Analyzing TRV of CB When Installing Current Limit Reactors in UHV Power Systems

H.S.Park, J.W.Woo, J.W.Kang, K.S.Han, S.O.Han

Abstract-- Due to the high-capacity and complexity in power systems, an increase of high transmission capacity lowers the system impedance of the power system. Generally, according to the lower equivalent impedance of the system, system stability will be improved, but fault current also increases.

Regarding high-fault currents, KEPCO (Korea Electric Power Corperation) plans to use CLR (Current Limit Reactors) on UHV transmission lines or the bus in substations to limit the magnitude of fault currents. CLRs make a significant contribution to reduce the severity of the TRV (Transient Recovery Voltage) experienced by the feeder and bus circuit breakers when clearing feeder faults. Based on the conclusions of investigating actual circuit breaker failures while performing this duty, the mitigation of the TRV associated with the reactors is described.

This study describes the underlying principles of current breaking, insulation recovery, the occurrence of TRV and its analysis methods (2-parameter and 4-parameter methods) with regard to the rise in fault currents and TRV using EMTP [5][9]. Through the analysis of real fault cases, measurements which can be readily implemented in the field are closely studied and suggested. Also this paper describes two models ; one is Short Line Fault (SLF), the other is Bus Terminal Fault (BTF) [5][6]. The TRV of bus circuit breakers are in three positions in the 345kV substation when a three-phase short circuit fault occurs. The other case shows the TRV of two bus circuit breakers in four positions when a three-phase short circuit fault occurs and in two positions when a one-phase line-ground fault occurs.

Keywords: CLR (Current Limit Reactor), EMTP (Electro Magnetic Transient Program), TRV (Transient Recovery Voltage), SLF (Short Line Fault), BTF (Bus Terminal Fault)

I. Introduction

Transient recovery voltage (TRV) is the actual voltage appearing across the terminals of a breaker pole upon opening and usually refers to the first pole to interrupt current. For TRV studies, the two most important factors are: the maximum voltage attained depending on normal system operating voltage and the rate of rise of recovery voltage (RRRV) during oscillation - which is also dependent on the frequency of oscillations. Information about TRV that a circuit breaker (CB) is expected to encounter in service is of great important in the design and operation of the circuit breaker. A high TRV level can occur on the circuit breakers due to several causes such as fault clearing, unloaded line interruption, load current interruption, out-of-phase interruption [6].

Generally, when installing the Current Limit Reactor (hereinafter CLR) in power systems, there is a benefit of lowering the peak value of TRV, however the value of RRRV rises. In this case, the circuit breaker in a power system is over the rating, and it could not be broken the fault current.

Therefore, we simulate TRV phenomenon when installing CLR, so we must make a counter plan, in case it's needed, which can reduce TRV.

In this paper, we simulated TRV phenomenon in 345kV transmission lines at installed CLR. For this simulation we compressed the neighboring system by using PSS/E (Power System Simulation Engineering), and used EMTP (Electro Magnetic Transient Program).

TRV value can be changed by various factors. Especially, breakdown positions, failure types and line constants are important parameters that decide RRRV values and V_p value (Vp: voltage peak values). In this simulation, among various failure types, we assumed one and three phase grounding, and breakdown position set up SLF (Short Line Fault) [5][6][8].

II. Preparation of the Simulation

A. Comprehension of SLF (Short Line Fault)

If a fault occurs in relative short distance (2~3 km) from a circuit breaker, fault current interception electric potential round trip shock occurs between breaker and fault point. As explain in the next diagram, it produces sharply rising TRV. Figure 1(a) shows a SLF circuit. Circuit of power supply side is expressed by a one circuit constant that has single frequency, and it is also expressed by a distributed constant circuit that has a no-loss line.

The frequency of short circuit current is equal with electric power frequency and therefore, the effect of electrostatic capacity can be ignored and voltage distribution of the line is linear, see Figure 1(b). When this voltage distribution is not influenced by power side voltage after electric current interception, transient voltage shock ranges distribute

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following the diagram's dotted line. When is not influenced by power side voltage, voltage reflection coefficient is 1 at breaker interception last visual point, and breakdown visual point is 1. In Figure 1(b), voltage shock at point A and point B is recorded in Figure 1(c) and voltage that is energized between contact maker is expressed in figure 1(d). This is showing the SLF interception special quality when high dv/dt was energized at circuit breaker after breaking current interception [8].

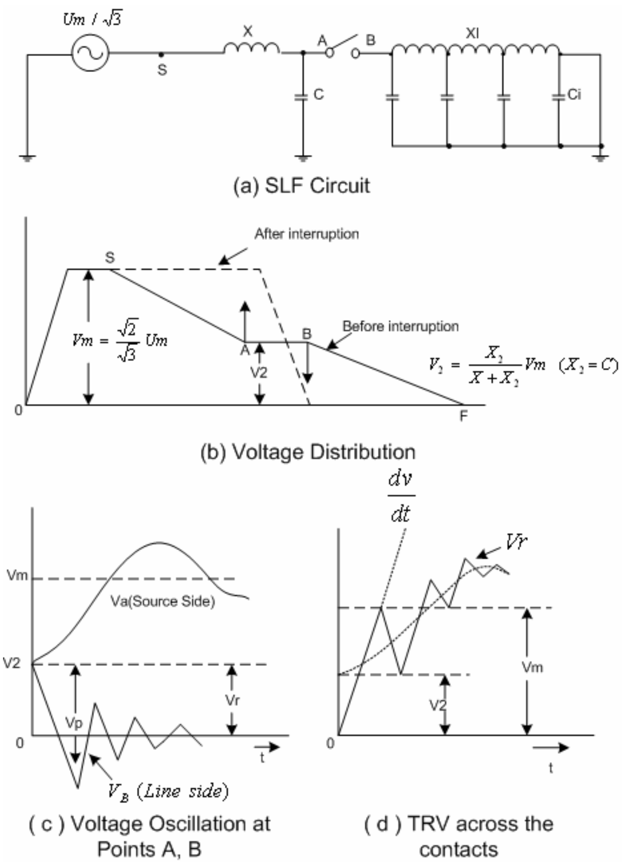


Fig. 1 - Comprehension of SLF

B. Calculation of SLF permissible level by IEC 62271-100 standard (L9, L75)

TABLE 1 - SLF TEST PERMISSIBLE LEVEL BY IEC 362KV

Classification			SLF L75	SLF L90
Fault current(breaking current)			30kA	36kA
TRV	Power side	Early wave height value	296kV	296kV
		Early wave height time	148	148
		Early rate of rising	2.0kV/	2.0kV/
		Wave height value	414kV	414kV
		Wave height time	444	444
	Line side	Early wave height value (U)	140.4kV	55.5kV
		Early wave height time(T)	16.41	5.5
		Early rate of rising	8.5kV/	10kV/
Line distance(fault position)			2460m	825m

C. Review of SLF

Firstly, in order to calculate transient recovery voltage, special qualities of the target system should be thoroughly examined. And it can calculate economical modeling range according to purpose of simulation. Therefore, established standards, quantity and position of current limiting reactors are set up according to Figure 2. Figure 2 displays a busbar of breaker surrounding that becomes compressed for EMTP simulation. We simulated the TRV of each line and power centering around two breaker poles (positive and negative) and considered Grading Capacitor (2000 pF) between two poles of 362 kV breakers, and conducted the simulation by inserting two granding capacitors as considering 1.5 interception method.

Figure 2's arrows mark the point at which SLF is assumed to occur.

TABLE 2 - STANDARD AND ESTABLISHMENT POSITION OF PLACED CLR

Position	Standard	Quantity
T/L	345kV 2200A 0.005PU (5.95Ω)	2set

※ 345kV system basis impedance(100MVA base) : 1190.25[Ω]

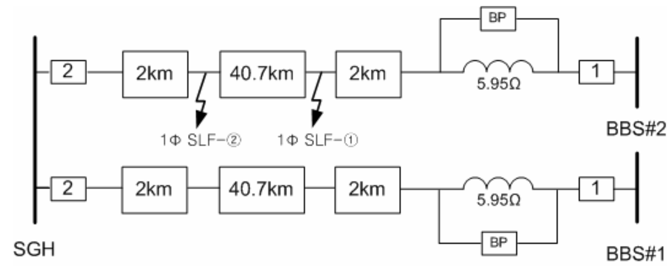


Fig. 2 - Simulation Condition on T/L

D. Compression of neighboring system

During foreign studies, in TRV calculation data for 400kV systems in Britain, it is known if system is simulated within radius 100km from breakdown substation to two sectors, the simulation result is satisfied. Also, in Japan, TRV data analyzed from substation breakdowns in two sectors for 500 kV and 275 kV systems was announced.

When considering these results, it seems that substations may get correct results even if simulate neighboring system (below 3-4 sectors from target substation) at TRV analysis.

Therefore, in this paper, neighboring substations is simulated detailed, we executed equivalence compression by impedance compression method using PSS/E data because rear system does not affect entirely to TRV.

Next, Figure 3 is a system compression diagram that represents a 345 kV system that we will examine doing equivalence using PSS/E.

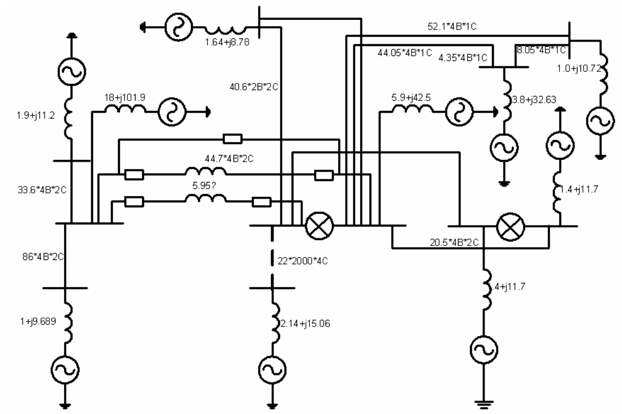


Fig. 3 - Neighbor system compression diagram

E. *Result of SLF*

We simulated TRV considering a Grading Capacitor (2200 pF) and 1.5 interception methods but it is hardly affected. We achieved satisfied results below TRV standards at SLF on the number 2 circuit breaker of the SGH substation marking in Figure 2.

TABLE 3 RRRV ON T/L BETWEEN BOTH SIDES SUBSTATION AT SLF

Year 2006		
CB position	#1 T/L	#2 T/L
Breaking current	14.133 kA	11.583
RRRV	10.805 kV/us	6.578kV/us
Year 2010		
CB position	#1 T/L	#2 T/L
Breaking current	12.158 kA	10.222kA
RRRV	9.264 kV/us	7.792kV/us
Year 2017		
CB position	#1 T/L	#2 T/L
Breaking current	11.256 kA	10.001kA
RRRV	8.569 kV/us	7.7324kV/us

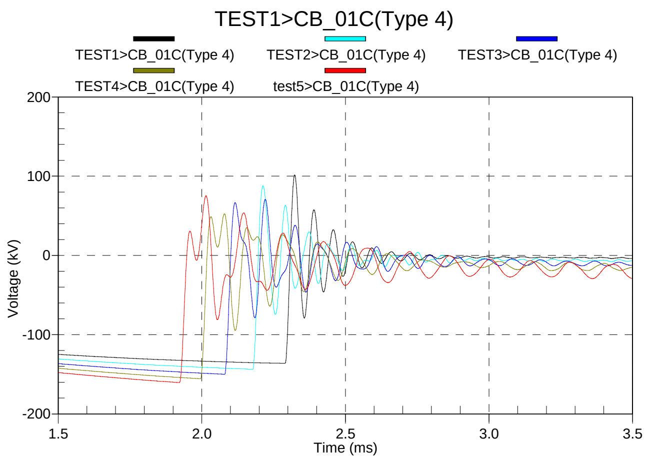


Fig. 4 RRRV waveform by distance at SLF

However, RRRV could exceed IEC standards at SLF in BBS substations. Therefore, we examined the interrelation of fault currents, RRRV values and distances at SLF according to the distance between both sides of 345 kV T/L substations. The results are as follows.

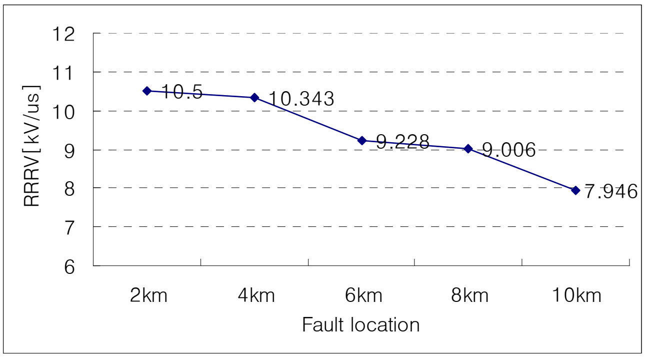


Fig. 5 - RRRV value by distance at SLF

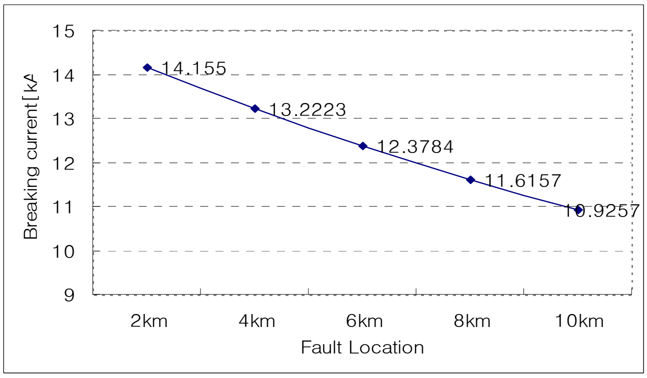
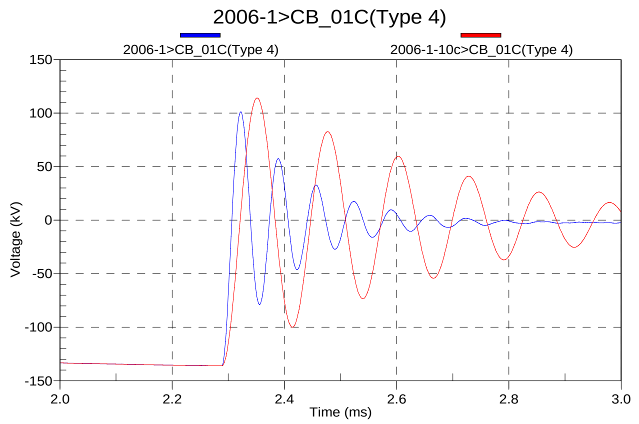


Fig. 6 - Breaking current by distance at SLF

III. TECHNICAL COUNTERMEASURE

A. *RRRV of Line Side exceeds IEC standard at SLF*

To solve this problem, extra capacitors should be established in parallel except grading capacitor 2000 pF of 362 kV circuit breakers.



Comparison - Before and After Installing 20000pF capacitor in circuit breaker on both sides of 345kV T/L	
Before RRRV	After RRRV
10.805kV/us	**5.206kV/us**

Fig. 7 - Waveform comparison before and after installation grading capacitor 2000pF

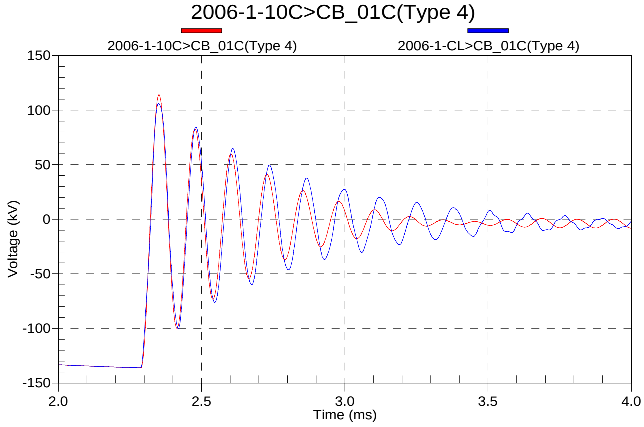


Fig. 8 - Waveform comparison at breaker/series reactor and 20000 pF capacitor parallel establishments

In case of establishing capacitor 20000 pF for RRRV compensation by parallel in both circuit breaker and series reactor, RRRV has same value.

B. Recommend capacitor size (capacity)

It is reasonable to install capacitors for compensation in parallel series reactors, if capacitors are installed in circuit breakers, they be cause economic problem because they should be installed in both side circuit breakers. Therefore installing a 20nF capacitor in parallel with the series reactor is desirable.

TABLE. 4. RECOMMEND FOR CAPACITOR SIZE

Rating voltage	BIL	Capacity
345kV	1200kV	Above 20000pF

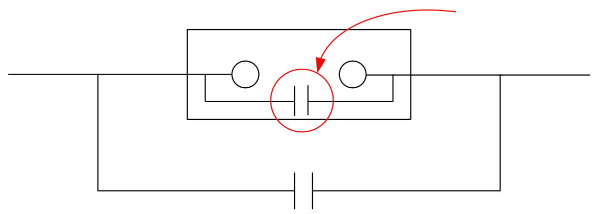


Fig. 9. 20000 pF capacitor parallel establishment with series reactor

IV. CONCLUSION

When occuring one phase SLF, RRRV value exceeded IEC standards, but according to compare IEC standards, breaking current that appear in actuality system and RRRV which is 10kV/㎲ at L90 (breaking current 36 kA). The value that appeared in the actual system is 10.8 kV/㎲ when the breaking current is 14.1kA. In this case, RRRV value is similar, and SF6 extinguishing gas and metal stream of breaker point is less than at 36 kA fault current shut off in 362 kV breaker insides because actual breaking current (14.1kA) is less. Therefore it's reasonable to conclude that a 362kV circuit breaker can shut off fault currents.

TABLE 5 - EXCEED RRRV ON T/L BETWEEN BOTH SIDES OF SUBSTATION

	Classification	SLF L75	SLF L90	Worst case
	Breaking current	30kA	**36kA**	**14.1kA**
T	Early wave height value (U)	140.4kV	55.5kV	-
R	Early wave height time (T)	16.41	5.5	-
V	Early rate of rising	8.5kV/	**10kV/u**	**10.8kV/u**
	Line distance (fault position)	2460m	825m	

Finally, in order to reduce RRRV values of 362kV circuit breakers, we conclude that extra capacitors must be established (except Grading Capacitor 20000 pF) parallel with breakers or series reactors.

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