The Investigation for adaptation of High Speed Grounding Switches on the Korean 765kV Single Transmission Line

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Abstract—This paper analyze 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 at June 2006 in Korea.

Especially both frequency independent and frequency dependent line models are compared to make our final decisions. And the significant simulation results are investigated by EMTP program.

As a result, there is no need of HSGS in the Korean 765kV single transmission line in practical and economical point of view.

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

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 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 Korea 765kV transmission lines, high speed grounding switches has already applied to 765kV double transmission lines since the first stage of 765kV business. It is scheduled to energize 765kV single transmission line (79km) between Sin-Ansung S/S and Sin-Gapyeong S/S at June 2006[1-3].

Therefore this paper analyzes characteristics of the secondary arc extinction on 765kV single transmission line using EMTP program. Also both frequency independent and frequency dependent line models using 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.

II. Overview of Korean UHV Transmission Lines

A. Korean 765kV Power Systems

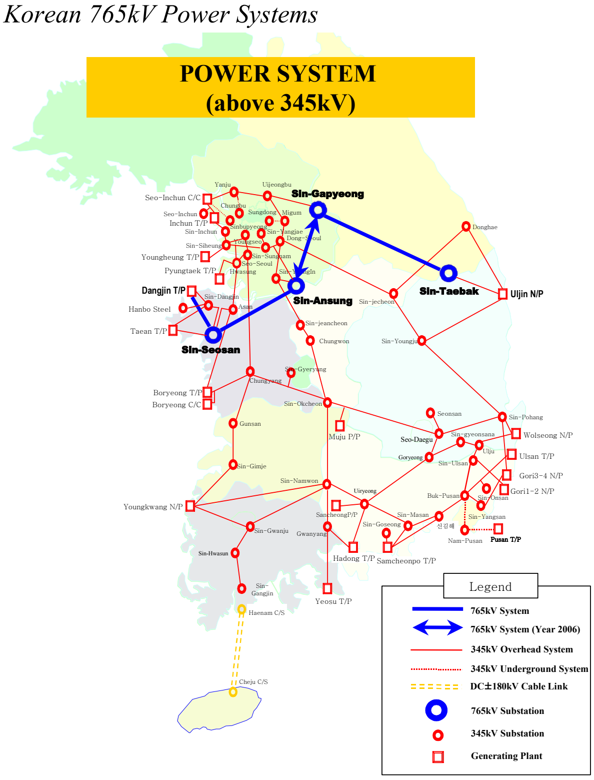

Fig. 1. Korean Power System Lines

From 1991, the necessity of UHV transmission lines was brought up because the increasing rate of the peak demand is more than 10% per annual. So KEPCO has launched the 765kV Project team since 1992. For this 765kV project,

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KEPCO and KEPRI (Korea Electric Power Research Institute) have researched various field of 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 765kV system operation with completion of 765kV Sin-Ansung, Sin-Seosan substations. Thus 765kV power system has played an 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 region and becoming the backbone of the transmission system.

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

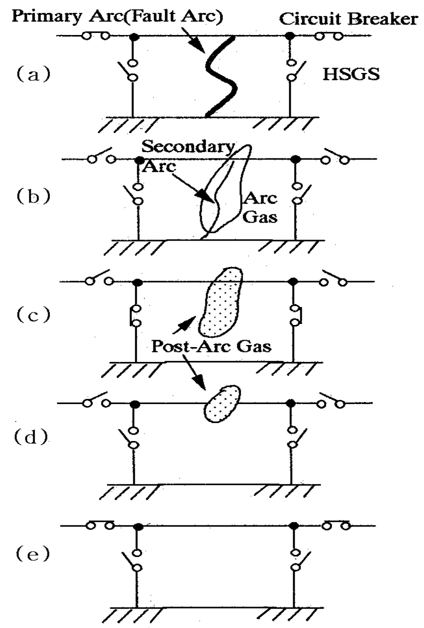
TABLE I
DETAILED INFORMATION OF KOREAN 765KV POWER SYSTEM

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

B. High Speed Grounding Switches (HSGS)

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. 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. 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.



(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. 2. Operating Sequence of HSGS

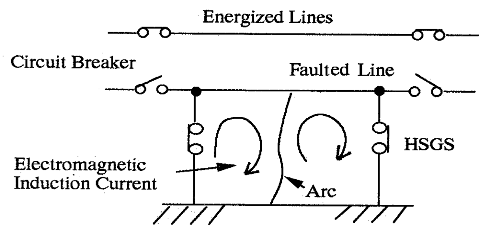


Fig. 3. Electromagnetic Induction Current

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

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

III. ARC SIMULATION STUDIES

A. 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 is no field measurement of arc phenomena to set up dynamic parameters until now. Thus linearized modeling technique is used for our study as follows.

Fig. 4 shows the total diagram for simulating arcing faults. When fault occurs, Johns and Aggarwal's primary arc model[4] 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 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 reignition 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 reignition of arcs can occur so long as the arc energy voltage at fault point is larger than the reignition voltage of power system. So, MODEL logic(AND-gate) is applied to the simulation for satisfying two conditions of the arc extinction.

This paper implements not only a dynamic conducting characteristic but also the reignition voltage characteristic which have the variation of the arc length using MODELS routine within EMTP data card. Namely, each mathematical model is programmed by 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 model system.

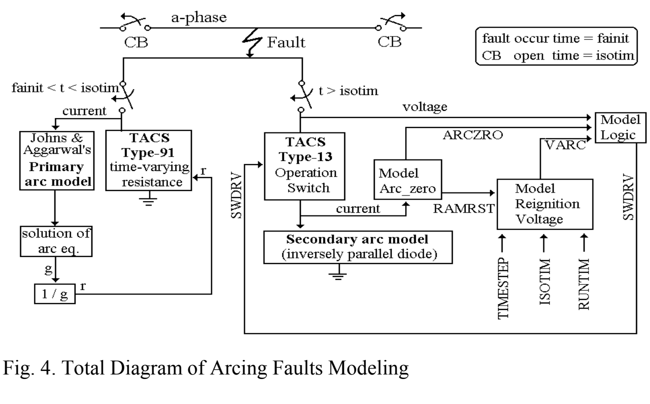


Fig. 4. Total Diagram of Arcing Faults Modeling

B. 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 at June 2006 in Korea as depicted in Fig. 1.

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 source on both sides of a single transmission line.

The simulation assumes a-phase to ground fault at four point, which located on 16, 32, 48, 64km from Sin-Ansung S/S. Fault inception occurs after 1 cycle (0.01667 sec., A-point) from simulation starting. 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). 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 point and study transient phenomena, simulations are proceeded without HSGS.

C. Arc Simulation Results

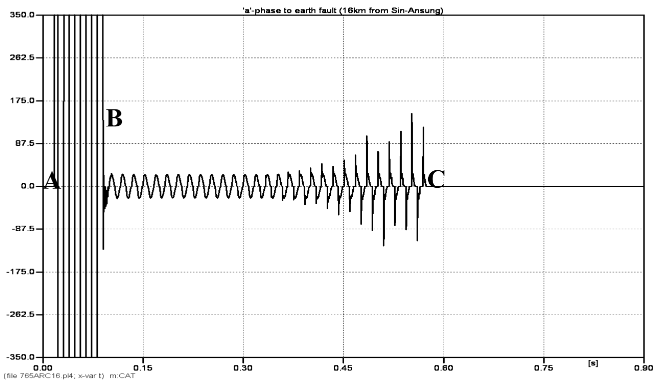


Fig. 5. Enlarged current waveform at 16km fault point

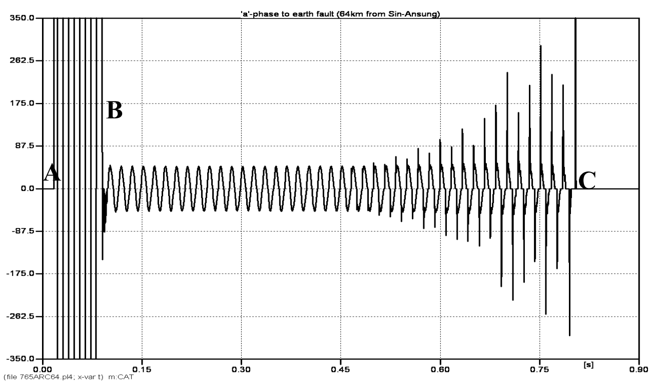


Fig. 6. Enlarged current waveform at 64km fault point

Fig. 5 shows a current waveform at fault point in the case of 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 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 64km fault point is depicted in Fig. 6, which is plotted by the same scale of X-Y axes.

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

TABLE II
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 Fig. 7, 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.

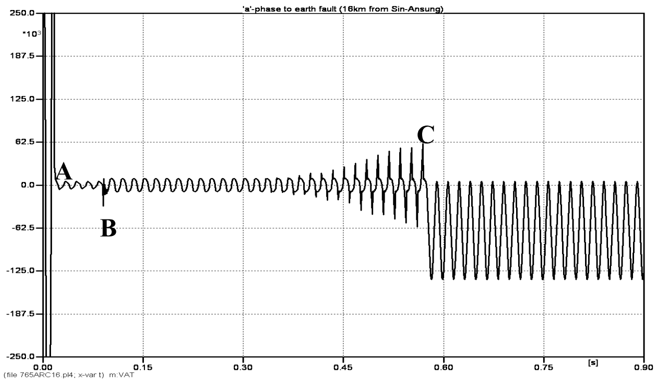


Fig. 7. Voltage waveform at 16km fault point

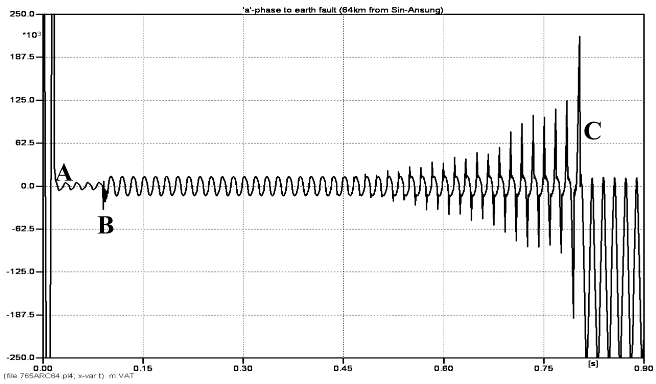


Fig. 8. Voltage waveform at 64km fault point

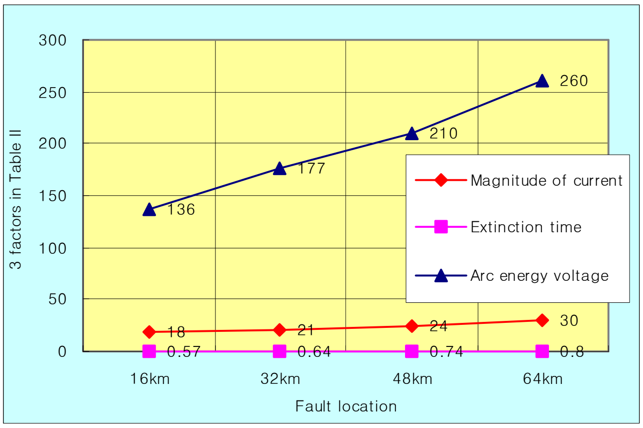


Fig. 9. Relation between fault location and 3 factors in Table II

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 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 II and Fig. 9.

IV. HSGS SIMULATION STUDIES

A. HSGS of Frequency-independent line model (K.C.LEE)

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

Thus new simulation cases are implemented, which have only one HSGS on Sin-Gapyeong S/S. Total simulation timing is the same as stated in III-B section except 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)

From these cases, important simulation results are reported. Fig. 10 shows that the secondary arc is reignited 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 II-B. 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. Anyway 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 Earth switch.

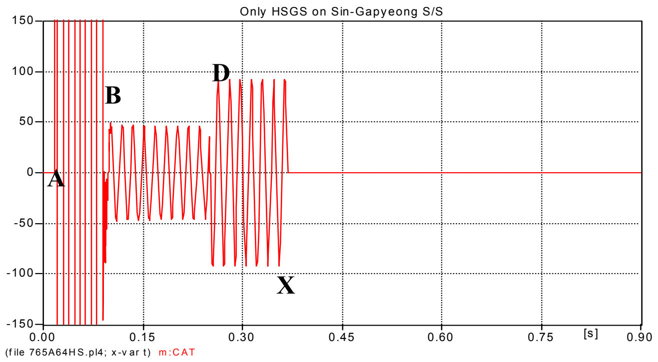
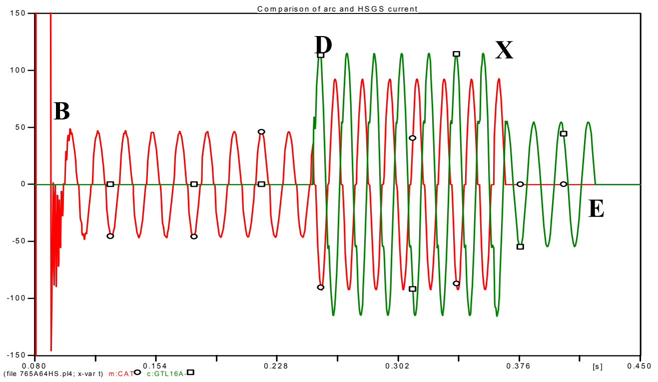


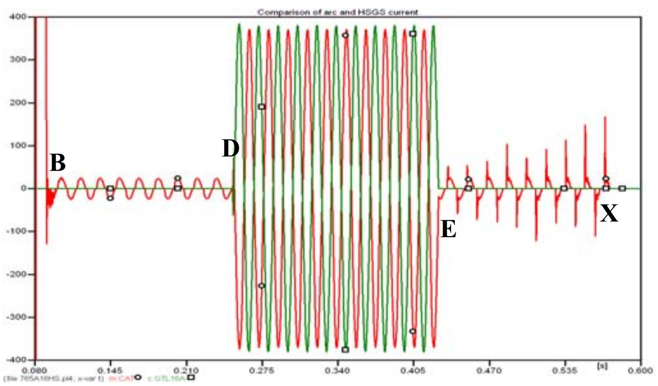
Fig. 10. Enlarged current waveform at 64km fault point in the case of HSGS on one side (Sin-Gapyeong S/S) of a single line [K.C.LEE]



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]

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



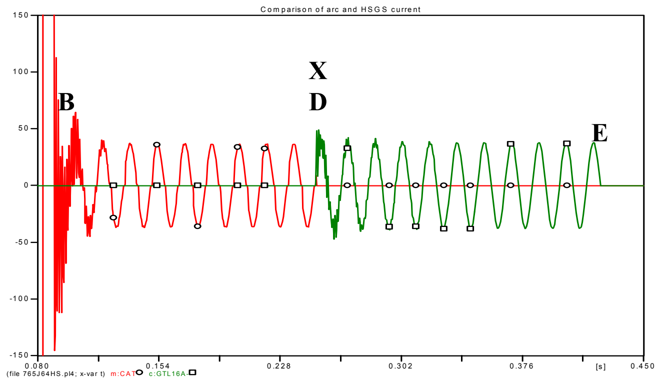
O : arc fault current / ▯ : HSGS current

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]

B. HSGS of Frequency-dependent line model (JMARTI)

Simulation conditions are the same as those of section A. In this paper bandwidth of first frequency card for JMARTI setup is 1,000Hz for switching and surge analysis. Fig. 13 gives a new phenomenon for current waveform at 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 of it earth current flows to ground as much as the same of the peak of arc current. Then this current also is turned to zero at Earth switch opening at 0.42 sec. (E-point)

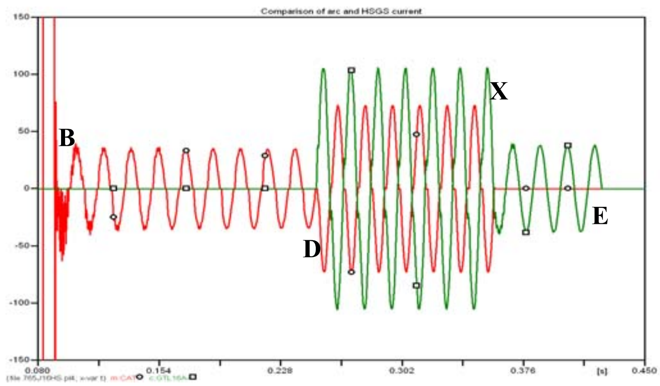


O : arc fault current / ▯ : HSGS current

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 16km location from Sin-Ansung S/S. is much similar to Fig. 11, which simulated at 64km location from Sin-Ansung S/S in the case of 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 Earth switch.

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

C. HSGS on both sides

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

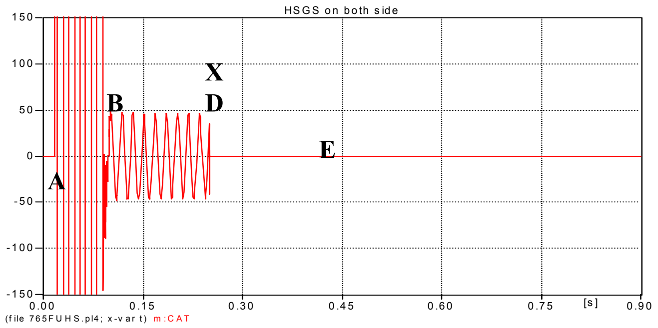


Fig. 15. Enlarged current waveform at 64km fault point in the case of installing HSGS on both sides

V. Conclusions and Discussions

Arc simulation results shows that the highest value of the secondary arc is $30A_{rms}$ and the auto-extinction time of it is longer to 0.8 sec. at closer fault point to 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. Because generally frequency dependent line model is more accurate than frequency independent line model in the area of switching analysis.

In the point view 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 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 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.

In the reliability and safety point of view, a pair of HSGS should be installed on both sides of transmission lines in spite of some financial loss in principle. Even if one HSGS is installed on the 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 of longer 765kV lines, actually it should be taken into consideration to implement arc faults on 765kV field lines for study of dynamic field characteristics.

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VII. Biographies

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Chul-Hwan Kim (SM’2004) was born in Korea on January 10, 1961. In 1990 he joined Cheju National University, Cheju, Korea, as a Full-time Lecturer. He has been a visiting academic in university of BATH, UK, in 1996, 1998 and 1999. Since March 1992, he has been a Professor in School of Electrical and Computer Engineering, Sungkyunkwan University, Korea. His research interests include power system protection, artificial intelligence application to protection and control, the modelling/protection of underground cable and the EMTP software. He received B.S and M.S degrees in Electrical Engineering from Sungkyunkwan University, Korea, 1982 and 1984, respectively. He received a Ph.D in Electrical Engineering from Sungkyunkwan University in 1990.

Hyung-Jun Ju was born in Korea on February 20, 1972. He received his B.S degree in Electrical Engineering from Chungnam national University, Korea. He is currently pursuing his M.S./Ph.D. degree at Chungnam national University. He is working in the Transmission and Substation Group at the Korea Electric Power Research Institute (KEPRI).

Eung-Bo Shim was received his B.S. degree of Electrical Engineering from Hanyang University, Korea in 1982. He has been worked for Korea Electric Power Research Institute (KEPRI) and he is in charge of the Transmission and Substation Group. His research interests include the analysis of overvoltage characteristics of power system.