400 *Journal of Electrical Engineering & Technology Vol. 5, No. 3, pp. 400~406, 2010*

A Practical Power System Stabilizer Tuning Method and its Verification in Field Test

Jeonghoon Shin[†], Suchul Nam*, Jaegul Lee*, Seungmook Baek*,
Youngdo Choy* and Taekyun Kim*

Abstract – This paper deals with parameter tuning of the Power System Stabilizer (PSS) for 612 MVA thermal power plants in the KEPCO system and its validation in a field test. In this paper, the selection of parameters, such as lead-lag time constants for phase compensation and system gain, is optimized using linear and eigenvalue analyses. This is then verified through the time-domain transient stability analysis. In the next step, the performance of PSS is finally verified by the generator's on-line field test. After the field test, measured and simulated data are also compared to prove the effectiveness of the models used in the simulations.

Keywords: Power system stabilizer, Phase compensation, Gain tuning, Field test, AVR step, Gain margin test

1. Introduction

The power system stabilizer (PSS) is a supplementary control system of a generator's excitation system. The output signal of the PSS is injected into the summing junction of the excitor block in the generator to damp out low frequency oscillations of the power system. It is the most economical way to mitigate this kind of low frequency oscillations. In order for the PSS to perform its role, it is very important to optimally tune the internal parameters of the PSS, which are composed of lead-lag time constants and a gain.

The tuning of the PSS and its application have been studied and applied to power systems around the world since the 1960s. The basic reasons for tuning PSS parameters are to compensate for the phase lag due to the power system, generator and excitation system; and to provide electrical torque in phase with speed via the excitation system and generator [1].

However, the difficulties of tuning the PSS parameters and applying them to the power system, derived from the complexity of the power system and the wide range of operating points, have made authorities reluctant to use PSS. In spite of these difficulties, excellent PSS tuning guides for single-input PSSs have been suggested [2], [3] and dual input PSSs have been reported as an alternative for successful operation [4]. The dual-input PSS, which uses power and frequency as inputs, has many advantages over a single-input PSS, such as the speed-input PSS or power-input PSS. This is because dual-input PSS provides a damping torque for the power system on a wider range of frequencies of concern and is less sensitive to shaft torsional oscillation.

Although tuning of the PSSs is performed on a hundred units without major complications, most PSSs use high-order filters, making it difficult for engineers to determine the required, properly tuned PSS parameters.

Meanwhile, in Korea, operation and periodical retuning of PSSs of all generators with over 500 MVA capacity have been compulsory in the system reliability regulation since 2005. Generation companies equipped with these generators are interested in the tuning of their PSSs.

In this paper, an effective and practical tuning method of PSSs and their application to the KEPCO system are presented. The selection of parameters, such as lead-lag time constants for phase compensation and system gain, are optimized using linear and eigenvalue analyses; these are verified through time-domain transient stability analysis. In addition, the performance of the PSS is verified by the generator's on-line field test. Through the comparisons of simulation results and measured data before and after tuning of the PSS, the models of the generator and its controllers, including AVR, Governor and PSS used in the simulation, are validated and confirmed.

2. Offline Tuning of PSS Parameters (IEEEST)

2.1 System Modeling

Fig. 1 shows one machine and an infinite bus, which represents a 612 MVA thermal power plant in the KEPCO system. It is used throughout this paper for tuning the PSS parameters. The unit is assumed to have loading conditions of 500 MW and 0.0 MVAR (1.0+j0.0 p.u.), at which point the total system gain is at its highest and in the least stable condition [2]. The excitation system of the machine is static, as shown in Fig. 2. The model parameters of the generator and the excitation system are in the Appendix.

[†] Corresponding Author: Korea Electric Power Company (KEPCO) Research Institute, Korea. (jhshin@kepri.re.kr)

* Korea Electric Power Company (KEPCO) Research Institute, Korea.

Received: March 30, 2010; Accepted: May 10, 2010

The parameters derived from the field test are used so that reliable PSS parameters can be determined. To validate the models, the AVR step test, which is implemented to give the small step voltage into the summing junction of the AVR reference, is simulated in terms of both armature voltage, Vt, and generator field voltage, Efd. Fig. 3 shows the response of the excitation system to a 5% step change of AVR. The system successfully controls the terminal voltage of the generator.

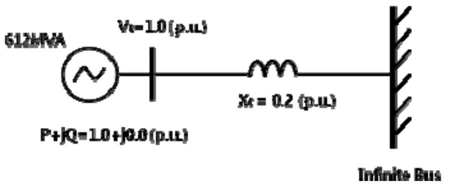

Fig. 1. Single machine and an infinite bus system.

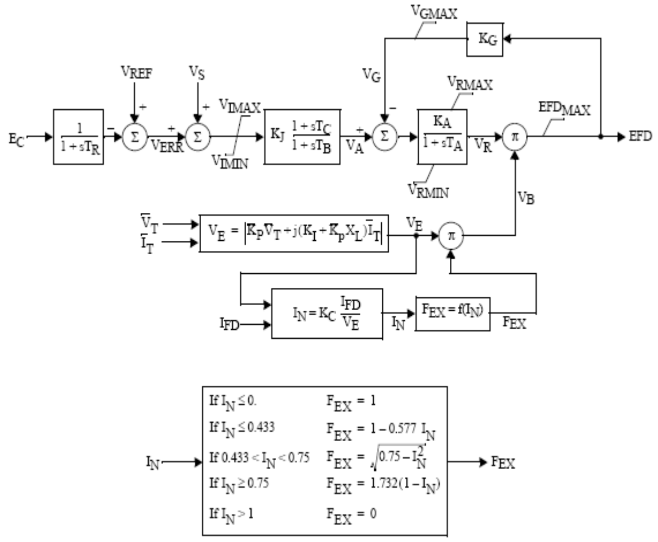

Fig. 2. Excitation system model (EXST3).

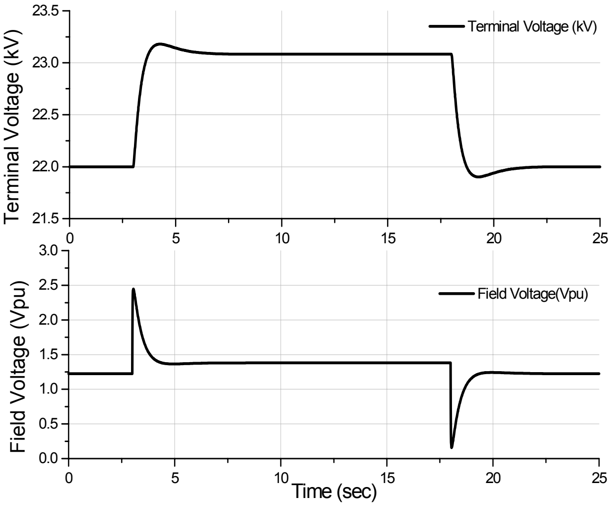

Fig. 3. Response of 5% AVR step test with open-circuited unit.

2.2 Phase Compensator Tuning

Phase compensator tuning is the most important part of PSS tuning. The purpose of phase compensation is to compensate for phase lags between excitor reference and air - gap torque in the system. In other words, time constants of two lead-lag blocks (T1=T3, T2=T4) in IEEEST-type PSS (Fig. 4) should be optimally determined for this purpose. Normally, in the range of low frequency oscillations ranging from 0.1 to 2 Hz, time constants of the PSS should be selected to compensate for the phase lags of the system by linear analysis.

Fig. 5 represents the phase lagging characteristics of Power System-Generator-Excitation System or PGE(s) blocks without PSS. The figure shows that the maximum phase lagging of the system is approximately 100 degrees at 2 Hz.

Fig. 6 shows the frequency response characteristics of PGE(s)PSS(s), according to the variation of time constants. In these cases, T1 was used to calculate the central frequency for the phase compensation. In this case, 0.25 of T1 was selected for optimal time constant of the phase compensation because it was slightly under compensation on the designated frequency range and has little effect on the synchronizing torque of the system. The optimization programs, such as PWRSTAB [8] and DSA, are normally used in this process.

The final parameters selected for the phase compensation of the PSS are given in Table 1.

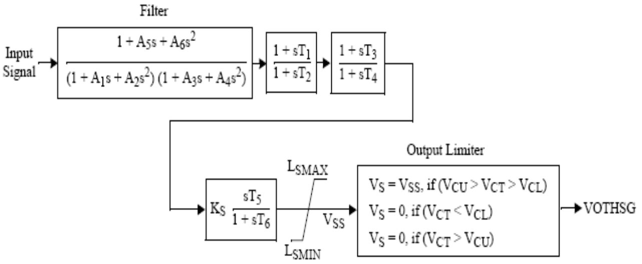

Fig. 4. PSS model (IEEEST).

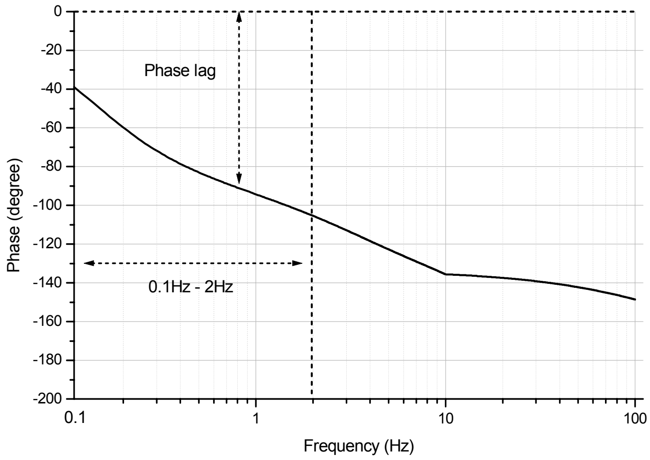

Fig. 5. Phase lagging characteristics of PGE(s).

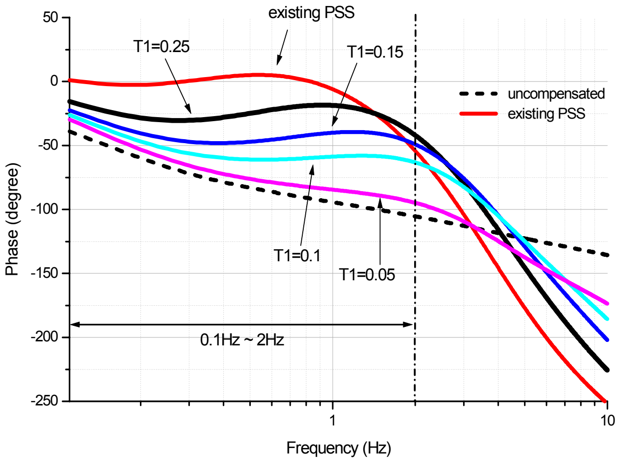

Fig. 6. Frequency responses of PGE(s)PSS(s) according to the variation in time constants.

Table 1. Selected time constants for the phase compensation

Time Constants	T1	T2	T3	T4
Seconds	0.25	0.025	0.25	0.025

Washout time constants (T5=T6=10.0) were not considered for the tuning of the PSS in the paper. This is because they do not have much effect on the performance of the PSS to damp local mode of oscillations (see Fig. 7). For the upper and lower limits (LSMAX, LSMIN), typical values were simply set as ±0.1 p.u.

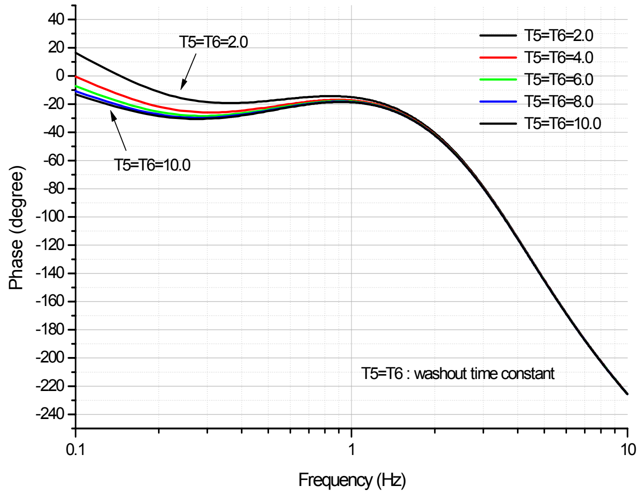

Fig. 7. Frequency responses of PGE(s)PSS(s), according to the variation in washout time constants.

2.3 Gain Tuning

For the gain tuning of PSS, eigenvalue analysis was used to determine a range of the gain instead of a single gain value. It had to be determined, not only from analytical methods, but also from field testing, in order to obtain the gain that could provide the best possible damping of the selected modes while keeping the noises from the PSS at an acceptable level.

Fig. 8 represents the root-locus plot derived from eigenvalue analysis. The control mode of the system became unstable while the local mode of oscillations is stabilized as the system gain, Ks, increased. At approximately 25 p.u. of the system gain, the control mode became unstabilized. Therefore, the tentative range of the gain can be selected near a third of the unstabilized gain value at which the local mode has been stabilized. The maximum gain is supposed to be in the range of 7 to 8 p.u. This was finally determined in the field test.

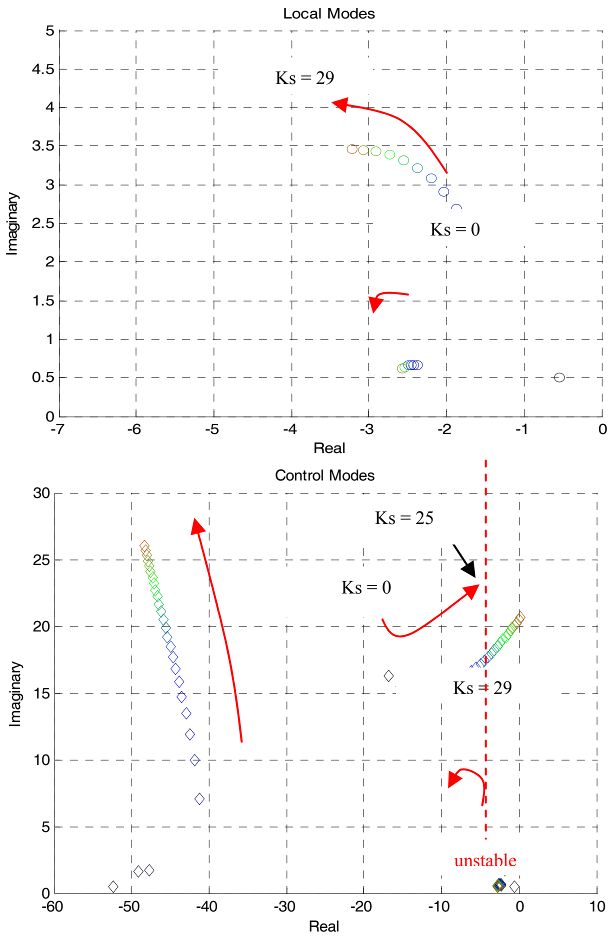

Fig. 8. Root-locus plots for local and control modes.

2.4 Time-Domain Simulation

After the tuning of the PSS parameters, the effect of the tuned PSS was simulated in the time-domain by transient stability programs, such as PSS/E or TSAT, among others. A 2% AVR step response and a three-phase fault test were simulated in the time-domain for this purpose. Figs. 9 and 10 represent the response of the generator (active power) when 2% AVR step-up and three-phase fault on the generator bus were applied, respectively. Both of these, together with the degree of damping to the oscillations, were greatly

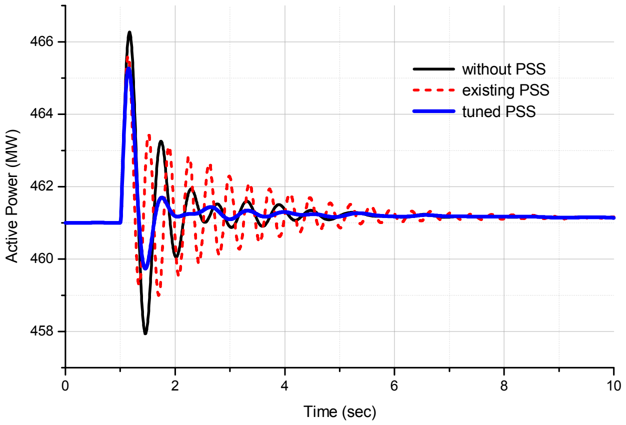

Fig. 9. The 2% AVR step response – Generator active power (MW).

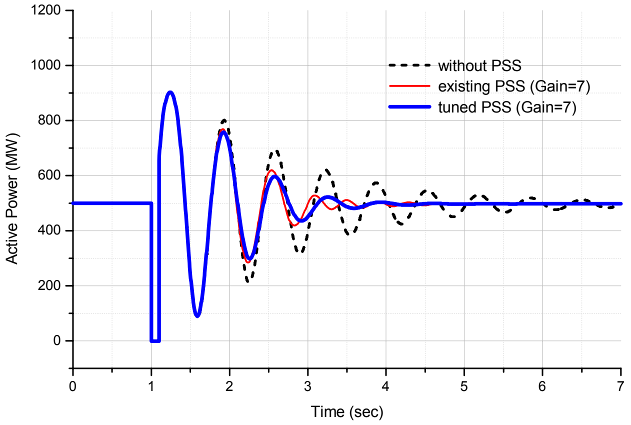

Fig. 10. Generator response after 3-phase fault – Generator active power (MW).

enhanced compared with the existing PSS and the system without PSS.

3. Performance Verification in Field Tests

In this study, the results of an on-line field test for the PSS installed in a 612 MVA thermal power plant have been demonstrated using the speed-input analogue PSS, with initial values of PSS parameters set by the manufacturer before tuning.

The following items were tested to verify the tuned parameters of the PSS:

a. A 3% AVR step test without load (open-circuited);
b. A 2% AVR step test with full-load; set as initial value of parameters;
c. PSS Gain Margin test (set as tuned parameter); and
d. A 2% AVR step test with full-load (on-line) Gain=0, 1, 3, 5, 7.

System operating conditions on each test item are shown in Table 2.

Table 2. System operating conditions in the test

Test Items	a	c	b and d
Gen. MW	-	470 MW	440 MW
Gen. MVAR	-	145 MVAR	150 MVAR
Terminal Voltage	21.8 kV	22.0 kV	22.0 kV

3.1 AVR Step Response Test with Open-Circuited Generator

This test checked the establishment of the internal DC voltage of the AVR and looked at the behavior of the excitation system of the generator. It also confirmed the validation of the excitation models used in offline simulation of PSS tuning.

A 3% AVR step signal was injected into the summing point of the AVR at 3600 turbine speed (rpm), with the main circuit breaker open. Fig. 11 shows the terminal voltage of the generator after a 3% AVR step, compared with the off-line simulation. The results are matched exactly; therefore, the models used in the simulation are valid.

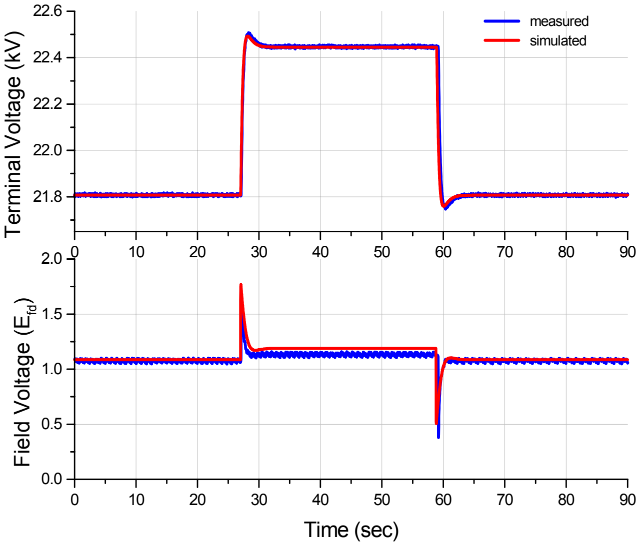

Fig. 11. Comparison of results with 3% AVR step test (measured vs. simulated).

3.2 AVR Step Response Test with Full Load (Before Tuning)

In this test, the validation of the existing PSS parameters set by the manufacturer was checked by a 2% AVR step test. The time constant for phase compensation was 0.5 sec. and the gain was approximately 7 p.u.

Fig. 12 shows the active power of the generator in the test. A high-frequency oscillation appears in the outputs. As expected in the off-line simulation, the control mode of the system seems unstable because of the inappropriate parameters of the PSS, including time constants for phase compensation and system gain.

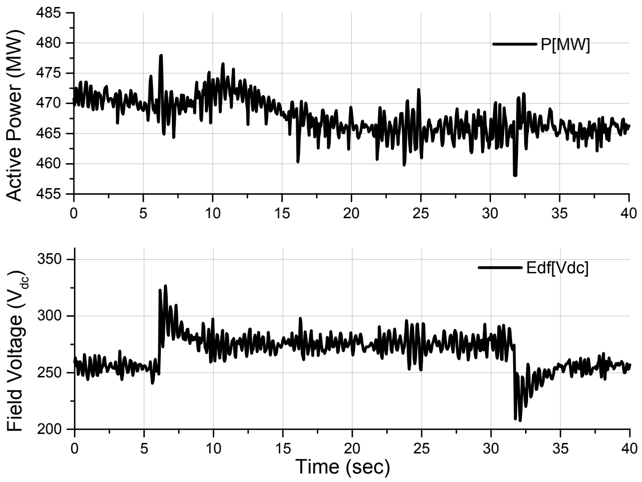

Fig. 12. The 2% AVR step response of the existing PSS (field voltage and active power).

3.3 PSS Gain Margin Test

After setting the tuned parameters in the PSS, the gain margin test was performed by increasing the gain step-by-step, without applying step signal until one of the output signals was hunted (Fig. 13). At approximately 20 p.u. of the gain, the MW and field voltage were hunted. Therefore, the maximum gain was tentatively considered as 7 p.u. The final value of gain was selected in the next test.

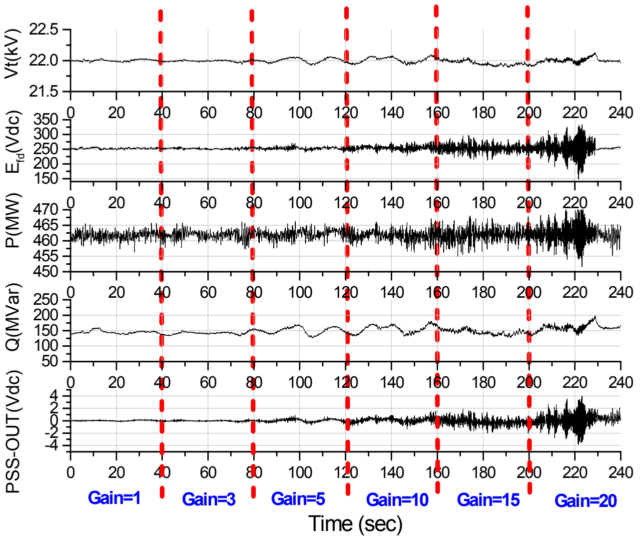

Fig. 13. The results of the PSS gain margin test (Terminal voltage, Field voltage, MW/MVAR, PSS output).

3.4 AVR Step Response Test with Full Load (After Tuning)

In this test, the damping effects at each gain were observed according to an increase in the gain, up to the tentative value set in the previous gain margin test. Then, the final value of PSS gain was set at 7 p.u. after an analysis of the damping of power oscillations, number and amplitude of swings, and field voltage variation.

Compared with the results without PSS (gain=0), the damping of low-frequency oscillation was significantly enhanced for the tuned PSS (gain=7) (Figs. 14 and 15). Therefore, the parameters of PSS were successfully tuned so that the performance of PSS was finally verified in the field test.

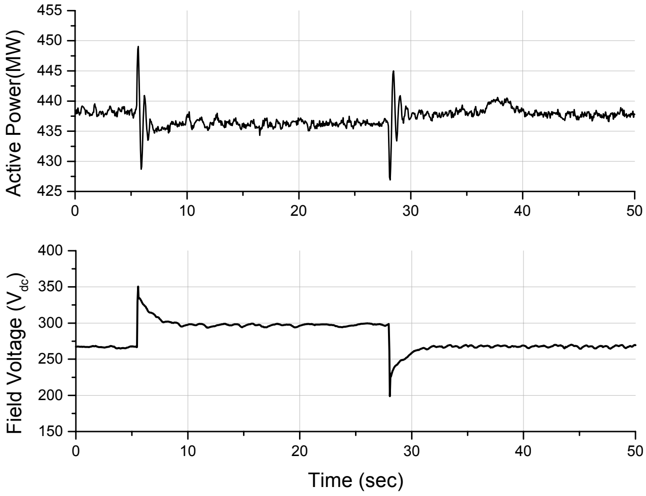

Fig. 14. The 2% AVR step response without PSS (Gain=0) (active power and field voltage).

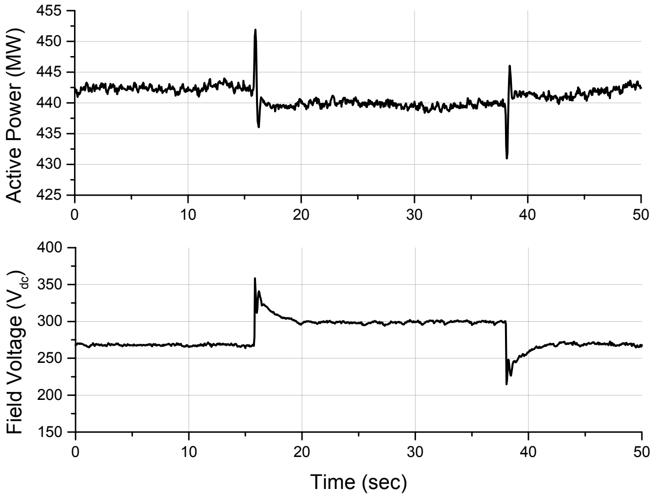

Fig. 15. The 2% AVR step response with PSS (Gain=7) (active power and field voltage).

4. Validation of Models Used in the Simulation

The system models used in the offline simulation were finally validated through the comparison of results between simulated and measured data. To do that, system operating conditions for offline simulation were slightly changed to that of the field test. Generator outputs (MW and MVAR) and terminal voltage were changed to the same values as the measured ones.

The results were compared to validate the models used in the simulation (Figs. 16 and 17). The field voltages and generator outputs (MW), with and without PSS, were compared respectively. The results are very similar in both voltages and outputs, except field noises. Therefore, the models used in the simulation were finally validated.

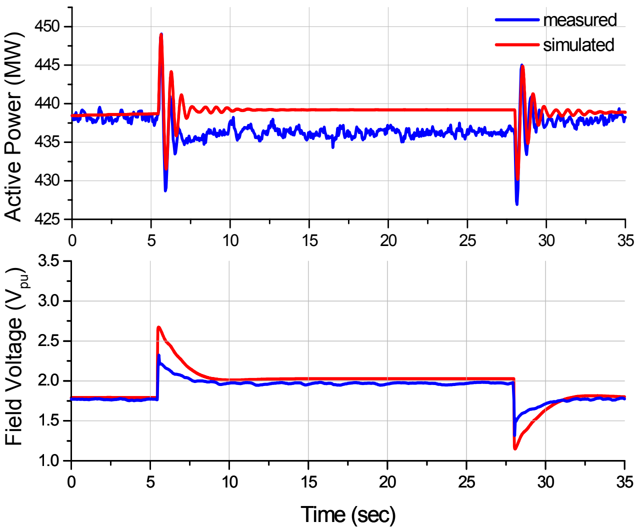

Fig. 16. The 2% AVR step response without PSS (Gain=0) (measured vs. simulated).

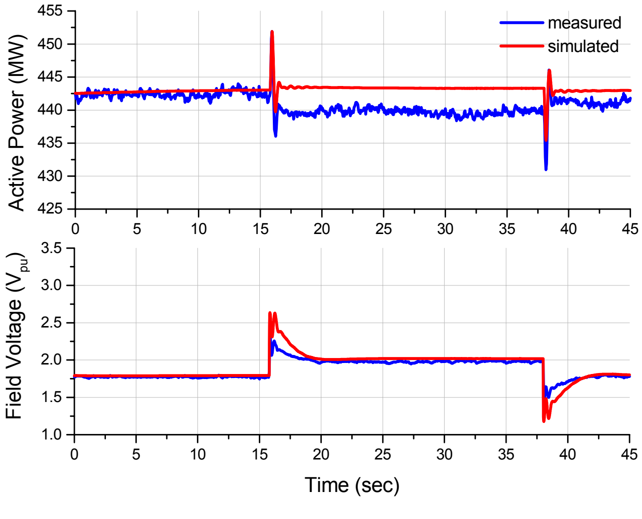

Fig. 17. The 2% AVR step response without PSS (Gain=7) (measured vs. simulated).

5. Conclusion

In this paper, the effectiveness of PSS parameters, which were tuned in advance through the offline simulation, was demonstrated based on the online field test. The lead-lag time constants for phase compensation were selected as slightly under-compensated in order not to decrease the synchronous torque of the system. The PSS gain, Ks, was finally determined by the 2% AVR step test at a load of 440 MW.

After performing the field test, the measured data were compared to the simulated ones for the validation of the system models used in the off-line simulation. In addition, a kind of field test method and a procedure for the performance test of the PSS were described in the paper.

Based on a practical tuning method presented in the paper, multi-band PSSs and PSSs for the inter-area mode of oscillations, which are widely accepted in North America, could also be tuned in the near future.

References

[1] F.P. de Mello, C. Concordia, “Concepts of Synchronous Machine Stability as Affected by Excitation Control”, *IEEE Trans. Vol. PAS-87, June 1969, pp.316-329.*

[2] Larsen, E.V. and D.A. Swann, “Applying Power System Stabilizers, Parts I, II, and III”, *IEEE Trans., Vol. PAS-100, No. 6, June 1981, pp.3017-3046.*

[3] P. Kundur, D.C. Lee, H.M. Zein El-Din, “Power System Stabilizers for Thermal Units: Analytical Techniques and On-Site Validation”, *IEEE Trans. Vol. PAS-100, No.1, January 1981, pp. 184-198.*

[4] F.P. de Mello, L.N. Hannett, J.M. Undrill, “Practical Approaches to Supplementary Stabilizing from Accelerating Power”, *IEEE, Trans., Vol. PAS-97, September/October 1978, pp. 1515-1522.*

[5] P. Kundur, M. Klein, G.J. Rogers, and M.S. Zywno, “Application of Power System Stabilizers for Enhancement of Overall System Stability”, *IEEE Trans., Vol. PWRS-4, May 1989, pp. 614-629.*

[6] J.S. Czuba, L.N. Hannett, J.R. Willis, “Implementation of Power System Stabilizer at the Ludington Pumped Storage Plant”, Presented at the *IEEE PES summer meeting, Vancouver, July 1985.*

[7] P. Kundur, Power System Stability and Control, McGraw-Hill, 1994.

[8] D.J. Kim, J.H.Shin, “Basic Study for PSS tuning: PART I-Torque Characteristics according to the system conditions”, *KIEE Trans., Vol. 48-9, Sep. 1999.*

[9] J.H.Shin, J.G.Lee “A Tuning Method for the PSS of a Large Thermal Power Plant and its Application to Real Power System: Part I-Selection of parameters by Off-line Simulation”, Journal of *KIIEE., Vol. 23, No. 12, Dec. 2009.*

APPENDIX

1) GENERATOR PARAMETERS (612 MVA, 22.0 KV)

$T_{do}{}' = 7.90$ sec. $T_{do}{}'' = 0.043$ sec. $T_{qo}{}' = 0.38$
$T_{qo}{}'' = 0.073$ sec. $H = 3.75$ $D = 0.000$
$X_d = 2.1957$ $X_q = 1.4578$ $X_d{}' = 0.26$

$X'' = 0.2029\ X_l = 0.15$
$S(1.0) = 0.1976\ S(1.2) = 0.4589$

2) EXCITATION SYSTEM PARAMETERS

$T_R = 0.02\ K_A=8.5\ T_A=0.4$
$V_{1max}=0.2\ V_{lmin}=-0.2\ V_{RMAX}=1.0$
$V_{RMIN}=0.03\ K_p=4.8\ K_j=200\ K_G=1.0\ K_P=4.8$
$K_I=0.0\ K_c=0.0,\ Xl=0.0$
$T_c=1.0\ T_A=0.4\ T_B=8.0$
$E_{FDMAX}=5.0\ VG_{Max}=4.8\ THETAP=0.0$

Jeonghoon Shin received his B.S., M.S., and Ph.D. degrees in Electrical Engineering from KyungPook National University, Korea, in 1993, 1995 and 2006, respectively. He was a Visiting Scholar at EPRI (Electric Power Research Institute), Palo Alto, CA, USA, from March 2003 to Feb. 2004. He has been with KEPRI, the research institute of Korea Electric Power Company (KEPCO), as a Senior Research Engineer since 1995. His research interests include real-time digital simulation, transient and dynamic stability, and power system planning and operation.

Suchul Nam received his B.S. and M.S. degrees in Electrical Engineering from Korea University, Korea, in 2001 and 2006, respectively. Mr. Nam joined KEPRI's Power System Lab. as a research engineer in Feb. 2006, where he is now developing an integrated optimization scheme for a reactive power management system for KEPCO. He is also participating in several transmission power system studies.

Jaegul Lee received his B.S. and M.S. degrees in Electrical Engineering from Inchon University in 2001 and 2003, respectively. Upon graduating from Inchon University, Mr. Lee joined the Korea Electric Power Company (KEPCO) Research Institute in 2004. In KEPRI, he was involved in several project areas, including real-time simulation of transient phenomena, model development, and studies involving power electronics.

Seungmook Baek received his B.S. M.S. and Ph.D. degrees from the School of Electrical and Electronic Engineering, Yonsei University, Seoul, Korea, in 2006, 2007, 2010 respectively. He joined the Korea Electric Power Company (KEPCO) Research Institute (KEPRI) as a research engineer in 2009. His research interests include power system dynamics, hybrid systems, optimization control algorithms, flexible ac transmission system (FACTS) devices, application of artificial neural networks, and real-time digital simulation.

Youngdo Choy received his B.S. and M.S. degrees in Electrical Engineering from Myungji University, Korea, in 2000 and 2002, respectively. He joined KEPRI, the research institute of the Korea Electric Power Company (KEPCO), Korea, as a research engineer in 2005. His research interests include power electronics, renewable energy in electric power systems, and power system operation.

Taekyun Kim received his B.S., M.S., and Ph.D. degrees in Electrical Engineering from Hanyang University, Korea, in 1986, 1989 and 1993, respectively. He is a principal research engineer in KEPRI, Korea. He has been a project leader in several simulator studies related to the development of various models and software for the KEPS. His research interests include real-time digital simulation, transient and dynamic stability, as well as power system planning and operation.