Journal of Industrial Information Technology and Application Vol.4 No.1

ISSN(Online): 2586-0852

Estimation of Sub-synchronous Resonance Risk in Thermal Power Plants due to the Nearby Installation of TCSC

Minh-Chau Dinh [1)], Minh-Quan Tran [2)], Jae-In Lee[3], Minwon Park [3,*)], Jongsu Yoon [4)]

[1)] Institute of Mechatronics, Changwon National University, Changwon, Korea
[2)] Dept. of Electrical Engineering, Eindhoven University of Technology, Eindhoven, Netherlands
[3)] Dept. of Electrical Engineering, Changwon National University, Changwon, Korea
[4)] Korea Electric Power Research Institute, Daejeon, Korea

Abstract. Korea Electric Power Corporation (KEPCO) is installing Thyristor Controlled Series Capacitors (TCSCs) on 345 kV transmission lines in their system. With the first installation of TCSCs, the operating characteristics of the surrounding power system should be analyzed in advance, especially the subsynchronous resonance (SSR) problem. This paper deals with the SSR analysis in the thermal power plant due to the installation of TCSC in a nearby transmission line. Through the mechanical modeling, we investigated the mechanical properties of the most affected thermal power plants by the TCSCs such as mode shape, natural frequency, and damping time constant, etc., . We used the most direct method for determining the SSR by examining the damping of torsional mode. All analysis was done by using PSCAD/EMTDC and MATLAB programs. The simulation results show that the installation of TCSCs in Korea power network has no risk of SSR in the nearby thermal power plant.

Keywords; Korea power network; thermal power plant; SSR; TCSC

1. Introduction

By compensating the line impedance, thyristor controlled series capacitor (TCSC) opens up new opportunities for power flow control and enhancing the usable capability of the existing transmission lines. Considering the advantages of the TCSCs, the Korea Electric Power Corporation (KEPCO) considered to install the TCSCs on two double-

---

[*] Corresponding author: pakumw1@gmail.com

Received Jan 15, 2020; Received Mar 3, 2020; Accepted Mar 31, 2020

circuits, 345 transmission lines in Korea power network. The proposes of series compensation are to support future load growth and reduce the transmission constraints between east coast power plants and the Seoul metropolitan load center on the west coast. The compensated 345 kV transmission lines can minimize the power generating facilities trip and enhance system dynamic stability following the loss of the primary 675 kV transmission corridor between east coast generation facilities and the Seoul load center [1].

However, many reports showed that sub-synchronous resonance (SSR) is always a concern with series compensation and TCSC is not an exception [2-5]. As reported in [6], the first SSR accident occurred at the Mohave generator in Arizona, USA in 1971 due to the installation of the fixed series capacitor. The SSR caused the large vibration on the generator shaft and led to the shaft fatigue. Therefore, it is necessary to analyze the SSR in detail before installing the TCSCs in the Korea power network.

In this paper, the analysis of SSR for the Korea power network with the first installation of TCSCs was presented. For SSR analysis study, several frequency scanning methods are found in the literature. As reported in [6], they are the simplified analytical method, two-axis analytical method and test signal method. With this study, we used the direct method to analyze the SSR by examining the damping of torsional modes. In this method, the disturbance (base contingency and extreme conditions) was created in the power network with TCSCs installation, and the torques on the generator shafts is evaluated. Through digital filtering, each torsional mode is extracted from the torques and damping time constants of torsional modes at the studied plants are obtained. Together with mechanical damping time constant, we can know whether the SSR happens in the system or not with the various situations. All studies were conducted through the detailed modeling of part of Korea power network with detailed generator model and TCSC with its synchronous voltage reversal (SVR) control in PSCAD/EMTDC program.

The simulation results show that there was no SSR in the nearby thermal power plants due to the first installation of TCSCs in Shin-Youngju and the Shin-Jecheon substations.

2. Modeling of the Korea Power Network with the TCSCs

A. Modeling of the Korea Power Network

In this study, only part of Korea power network was modeled. Portions of the 345kV and 765kV transmission were represented as illustrated in Fig. 1. The PSCAD/EMTDC system models were derived from the original PSS/E simulation provided by KEPCO. After the PSCAD/EMTDC transmission network was in place, the model was enhanced to include the detailed generator models and TCSC models described in the next section.

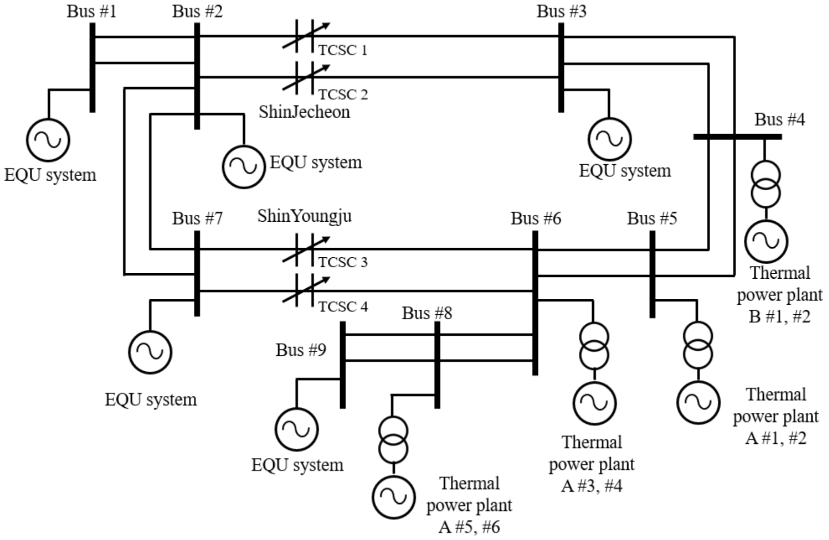


Fig 1. Configuration of 345 kV power network nearby TCSCs installation location

B. Modeling of TCSCs

The compensation level of both Shin-Youngju and Shin-Jecheon TCSCs are 50% for continuous operation, temporary overload and 70% for dynamic overload. The main parameters of Shin-Youngju and Shin-Jecheon TCSCs are summarized in Table 1 [7-9].

The SVR was selected and as the control method for Shin-Youngju and Shin-Jecheon TCSCs [10]. The PSCAD TCSC model with the SVR controller was developed after carefully tuning the control parameters.

TABLE I. PARAMETERS OF SHIN-YONGJU AND SHIN-JECHEON TCSCS

Parameters	**Shin-Youngju TCSC**	**Shin-Jecheon TCSC**
TCR reactor	5.23 mH	5.23 mH
Physical capacitor	198.94 μF	186.93 μF

3. Generator Mechanical Modeling

Due to the installation of Shin-Youngju & Shin-Jecheon TCSCs in the 345 kV transmission lines, Korea power network, the thermal power plant A (No.1 ~ 6) and the thermal power plant B (No.1 ~ 2) will be influenced. Units #3 and #4 of the thermal power plant A were located near the compensated transmission line between bus #6 and bus #7, so these were selected for the evaluation of the SSR risk due to the TCSC installation. The generator to be analyzed will be considered as detailed generator model while voltage sources are used to represent the other generator. Based on the multi-mass shaft system model of a generator, the motion equations of generator rotor and then system state space matrix have been built. Table II summarizes the mechanical data of the thermal power plants unit #3, 4.

TABLE II. THERMAL POWER PLANT A UNITS #3, 4 MECHANICAL DATA

Mass	**Inertial [kg.m2]**	**Shaft**	**Stiffness [106N.m/rad]**
1	13040	1-2	218.51
2	80860	2-3	356.20
3	81700	3-4	638.32
4	82980	4-5	447.23
5	114800	-	-

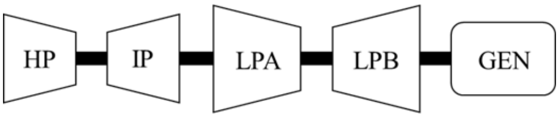


Fig 2. Multi-mass model of the thermal power plant A unit #3, 4

The multi-mass model of the units #3 and #4 is shown in Fig. 2. There are five masses in the model: high pressure (HP), intermediate pressure (IP), two low pressure (LPA, LPB) and generator (GEN) section. The mechanical data of the units #3 and #4 of the turbine generator A were used as the input data for eigenvalue analysis. Based on the system state matrix and power plant mechanical input data, power plant torsional parameters have been achieved. The detailed results of natural frequencies, mode shape, and damping parameters in each mode shape are shown in Table III. The first mode had an oscillation frequency of 8.3 Hz. It had one polarity reversal point in the mode shape between the LPA and LPB masses. This indicated that, when this mode was excited, the oscillation of generator and the LPB masses were against the other three masses. Similarly, the mode 2, 3 and 4 at oscillation frequencies of 14.6 Hz, 22.2 Hz and 23.8 Hz had 2, 3 and 4 polarity reversal points, respectively.

TABLE III. THEMAL POWER PLANT A UNITS #3, 4 TORSIONAL DATA

Parameters		**Value**				
Mode		0	1	2	3	4
Mode natural frequency [Hz]		0	8.34	14.64	22.22	23.87
Mode shape	HP	-1.0	-1.0	1.0	-1.0	-1.0
	IP	-1.0	-0.8361	0.4948	0.1629	0.3318
	LPA	-1.0	-0.2143	-0.7660	0.1556	-0.5320
	LPB	-1.0000	0.2080	-0.6396	-0.2365	0.5056
	GEN	-1.0000	0.7047	0.5453	0.0591	-0.1069
Modal inertia (H) [s]		5.44	3.93	7.29	92.60	86.11
Mechanical damping constant (σ_m) [s^{-1}]		-0.0018	-0.0210	-0.0368	-0.0558	-0.0598

4. SSR Analysis and the Results

The disturbance was created in the power network, and the torques on the generator shafts has been evaluated. Each torsional mode is extracted from the torques via the Fast Fourier Transform (FFT). The torque amplitude of each oscillatory mode will change exponentially over time according to the function:

$$T(t) = T_0.e^{\sigma.t} \qquad (1)$$

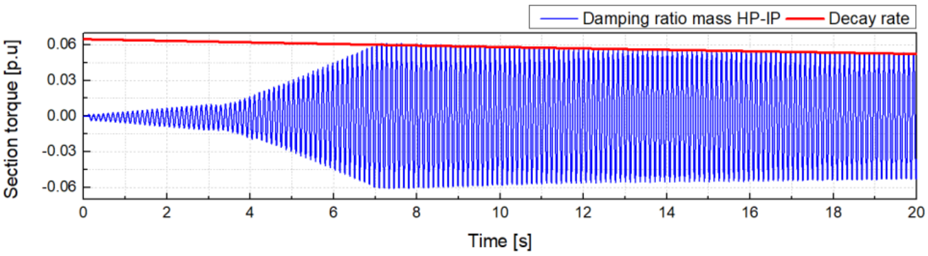
If the value of σ is negative, the oscillatory mode is damped and finally decays away. If σ is positive, then the oscillatory mode will grow exponentially over time. A positive σ means that the TCSCs have undamped, the modeled mechanical damping of the torsional generator shaft and further evaluation is necessary. The following table shows the test cases for the thermal power plant A unit #3 & #4.

TABLE IV. SELECTED SIMULATION SCINARIOS FOR SSR ANALYSIS OF THE THERMAL POWER PLANT A UNIT #3, 4

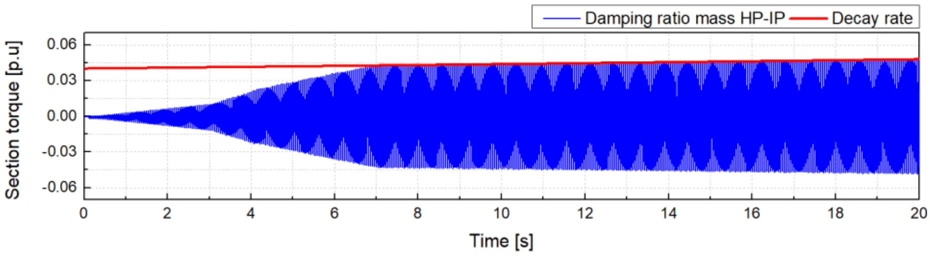
Simulation scenarios	**Bus #6 - Bus #8**		**Bus #5 – Bus #6**	
Cases	Line 1	Line 2	Line 1	Line 2
Case 1: Normal operation	O	O	O	O
Case 2: One line disconnected	O	X	O	X
Case 3: Extreme condition	X	X	X	X

(O = In service; X= Out of service)

In this study, disturbances were provided by applying three-phase short circuits for 5 cycle at the generator terminal. As shown in Fig. 3, the disturbances caused the oscillation in turbine-generator system. However, in case 1 the decay rate or damping time constant (σ) is negative, then the oscillation will damp. In case 3, the decay rate or damping time constant (σ) is positive value, the oscillation will grow exponentially over time.



(a)



(b)

Fig 3. Torque oscillation between section HP-IP for difference test cases: (a) Case 1; (b) Case 3

For each test case, the simulations with different TCSC compensation degree (from 50% to 70%) were conducted. The damping time constant (σ), and damping time constant (σ) plus mechanical damping constant (σ_m) of torsional modes at the thermal power plant A unit #3 and #4 for various simulations is depicted in Fig. 4. As shown in Fig. 4 (a), the damping time constant is positive in some cases. However, the total damping time constant is negative. So there was no risk of the SSR problem in the unit #3 and #4 of the thermal power plant A.

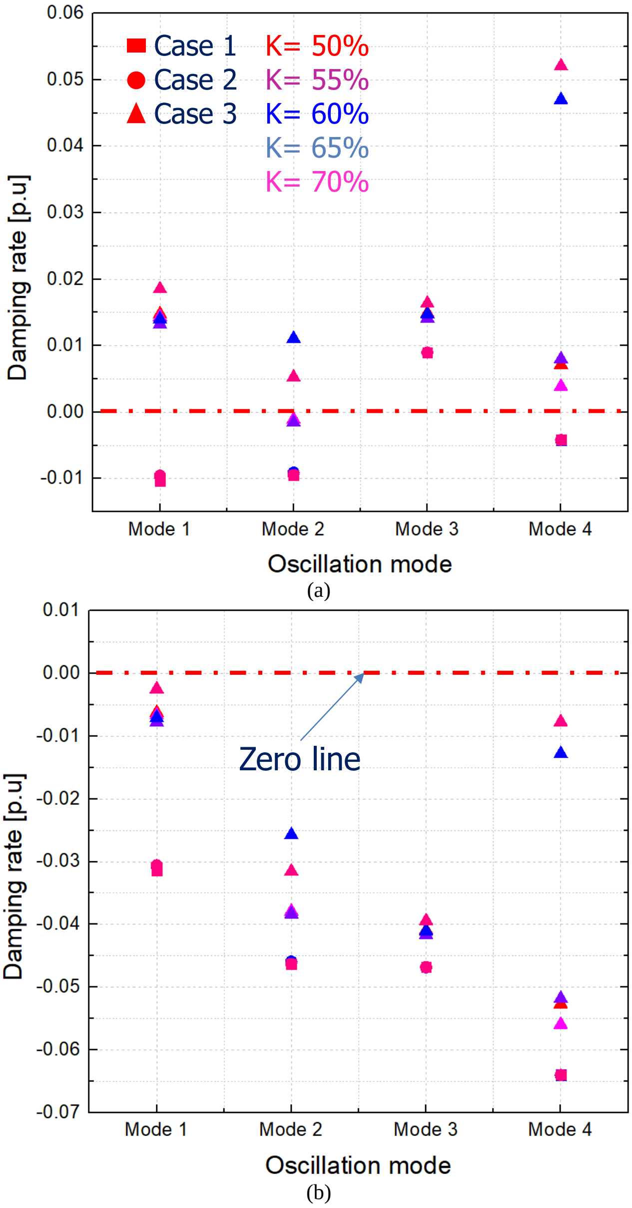


Fig 4. Analysis results of torsional modes at thermal power plant A unit #3, 4: (a) Damping time constant (σ); (b) Damping time constant (σ) plus mechanical damping time constant (σ_m)

5. Conclusions

This paper evaluated the SSR risk of the power plants nearby the installation location of the first TCSCs in the Korea power network. When a three-phase short circuit was applied near the generator, the generator's torque response was analyzed in different system configurations via time-domain simulation. The damping time constant was calculated from the torque response and the total damping time constant were also presented. Based on these values, we assessed the risks of SSR problems. Units #3 and #4 of the thermal power plant A were stable in terms of SSR problems.

Acknowledgment

This work was funded by Korea Electric Power Corporation (No. CX72180005)

References

[1] KEPCO. Technical Specification for Shin-Youngju and Shin-Jecheon TCSC Project, May 2017.

[2] Joshi, S.R.; Kulkarni, A.M., “. Analysis of SSR Performance of TCSC Control Schemes Using a Modular High Bandwidth Discrete-Time Dynamic Model”, IEEE Transactions on Power Systems, vol. 24, pp. 840-848, 2009.

[3] Qianjin, L.; Changchun, Z.; Angquist, L.; Rehtanz, C., “A novel active damping control of TCSC for SSR suppression in a radial corridor”, In Proceedings of 2008 Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies, pp. 136-142, April 2008.

[4] IEEE Standard 1534-2009, IEEE Recommended practices for specifying thyristor-controlled series capacitors, IEEE Power & Energy Society, 2009.

[5] Harnefors, L., “Proof and Application of the Positive-Net-Damping Stability Criterion”, IEEE Transactions on Power Systems, vol. 26, pp. 481-482, 2011.

[6] Johansson, N.; Angquist, L.; Nee, H, “A Comparison of Different Frequency Scanning Methods for Study of Subsynchronous Resonance”, IEEE Transactions on Power Systems, vol. 26, pp. 356-363, 2011.

[7] Tran, M.Q.; Lee, S.J.; Lee, J.I.; Park, M.; Yu, I.K.; Yoon, J.; Sim, H., “Design and performance analysis of a TCSC for real grid application”, Proceeding of KIEE, pp. 178-179, 2018.

[8] Minh-Quan Tran, Minh-Chau Dinh, etc., “Analysis and Mitigation of Subsynchronous Resonance in a Korean Power Network with the First TCSC Installation,” Energies 2019, July 2019.

[9] Minh-Chau Dinh, Minh-Quan Tran, etc., “Suggestion of a New Protection Scheme for a Transmission System Equipped with a Thyristor-Controlled Series Capacitor,” Energies 2019, June 2019.

[10] Ängquist, L.; Ingestrom, G.; Jonsson, H. A; “Dynamical performance of TCSC schemes”, CIGRE, Paris, 1996.