec., E-point).



O: arc fault current / □: HSGS current

Fig. 11. Enlarged current waveform at 64km fault point in the case of HSGS on one side with the current flowing on closed HSGS [K.C.LEE]



O: arc fault current / □: HSGS current

Fig. 12. Enlarged current waveform at 16km fault point in the case of HSGS on one side with the current flowing on closed HSGS [K.C.LEE]

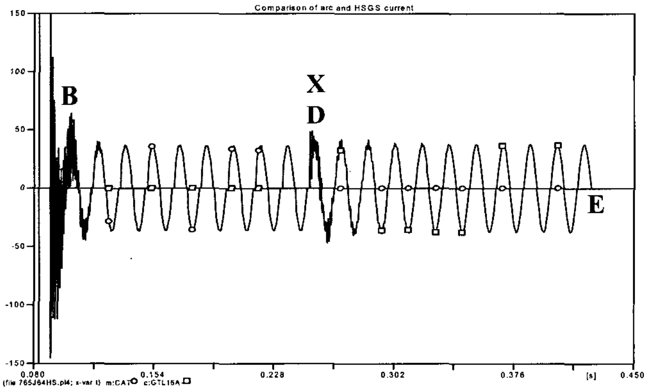
From these cases, important simulation results are reported. Fig. 10 shows that the secondary arc is re-ignited with high level when HSGS on one side are closed at point D. This unsatisfactory phenomenon can be occurred by means of no cancellation of an electromagnetic induction current referred to in Section 2.2. But, in Fig. 11, which plots both the secondary arc current and the current flowing on closed HSGS (i.e. Earth switch) as the same case, it can be analyzed that an electromagnetic induction current circulates within two points, i.e. fault point and HSGS point. In any case, the secondary arc current is finally extinguished at 0.37 sec. (X-point) before HSGS open. And induction current flows until 0.42 sec. (E-point), which is eliminated by the opening of the Earth switch.

Unpredictably, this result cannot be similarly applied to other cases such as a fault inception at the 16km location from Sin-Ansung S/S. In this case as presented in Fig. 12, the secondary arc is not quenched and is re-ignited to 0.57 sec. (X-point) after HSGS open. So re-adjustment of HSGS duty cycles should be considered, and therefore it is realistically not useful to implement the high-speed reclosing method.

4.2 HSGS of Frequency-Dependent Line Model (JMARTI)

Simulation conditions are the same as those in Section 4.1. In this paper, bandwidth of the first frequency card for JMARTI setup is 1,000Hz for switching and surge analysis. Fig. 13 gives a new phenomenon for current waveform at the 64km fault point (near Sin-Gapyeong S/S, i.e. HSGS installation point).

The secondary arc current is forced-extinguished as soon as HSGS is closed at 0.25 sec. (D-point ≈ X-point). Instead, earth current flows to the ground as much as that of the peak of arc current. Then this current is also turned to zero at Earth switch opening at 0.42 sec. (E-point)

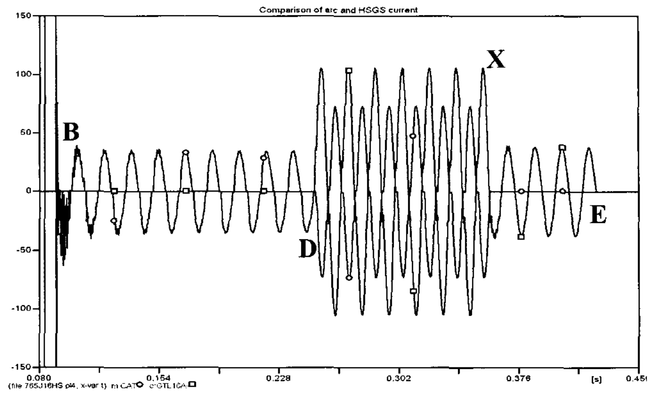


O: arc fault current / □: HSGS current

Fig. 13. Enlarged current waveform at 64km fault point in the case of HSGS on one side with the current flowing on closed HSGS [JMARTI]

Reversely, the current waveform at the 16km location from Sin-Ansung S/S is much similar to Fig. 11, which is simulated at the 64km location from Sin-Ansung S/S in the case of the frequency independent line model. The secondary arc current is finally extinguished at 0.35 sec. (X-point) before HSGS open. And induction current flows until 0.42 sec. (E-point), which is eliminated by the opening of the Earth switch.

Based on Fig. 13 and Fig. 14, the secondary arc is not re-ignited at two fault points in the case of the frequency dependent line model.



O: arc fault current / □: HSGS current

Fig. 14. Enlarged current waveform at 16km fault point in the case of HSGS on one side with the current flowing on closed HSGS [JMARTI]

4.3 HSGS on Both Sides

Fig. 15 shows the perfect forced-extinction of the secondary arc as soon as HSGS are closed on both sides of the single line in the case of the K.C.LEE model (D-point ≈ X-point). The peak value of the secondary arc is about 45A. As for the JMARTI setup case, the shape of waveforms and the extinction time of the secondary arc are identical except that the peak value is about 35A.

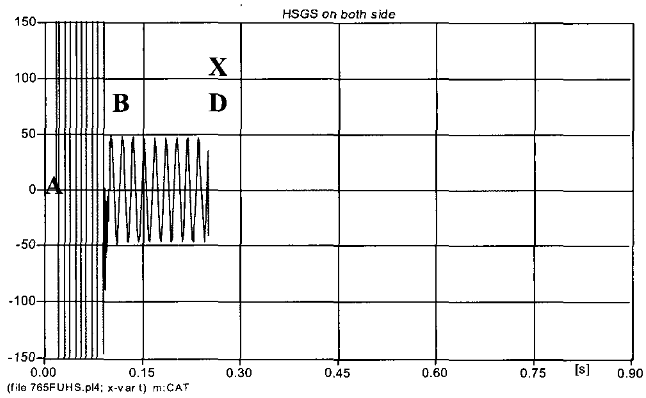


Fig. 15. Enlarged current waveform at 64km fault point in the case of installing HSGS on both sides

5. Conclusions and Discussions

Arc simulation results indicate that the highest value of the secondary arc is $30A_{rms}$ and the auto-extinction time is longer into 0.8 sec. at the closer fault point of the Sin-Gapyeong S/S.

For the adaptation of HSGS, it is conclusively stated that

ONCE there is no need of HSGS in the Korean 765kV single transmission line (79km) between Sin-Ansung S/S and Sin-Gapyeong S/S, which will be installed at June 2006 in Korea. Generally, the frequency dependent line model is more accurate than the frequency independent line model in the area of switching analysis.

From the viewpoint of engineering and practical use, there can be no considerable problem in the case of no adaptation of HSGS, because the line is short and the extinction time is not more than 1 sec. In America, there is also no installation of HSGS on not more than 80km lines of 500kV, which may have the auto-extinction of the secondary arc.

But through our simulation studies, only one HSGS on either side of the transmission line is not recommended for any other cases including longer UHV lines on account of some damages to HSGS by circulated induction current depending on various factors such as a fault location, line length, HSGS duty cycles, etc.

From the reliability and safety point of view, a pair of HSGS should be installed on both sides of transmission lines despite some financial loss in principle. Even if one HSGS is installed on either side, HSGS should withstand a post-fault current and duty time of HSGS should be re-arranged.

For the future works of UHV business such as a plan for longer 765kV lines, it should be taken into consideration to implement arc faults on 765kV field lines for study of dynamic field characteristics.

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