ANALYSIS AND REDUCTION OF TRV EFFECT ON CIRCUIT BREAKER IN A REAL POWER SYSTEM WITH TCSC

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Abstract - Athyristor-controlled series capacitor(TCSC) increases the power transmission capacity of a transmission line by adjusting the total transmission line impedance, however this change will affect the line circuit breaker(LCB) transient recovery voltage(TRV).In this paper, we analyze the TRV effect of LCB in the cases with and without TCSC via simulation and suggest a method to overcome the increase of TRV due to the TCSC installation. To reduce the TRV of the LCB, a thyristor bypass strategy was implemented for the TCSC. With this strategy, the TRV in the case with the TCSC was similar to the one in the case without the TCSC in the same transmission line. This means that the TCSC with the proposed strategy will not have a significant effect on the TRV of the LCB. So, the conventional LCB can continuously be used in the transmission line employed with the TCSC.

Keywords - Transient recovery voltage, TCSC, Thyristor bypass.

I. INTRODUCTION

A thyristor-controlled series capacitor (TCSC) is an effective device that adjusts impedance through thyristorcontrol to increase power transfer capability in a transmission line [1], [2].Before installation of TCSCs, it is necessary to study the effect of the TCSC on a conventional power system. One of these studies is transient recovery voltage (TRV) of a line circuit breaker (LCB) according to the series capacitor compensation of the transmission line when a fault occurs. TRV means the voltage across circuit breaker contacts immediately after current interruption. In TCSC system, an increase of TRV is caused by the trapped charge that can remain in series capacitor at the moment of line current interruption; the associated voltage adds to the TRV that occur without series capacitor. The important factors of TRV study are the amplitude of TRV and the rate of rise of recovery voltage (RRRV).The circuit breaker must withstand both the amplitude and rate of rise of TRV for successful current interruption[3]-[7]. The International Electronical Committee (IEC) presented the IEC standard 62271-100 for TRV tolerance according to circuit breaker capacity[8].

This paper deals with the reduction of TRV through the thyristor valve bypass operation when the LCB fault interruption in the transmission line with TCSCs.A 345 kV transmission line in Korea was selected asa study case. Grid system including transmission lines, detailed TCSC models, circuit breakers, and nearby power stations were modelled using PSCAD/EMTDC. The TRV was analyzed by implementing short circuit along the transmission line and at the breaker terminal. A three-phase ground fault was selected according to IEC standard for TRV. The differences of TRV according to the TCSC installation status was compared.

II. TCSC CONFIGURATION AND PROTECTION SCHEME

2.1. Configuration of a practical TCSC

Fig. 1 shows the typical configuration of a single phase of a TCSC. The TCSC consists of the main part for compensating the impedance of a transmission line and the protection part for protecting the TCSC from disturbance and fault.

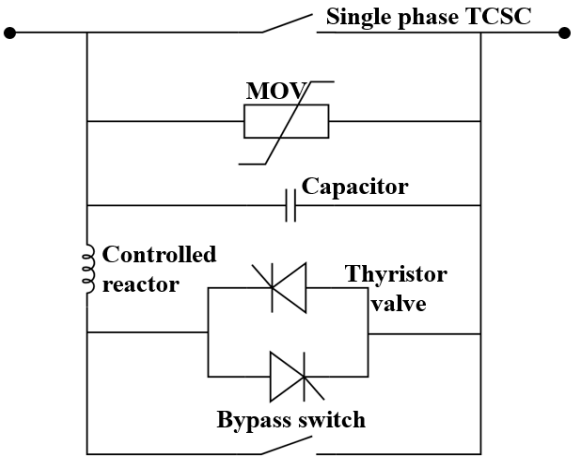


Fig. 1. The basic structure of a TCSC

The TCSC main part consists of a parallel structure of a capacitor and a thyristor-controlled reactor (TCR).The TCR functions to control the value of the current flow by adjusting the firing angle (α) of the bidirectional thyristor. TCSC can be operated in an inductive as well as a capacitive mode as per the system requirements. The protection facilities of TCSC consist of a metal oxide varistor (MOV) and a bypass switch. The function of each protection facility is as follows. The MOV performs as a primary protection device for protecting capacitor banks

during the system fault. In the steady state, since the MOV has a high impedance value, the current is conducted to the capacitor and TCR. In the case of a fault, when the MOV voltage is increased due to a fault current exceeding a certain level, its impedance reduces to a small value due to the change of the MOV characteristic. As a result, the fault current is primarily handled. In the steady state, the bypass switch is open. However, the bypass switch will be activated to prevent damage to the thyristor due to overcurrent.

2.2. Protection scheme of the TCSC

If an internal fault occurs in a line containing a TCSC, the protection scheme is as follows. The relay sends a picked-up (trip) signal to the TCSC protection facility with a delay of several milliseconds. The thyristor with the fastest response speed then switches to bypass mode at the point where the TCSC compensation is least affected. After that, the bypass switch is operated and the LCB operates after about 3 cycles from the occurrence of the fault. The MOV consumes the fault current by changing the impedance according to the characteristics before bypassing. Fig. 2 and Fig. 3 show the protection scheme and sequence of TCSC protection facilities operation.

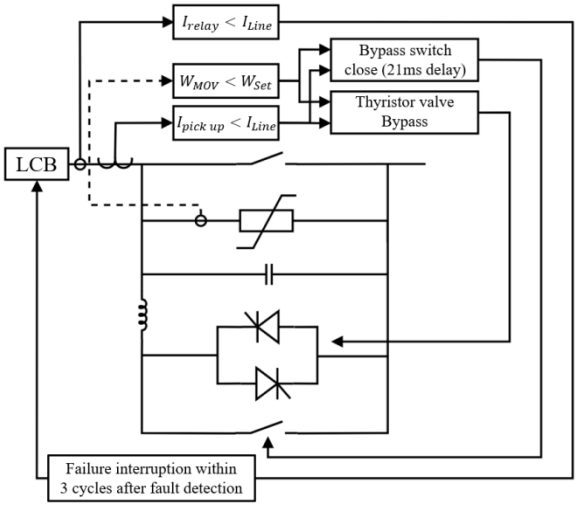


Fig. 2. Protection scheme of a TCSC

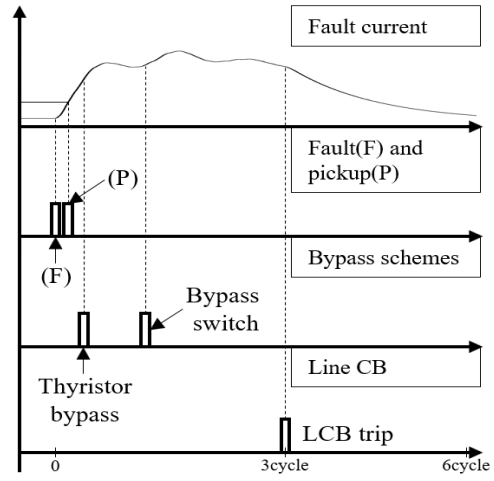


Fig. 3. TCSC protection facilities operation sequence

III. PRACTICAL TCSC AND GRID SYSTEM MODELING FOR TRV ANALYSIS

3.1. Design of a practical TCSC

To verify the effect of TCSC on TRV with real grid system conditions, simulation was carried out using an actual grid system in Korea. Korea Electric Power Corporation(KEPCO) plans to install TCSCs in the ShinYeongju-Hanul and the ShinJecheon-Donghae 345kV transmission lines as a part of the metropolitan power transmission project. For the simulation of TRV, ShinJecheon-Donghae transmission line was selected among the two installation lines.

The process for designing a TCSC is as follows. After confirming the parameters of the transmission line to install the TCSC, 3 factors are selected according to the target compensation rate. Then, the actual capacitor and inductor value are calculated through the selected factors. The parameters of the ShinJecheon–Donghae transmission line are shown in Table 1. The compensation level, the boost factor, and the resonance factor, which are related to the design of the TCSC, are shown in equations (1), (2) and (3), respectively [10], [11].

$$k(\%) = \frac{X_{TCSC}(\alpha)}{X_{Line}} \times 100 \qquad (1)$$

$$\omega_{order} = \frac{X_{TCSC-max}}{X_{TCSC-min}} = \frac{X_{TCSC-max}}{X_c} \qquad (2)$$

$$\lambda = \frac{\omega_0}{\omega} = \frac{1}{\omega\sqrt{LC}} = \sqrt{\frac{X_c}{X_L}} \qquad (3)$$

where, $k(\%)$, ω_{order}, λ are the items described in Table 2. X_L and X_c are the inductive reactance and capacitive reactance of the TCSC, respectively. X_{Line} and X_{TCSC} are the reactance of the compensated line and the total reactance of the TCSC. ω is the power system angular velocity.

The three factors for the TCSC design are based on the installation purposes which are easy control and operation, and economical fabrication. The values used in this study are shown in Table 2.From the equations (1), (2), (3), and the data in Table 2, the TCSC parameters of the ShinJecheon–Donghae transmission line are calculated as shown in Table 3.

Table1: Parameters of ShinJecheon–Donghae transmission line

Item	Symbol	Value	Unit
Resistance	R	0.144	%
Inductance	X_L	2.504	%
Conductance	B_C	60.84	%
Line length	L	97.505	km

Table2: The related data to design of the TCSCs

Item	Symbol	Value
Compensation level	k(%)	50

Boost factor	ω_{order}	1.05
Resonance factor	λ	2.68

Table3: Designed parameters of the TCSCs

Item	Symbol	Value	Unit
Thyristor controlled reactor	L	186.93	mH
Series capacitor	C	5.23	μ F

3.2 TCSC and grid system modeling for TRV analysis

For the accurate modeling of a grid system such as actual transmission line, substation, power plant, etc., the system modeling datain PSS/E program from KEPCO was converted into PSCAD/EMTDC. The system range extends from the transmission line where the TCSC is installed to the 3-step spaced bus. The transmission line was implemented as a Bergeron model.

Fig. 4 shows the reactance value of the TCSC according to firing angle.Since the designed TCSC operates at a 50% compensation rate in the steady state, in order to simplify the TCSC model, the main part including capacitor and TCR was replaced by a fixed series capacitor of 178.03uF, and the thyristor was modeled as a circuit breaker. The mechanical bypass switch is also set to operate with a physical delay after thyristor bypass switch operation. The TCSC model for the TRV analysis including the final determination of L and C values is shown in Fig. 5.

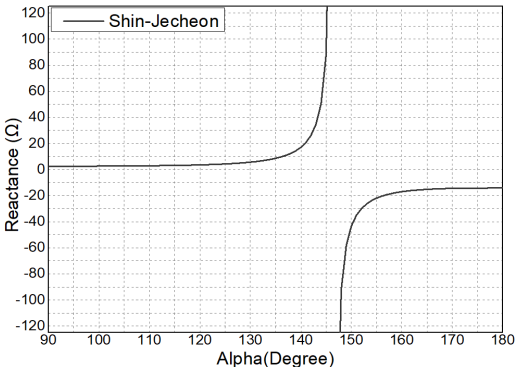


Fig. 4. Reactance of the TCSC with firing angle

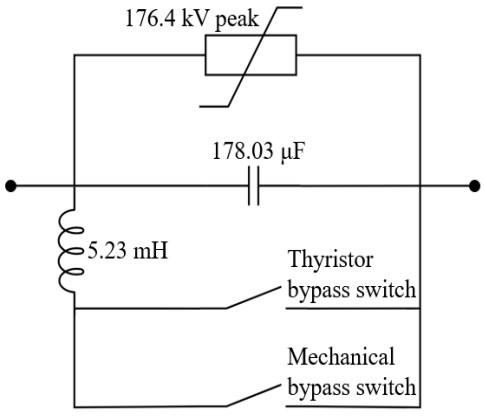


Fig. 5. Equivalent circuit of L and C in the TCSC model

The first swing is the transient current that occurs when the TCSC is started, the MOV should not dissipate energy during the first swing conditions. The design criterion is that there must be a 20 % minimum margin between the capacitor voltage under the first swing conditions and the protective level to ensure that no energy dissipation will occur under swing conditions. The rated current and the first swing current of the line can be used to determine the rated voltage and the protection level of the capacitor. These values are shown in Table 4.

Table4: Design data of the ShinJecheon TCSCs

Parameter	Symbol	Value	Unit
Rated current	I_R	3.64	kA
Rated reactance	X_R	14.9	Ω
Rated voltage	V_R	54.236	kV
First swing current	I_D	4.67	kA

A protective level (voltage-current characteristics) of the MOV is chosen as 2.3 pu (176.4 kV peak) for ShinJecheon TCSCs. This protective level typically ranges between 2.0 and 2.5 pu, based on the voltage drop at the rated bank current. The I-V characteristics of the MOV are shown in Fig. 6[9].

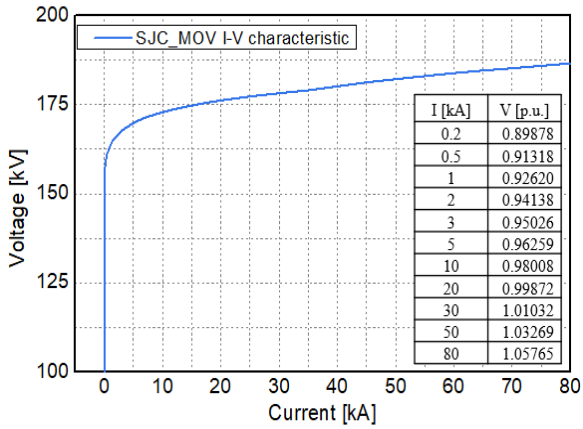


Fig. 6. I-V characteristic of MOV

IV. CASE STUDY AND TRV SIMULATION

4.1. Scenario of the TRV simulation

Transmission line is assumed to be in operation with 100% peak load. As shown in Fig. 7, the fault was simulated on one of the two transmission lines with TCSC installed. The TRV of the LCB generated during the interruption was confirmed.

Only a three-phase to ground fault is considered in the TRV simulations because it is the test standard recommended by IEC and the most serious failure. The fault location is at the TCSC terminal and along the transmission line. In the case of the transmission line, the failure occurred at each point by dividing by 10, as shown in Fig. 7. The moment of inception of the short circuit current has an impact on the TRV. Thirty

six (36) different inception angles are simulated, which means there is a 10 degree gap between the simulation cases. After the fault has occurred, the relay detects the fault if the fault current reaches 7.27 kA. This value is pick-up current, which is 10% higher than the first swing current. After that, protection and fault current interruption are performed according to the protection operation mentioned in section 2.2.

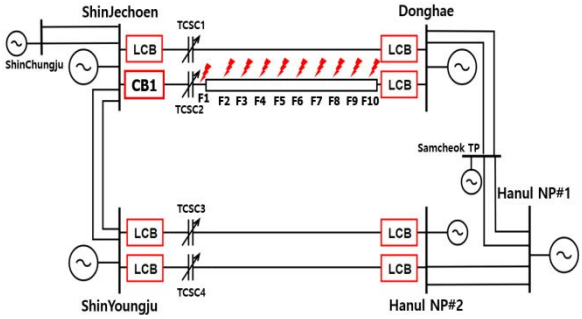


Fig. 7. A simplified single line diagram of the power system network with fault location

4.2. Simulation results

The TRV of the transmission line with the TCSC was compared with the TRV in the case without the TCSC. It has been confirmed that it satisfies the IEC standard. The reference voltage of the ShinJecheon-Donghae transmission line is 345kV and the installed LCB has a voltage capacity of 362kV. The TRV envelope for the 362kV circuit breaker is shown in Table 5.The standard values in Table 5 indicate the criteria for terminal faults. In the standard values such as T10, the number is the breaker rated current – fault current ratio. The LCB rated current is 63kA. For successful interruption, the TRV according to the fault current must be smaller than the envelope. Table 6 shows the fault currents in the CB1 of Fig. 7 according to the fault location.

Table5: TRV envelope of the 363kV circuit breaker

Standard	u1 [kV]	TRV [kV]	t1 [us]	t2 [us]
T10		678		97
T30		592		117
T60	288	576	96	576
T100	288	538	144	576

Table6: Fault current value measured in CB1 according to fault location

Location	F1	F2	F3	F4	F5
Fault current (RMS)[kA]	44	32	27	22	19
Location	F6	F7	F8	F9	F10
Fault current (RMS)[kA]	17	15	13.5	12	10.5

It can be seen that the current measured in the LCB decreases with increasing line impedance as the distance from the LCB to the fault point increases. Fig. 8 shows the TRV simulation results for the TCSC terminal fault which causes the highest fault current. The result of TCSC installed is indicated by bold line, and without TCSC by thin line. As can be seen in Fig. 8, the patterns of TRV were very similar. The TRV values at the maximum point were 459 kV and 431 kV, respectively, and the TCSC installed case shows 28 kV higher. However, the proposed TRV reduction strategy is well activated and satisfies the IEC recommendation criteria.

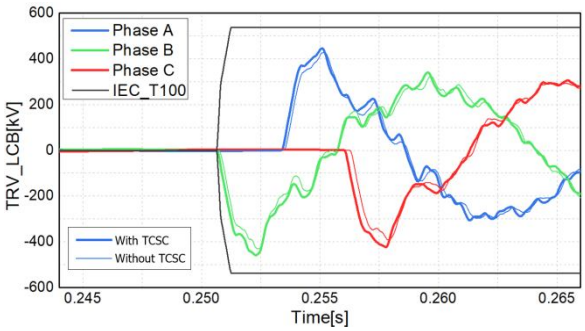


Fig. 8. TRV waveform according to TCSC installed or not

The TRV analysis results for the entire transmission line section are shown in Fig. 9. Overall, TRV was mostly distributed below about 620 kV in both cases, and in some cases more TRV occurred. Although there is a difference in the frequency of occurrence, there is a similar level of TRV in the absence of TCSC. The maximum values were 729 kV for TCSC and 708 kV for No TCSC, respectively. This is within an acceptable range with a difference of about 3%.

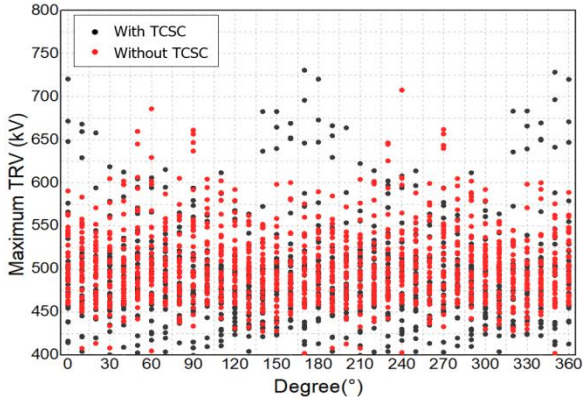


Fig. 9. TRV results of entire simulation case

CONCLUSIONS

In this paper, we analyzed the change of TRV in the LCB when a fault occurredon a transmission line with TCSC installed. In order to reduce the TRV in the transmission line with TCSC, a thyristor bypass strategy was proposed. Simulation results show that the proposed method satisfies the IEC standard and

have similar results to the case without TCSC. This result means that using the proposed thyristor bypass strategy can reduce the increased TRV caused TCSC, and thus the problem with TRV can be solved when installing TCSC.

REFERENCES

[1] S. Jamhoria, and L. Srivastava, "Applications of Thyristor Controlled Series Compensator in Power System: An Overview" Power Signals Control and Computations (EPSCICON), 2014 International Conference on. IEEE, pp. 1-6, January 2014

[2] N.G Hingorani, and L. Gyugyi, "Understanding FACTS: concepts and technology of Flexible AC transmission Systems", IEEE press, 2001 Edition Standard publishers distributors.

[3] A.Parvizi, M.Rostami, and A. M.Ghadiri. (2008, December). "Sensitivity analysis of TRV in TCSC compensated transmission lines during fault clearing by line CB". 2008 Power and Energy Conference, IEEE 2nd International, pp.1345-1349, December 2008.

[4] N. Mohsen, M.Pazoki, and M.Gholamzadeh. "TRV Evaluation in Advanced Series Compensated System." International Journal of Computer Applications 34.7 (2011).

[5] F. Iliceto, E. Cinieri, G. Asan, "TRVs Across Circuit Breakers of Series Compensated Lines: Status with Present Technology and Analysis for the Turkish 420-kV Grid",IEEE Transactions on Power Delivery, Vol. 7, No. 2, April 1992.

[6] M. H.Zakernejad, M.Mohammadi, M.Mehrtash, "A New Approach for Probabilistic Evaluation of Transient Recovery Voltage Across Circuit Breakers in TCSC Compensated Transmission Lines" Power System Conference (PSC), Tehran. 2014.

[7] F. Iliceto, E. Cinieri, G. Asan, "TRVs Across Circuit Breakers of Series Compensated Lines: Status with Present Technology and Analysis for the Turkish 420-kV Grid",IEEE Transactions on Power Delivery, Vol. 7, No. 2, April 1992.

[8] Standard, I. E. C. "62271-100." High-voltage switchgear and controlgear", May 2001.

[9] M. Coursol, C. T. Nguyen, R. Lord, X. Dai Do, "Modeling MOVProtected Series Capacitor for Short-Circuit Studies", IEEE Transactions on Power Delivery, Vol. 8, No. 1, pp. 448-453, January 1993.

[10] M. C. Dinh, S. M. Park, S. K. Kim, M Park, and I. K. Yu, "Suggestion of a novel PHILS method for operation analysis of a thyristror controlled series capacitor.", Power Electronics and Drive Systems, 2015 IEEE 11th International Conference, pp. 715-720, June 2015.

[11] V. K. Yedidi and B. K. Johnson, "Design of a TCSC for classroom and research application on an analog model power system," Power Engineering Society General Meeting, 2006.

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