Impact of Power System Stabilizer Installation on Steady State Stability Performance

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Abstract. The fast expansion of both transmission network and generation in the fast developing power system necessitates a continuous updating for its stability performance. One of the means to reinforce the steady state stability is by installing the power system stabilizer. This paper focuses on the impact of power system stabilizer on the performance of an existing power system. The choice of both location as well as the stabilizing signal is addressed. The normalized modes sensitivities combined with eigenvalue tracking guide the selection and tunning of the power system stabilizer parameters for acceptable stability region. The trade off between improvement in the interaction and rotor angle modes is emphasized. This investigation may assist utility decision makers in deciding to install or not such device.

List of Symbols

λ_{12} = Flux-linkage in the stator and rotor circuit for G_2
I_{12} = Current in the stator and rotor circuit for G_2
V_{12} = Voltage components of G_2
X_{12} = Internal reactance of G_2
T_{e2} = Electric torque of G_2
E_{FD2} = Field voltage of G_2
r_{12} = Resistance components of G_2
ω_2 = Rotor angular speed of G_2
δ_2 = Power angle of G_2
T_1, T_2, T_3 = Governor time constants
K_g = Actuator gain

V_{D2}, V_{Q2} = Voltage components in d- and q-axes referred to generalized reference frame

I_{D2}, I_{Q2} = Current components in d- and q-axes referred to generalized reference frame.

1. Introduction

Coordinated application and computation of stabilizers in multimachine power systems have drawn much attention in the last decade. Under heavy loading condition, the modern regulator-exciter system introduces negative damping and may lead to steady state instability. The fundamental idea of power system stabilizer (PSS) is to provide an additional positive damping to the system by introducing a stabilizing signal of proper phase through the excitation system. Maximum positive damping is achieved when suitable settings of the stabilizer parameters produce damping component through the machine, excitation and stabilizer which is in phase with the speed deviation. Accurate determination of PSS contribution to the system dynamics necessitate modeling both the interaction within the machine and with other machine [1-4]. However, the determination of appropriate stabilizer setting is needed since the system modes are function of stabilizer settings. This can be investigated through eigenvalue tracking approach. This paper presents the impact of utilizing power system stabilizer equipment on steady state stability of an existing power system in central of Saudi Arabia (SCECO-C), where PSS is not utilized though its cost is not expensive. The importance of such PSS implementation stems from the fact that the study system contains different type of excitation systems ranging from old regulator to advanced static excitation system. Both location and PSS parameter setting are discussed through an eigenvalue tracking approach combined with the normalized modes sensitivities.

2. System Description

The system contains 32 main buses connected via 132 kV double circuit ring transmission network as shown in Fig. 1. The loads are constant impedances. The hierarchical structure of the generation system is composed of five power plants. Each of them contains several identical gas-turbine generating units. So each power plant has been represented by an equivalent machine since the units are almost connected to the same bus. Moreover, modern excitation system such as static excitation of General Electric Company (GE) [5] shown in Fig. 2 and rotating excitation of Brown Boveri Company (BBC) [6] shown in Fig. 3 are utilized in the system.

The data for all generator components as well as system transmission are not included to limit the space and can be found elsewhere [7]. The system had been modelled for stability study and the system excitation parameters had been tuned for

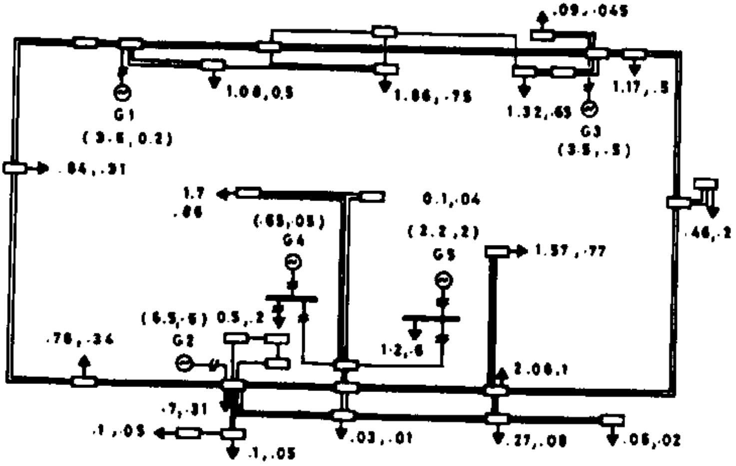
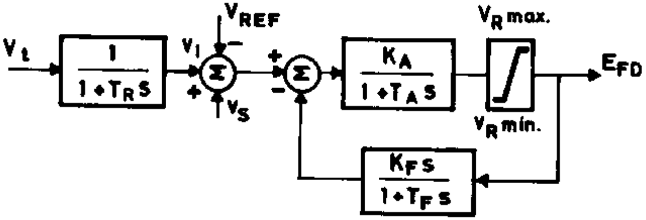
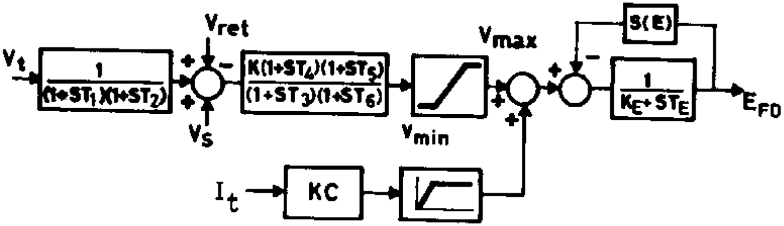


Fig. 1. SCECO-C network configuration



K_A, T_A = amplifier gain and time constant, T_R = Rekgulator filter time constant
K_F, T_F = stabilizing gain and time constant.

Fig. 2. Static excitation block diagram



K_c = compound circuit gain, K = AVR gain
V_t,I_t = terminals voltage and current
T_1,...,T_6 = time constants

Fig. 3. Rotating rectifier excitation system

an acceptable stability region. Appendix A shows the basic differential and algebraic equations for power plant G_2 and have been used in modelling the system dynamics. The load [p.u.] condition shown in Fig. 1 is considered as the steady state operating condition at which the steady state stability evaluation has been carried out.

The state space approach has been applied to construct the dynamic model for the system which can be written as $\mathring{X} = AX + Bu$ where X and u are system state and input vector respectively, A and B are constant matrices depending on system parameters and operating condition. The eigenvalues of the matrix A are indicative of system stability performance where the real part represents the amount of damping and the imaginary part indicates the amount of oscillation of the associated mode. Each synchronous machine is represented by fifth order model. The excitation systems modeled by fifth, fourth or third order model depending on the choice of system representation. The gas turbine is represented by a third order model. The whole integrated system under study contains sixty one states.

3. Results and Analysis

Second column of Table 1 shows the dominant eigenvalues of the system studied without including the PSS. As can be seen, the damping associated with torque angle is not large enough (modes are close to the imaginary axis) due to the fact that implementing fast response excitation system contributes negative damping component. That suggests the need to introduce positive damping component to such modes.

Fig. 4. shows the main block diagram and parameters definition of PSS used by BBC [8]. Since the system contains a few power plants equipped with modern excitation, the location of installing the PSS can be simply identified. Power Plant (G_1) is

Table 1. Normalized dominant modes sensitivities w.r.t. PSS parameters ($V_x = \Delta n$)

Dominant modes	Dominant modes without pss	Dominant modes sensitivities with installing pss at G_1 Base case $K_B=60$, $T_{1B}=0.2$, $T_{3B}=0.5$ $T_{4B}=0.05$				Dominant modes sensitivities with installing pss at G_3 keeping pss of G_1 at appropriate values Base case of pss of G_3 is $K_B=150$, $T_{1B}=1.3$, $T_{3B}=1.8$, $T_{4B}=0.6$			
		K_B	T_{1B}	T_{3B}	T_{4B}	K_B	T_{1B}	T_{3B}	T_{4B}
R_1	−0.134 ±j4.92	−11.66 +j4.92	13.51 +j4.08	−11.24 +j.12	2.31 +j2.55	−27 +j12	25.55 −j7.11	−22.86 +j6.89	−22.31 −j3.66
R_2	−0.2 ±j7.72	−0.24 +j.078	0.24 −j.22	−0.25 +j.22	0.09 −j.16	−0.6 −j.3	0.35 −j.104	−0.31 −j.25	0.22 −j.08
R_3	−0.36 ±j6.4	−1.44 +j1.44	1.87 −j.75	−2 +j.74	−0.64 +j.17	0.75 +j.3	−0.79 −j.24	−0.85 −j.11	−0.57 −j.15
R_4	−0.37 ±j4.58	0.4 −j.66	−0.58 +j.139	0.41 −j.3	−0.08 −j.14	−0.82 +j0.0	0.74 +j.026	−0.58 −j.63	0.49 +j.47
R_5	−0.51 ±j7.43	−135.48 −j168.6	−61.54 +j223.36	−81.61 −j197.3	−52.49 +j49.35	3 +j4.5	0.2 −j2.9	1.22 +j2.56	0.28 −j3.52
I_1	−0.25 ±j.2	−1.26 +j36.96	−5.74 −j2.67	−1.44 +j17.12	1.6 −j25.97	67.5 −j111	49.84 +j48.56	721.28 −j130.73	−112.67 +j354.31
I_2	−0.35 ±j.28	−101.4 −j62.04	−6.83 +j9.19	−15.31 −j33.84	32.89 +j50.34	−118.05 −j102	−6.89 −j28.16	−57.37 −j90.5	39.33 −j2.9
I_3	−0.45 ±j.16	17.4 −j881.4	−129.56 −j76.5	84.23 −j360.84	356.71 +j585.06	−372 +j1951.5	−217.32 −j1003.8	721.4 −j582.8	1632.63 −j1533.66
I_4	−0.45 ±j1.6	69 +j32.72	−22.57 −j86.68	−70.4 +j130.79	−20.43 +j20.79	139.5 +j24	5.42 +j17.68	73.17 +j70.81	−281.95 −j61.97
I_5	−0.57 ±j.99	412 +j556.2	45.34 +j55.88	96.65 +j267.47	−121.5 −j287.6	138.6 −j1020	−100.41 −j110.05	200.41 −j645.41	−282.01 +j708.35
I_6	−0.12 ±j1.07	−48.96 −j174	−16.43 −j24.65	−20.11 −j58.85	+13.55 +j70.88	79.5 +j208.5	−48.05 +j48.98	59.94 +j150.17	−97.09 −j165.5

All sensitivity values are multiplied by 10^3

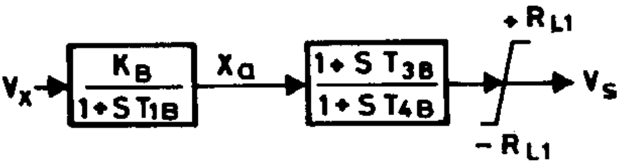


Fig. 4. PSS block diagram

newly commissioned with 120 MVA rating for each unit equipped with fast modern excitation of BBC, so it is selected as first candidate for PSS implementation. Column 3 in Table 1 gives the sensitivities of different modes w.r.t. the stabilizer gain (K_B) simulated in G_1 model. The speed deviation applied as an input to the stabilizer for this study which is in difference than the power signal used by BBC in other places. The rotor modes (R_1) are sensitive to the stabilizer gain (K_B). Also, the interaction mdoes (I_i) represent the dynamics within the machine such as the interaction between the excitation and the field circuit, in addition to those associated with the interaction between the machines dynamics, are sensitive to the stabilizer gain (K_B). It is necessary to state that identifying all the interaction modes in multimachine frame problem is a formidable task. The most sensitive modes are those modes associated with R_5, R_1, and the interaction mode (I_4). The normalized mode sensitivities given in Table 1, have been calculated using the $(\zeta/\lambda)(\Delta\lambda/\Delta\zeta) \times 1000$ where ζ is the stabilizer parameter and λ is the eigenvalue. The point to be mentioned that not only the sensitivities to be considered but also how critical are the modes to the stability margin. For instant the table shows large sensitivity for I_5 relative to that of I_4. But I_4 is more critical than I_5. Therefore, this concludes the importance of eigenvalue location status concurrently with their sensitivities. Increasing the gain improve the damping component in torque angle mode for R_5 and R_1 while it reduces the damping status of the interaction mode. So it is a trade off effect which should be considered with caution.

Fig. 5 shows the interaciton modes drift to the instable region with high stabilizer gain K_B, while the torque angle mode immigrate toward more stable region. That necessitates the choice of appropriate gain value through tuning technique. Column 4-6 give the normalized eigenvalues sensitivities w.r.t. the different stabilizer time constants. It can be stated that the interaction mdoes are more sensitive to the time constant variation relative to the stabilizer gain case. The time constant variation affects the rotor angle modes of R_5 and R_1 as well as the interaction mode (I_4). This effect is due to the change in angle between the stabilizing signal and the machine rotor speed, the more increase in the angle will be followed by decreasing the damping component obtained. It should be pointed out that since interaction mode (I_4) is the most sensitive one which may lead the system to be unstable, it should be considered as flag indicator in adjusting the PSS parameters. Careful scanning to various parameters impact suggests the choice of $K_B = 60$, $T_{1B} = 0.2$, $T_{3B} = 0.5$, $T_{4B} = 0.05$ sec. as an appropriate parameter setting for PSS utilized in power plant G_1. These parameters values have been obtained by tracking the eigenvalues rather than using optimization technique. This has been adopted mainly for its simplicity and its usefulness in providing insights in system mode identification.

Experience has shown that measurement of the shaft speed can initiate torsional vibrations, so an alternative for that is the active power signal. Table 2 shows the normalized modes sensitivities w.r.t. PSS parameters. Similar remarks are drawn for the trade off between the improvement in rotor modes (R_5) and interaction mode (I_4).

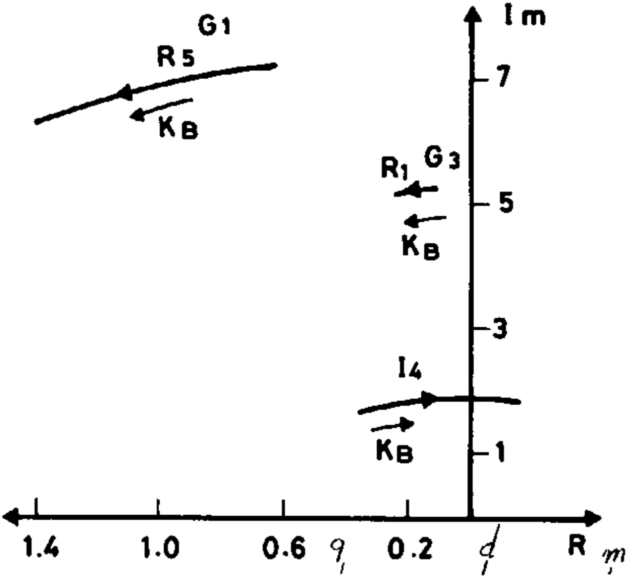


Fig. 5. Effect of PSS(G_1) gain K_B on dominant modes

Table 2. Normalized dominant modes sensitivities w.r.t. PSS gain K_B ($V_x = P_e$) PSS installed at G_1 base case $K_B=.4, T_{1B}=4, T_{3B}=5, T_{4B}=2$

R_1	R_2	R_3	R_4	R_5	I_1	I_2	I_3	I_4	I_5	I_6
−5.23 −j.96	−0.215 +j.39	−1.25 −j.95	0.174 −j.13	−57.8 −j74.72	−32.97 +j17.42	−46.57 −j102.1	−776.79 −j769.6	78.62 −j16.84	384.21 +j774.7	−84.26 −j201.7

However, the power signal has its own side effect, which is that it can not be determined whether or not the change in power originates from the network or from the turbine which may create unstable operation.

The second candidate for PSS location is at G_3 power plant, which has modern excitation system, not only that but also this power plant located at far location w.r.t. load center from G_1. The same stabilizer model has been considered, since both power plants are manufactured by BBC.

Column 7 in Table 1 shows the normalized sensitivities w.r.t. the stabilizer gain, keeping in mind that the PSS at G_1 parameters is held at the appropriate values giving above. The result shows large improvement in the R_1 mode which is mainly associated with machine G_3.

Increasing the PSS gain K_B attributed a negative damping to the interaction modes (I_4) and I_5. Fig. 6 shows that I_5 drifts to the right hand side resulting in unstable steady state operation. Column 8-10 show the normalized sensitivities w.r.t. different time constants. The modes are more sensitive to the variation in T_{1B} parameter. The interaction mode I_4 will be critically unstable for smaller value of T_{1B} (<0.1 sec). Also, increasing this time constant more than 0.1 sec will contribute positive damping to I_5 mode. However, this increase of time constant reduces the damping for the torque angle modes. T_{3B} shows effect in improving the rotor angle of G_3 and much less negative effect on the interaction modes. The same procedure is used to adjust T_{4B} parameter. The outcome of the eigenvalue tracking is the adjustment of the PSS parameters for G_3 at $K_B = 150$, $T_{1B} = 0.3$, $T_{2B} = 1.8$, and $T_{4B} = 0.6$ sec. Our study shows that installing PSS equipment at the any other power plant in this system will not contribute appropriate improvement for the system performance.

4. Conclusions

This study reveals the importance of installing power system stabilizer to generation units. The PSS does reinforce the steady state stability of power system network of SCECO-C. In operation, because of the fact that the system different modes are coupled together, a trade-off effect between the interaction modes and rotor angle modes should be considered carefully in varying the PSS parameters.

Acknowledgement: The authors wish to thank the Saudi Consolidated Electrical Company (SCECO-C) for providing the data. Thanks also extended sincerely to Mr. Munir A. Shaiq for typing this manuscript.

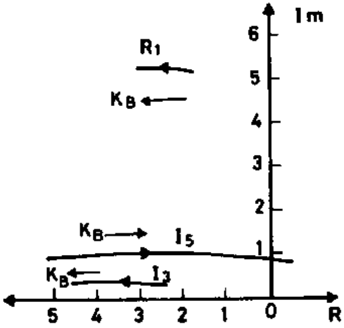


Fig. 6. Effet of PSS(G_3) gain on dominant modes

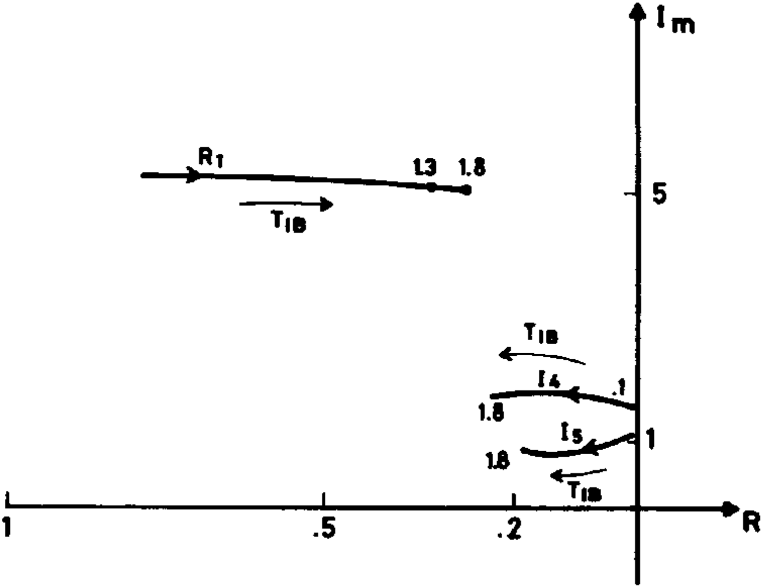


Fig. 7. Effect of PSS (G_3) time constant T_{1B} on dominant modes

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تأثير منظم القوى على الاتزان الإستاتيكي لأنظمة القوى الكهربائية

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ملخص البحث. إن التوسع السريع في أنظمة النقل والتوليد الكهربائية للأنظمة السريعة النمو يتطلب استمرارية تحديث خصائص الشبكة الاستقرارية. ويعتبر استخدام منظم القوى من وسائل تقوية استقرارية الشبكات الكهربائية. لذلك فإن هدف هذا البحث هو دراسة تأثير منظم القوى على خصائص النظم الكهربائية المتواجدة في المنطقة الوسطى ـ المملكة العربية السعودية. ويتناول البحث طريقة اختيار أماكن هذه المنظمات وكذلك مصدر الداخل لمنظم القوى. وسوف تستخدم الأيجن فاليو وحساسيتها كمرشد في اختيار عوامل المنظم للحصول على منطقة استقرار مقبولة.

وهذه الدراسة من الممكن استخدامها لمساعدة المسئولين في شركات الكهرباء لتحديد استخدامات هذه المنظمات من عدمه.