การปรับปรุง Oscillation damping ของระบบไฟฟ้ากำลังประเทศลาว โดยการใช้ตัวเพิ่มเสถียรภาพ
Oscillation Damping Improvement in the Lao PDR Power System by Power System Stabilizer

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บทคัดย่อ

บทความนี้นำเสนอการปรับปรุง การแดมพ์การแกว่งไกว (Oscillation damping improvement) ที่เกิดขึ้นในระบบส่งกำลังไฟฟ้าที่เชื่อมโยงระหว่างการไฟฟ้าลาวและการไฟฟ้าฝ่ายผลิตแห่งประเทศไทย ซึ่งการแกว่งไกวนี้เกิดขึ้นระหว่างโรงไฟฟ้าใน สปป.ลาว กับโรงไฟฟ้าที่ติดตั้งอยู่ในระบบของการไฟฟ้าฝ่ายผลิตแห่งประเทศไทย ดังนั้นการติดตั้งตัวเพิ่มเสถียรภาพ (Power System Stabilizer, PSS) ที่เครื่องกำเนิดโรงไฟฟ้าพลังน้ำเขื่อนน้ำงึ่ม 1 สามารถเพิ่มค่าแดมพ์ปิงของโหมดแกว่งไกวเนื่องจากความเฉื่อยของเครื่องกำเนิดไฟฟ้าได้ ตัวเพิ่มเสถียรภาพได้ถูกออกแบบ ให้มีการชดเชยเฟสแบบนำหน้า โดยใช้การเปลี่ยนแปลงความเร็วรอบของเพลา เป็นสัญญาณอินพุท โดยประยุกต์ทฤษฎีการควบคุมโหมด (Modal Control) ในการหาค่าพารามิเตอร์ที่เหมาะสมของตัวควบคุมของ PSS ผลการจำลองระบบ ที่ได้ติดตั้งคัวเพิ่มเสถียรภาพที่เครื่องกำเนิดไฟฟ้าโรงไฟฟ้าพลังน้ำเขื่อนน้ำงึ่ม 1 โดยใช้โปรแกรม PSS/E แสดงให้เห็นว่าสามารถปรับปรุง Oscillation damping ในระบบสายส่งเชื่อมโยงได้เป็นอย่างดี

Abstract

This paper presents a damping improvement for the Lao PDR-EGAT R2 Thailand tie-line power oscillation mode. This oscillation mode corresponds to an electromechanical oscillation mode between the Nam Ngum 1 generator in the Lao PDR system and machines in the EGAT system. This mode is partially influenced by the Nam Ngum 1 in the Lao PDR system. A power system stabilizer (PSS) will be installed at

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the Nam Ngum 1 generator to improve the initial mode damping of the machine. The designed PSS is a lead-lag compensation employing the generator angular speed deviation as the input signal. By applying modal control theory, suitable parameter values for the PSS can be determined. From the simulation using the PSS/E program, the designed PSS at the Nam Ngum 1 generators can significantly improve the tie-line oscillation as required.

คำสำคัญ: การวิเคาะเสถียรภาพพลศาสตร์, การปรับปรุงการแดมพ์การแกว่งไกว, การติดตั้งตัวเพิ่มเสถียรภาพ, ทฤษฎีการควบคุมโหมด

Keywords: Dynamic Stability Analysis, oscillation damping improvement, power system stabilizer, modal control theory.

Introduction

Poor damping of oscillations under small signal perturbations were determined in the EDL Lao PDR power system in a case study (Sadettan, 2008). The Commercial Program Power System Simulation for Engineering was used to perform an examination in time and frequency domain simulations (PSS/E, 2002; Maneerat, 2004). The time domain simulation curve result exposed oscillation of the power system. In frequency domain results, eigenvalues were analyzed associated with the poor damping ratio which indicates oscillations. Low frequency inter-area oscillation of 0.09891 Hz was determined between EDL and EGAT-R2 system, influenced by generators at Nam Pong thermal plant of EGAT-R2 system indicated by their participation factors in the electromechanical modes. Low frequency local-area oscillation of 1.9615 Hz was also determined in the group of machines in the EDL system.

The improvement of the phenomena of stability of synchronous machines under small perturbation by examining the case of a single machine connected to a large system through an external impedance has been studied (Demello and Concordia, 1969; Padiya, 1995). A Power System Stabilizer (PSS) is proposed to improve system damping. Time domain and eigenvalue analysis is used to examine the EDL and EGAT-R2 system dynamics.

As the Nam Pong thermal plant belongs to EGAT, this study is limited to considering the installation of the proposed PSS internally only for the Nam Ngum 1 machines in the EDL system. The proposed PSS design procedure is presented. The response results were observed for both inter-area and local area oscillations.

Nomenclature

H	inertia constant	E_{fd}	equivalent exciter voltage
δ	angle between quadrature axis and infinite bus voltage	E'_{q}	voltage proportional to d-axis flux linkages
ω	angular speed	T_{R}	terminal voltage transducer time constant
E_0	infinite bus voltage	V_{ref}	AVR reference signal
$T_{\mathrm{m}}, T_{\mathrm{e}}$	mechanical and electrical torque,	$K_{\mathrm{A}}, T_{\mathrm{A}}$	AVR gain and time constant, respectively
L_{adu}	unsaturated value of direct axis	ω_{s}, v_{S}	stabilizing signal
X_{d}	direct axis reactance	T_{W}	washout time constant
X_{q}	quadrature axis reactance	K_{STAB}	PSS gain
X'_{d}	direct axis transient reactance	T_1-T_2	PSS time constant
X_{l}	leakage reactance	i_{fd}	field current
R_{a}	stator resistance per phase	R_{fd}, L_{fd}	field winding resistance and inductance,
R_{e}, X_{e}	equivalent resistance and Inductance	$K_1 \sim K_6$	constants of the linearized model of synchronous machine

Power system model of Lao PDR system investigation

Figure 1. shows the Central 1 power system of EDL Lao PDR which consists of Nam Ngum 1 hydroelectric plant of 154MW, Nam Leuk hydroelectric plant of 60MW, Nam Mang 3 hydroelectric plant of 40MW, 13 power transformer substations and 19 circuits of 115kV transmission line. Central 1 is connected to the EGAT-R2 Thailand system by 115kV tie lines with 3 circuits at Phonetong S/S and 1 circuit at Pakxan S/S. A single machine-infinite bus (SMIB) system (Figure 2.) was used as the design model, and machines of Nam Ngum 1 were used for this purpose. Phonetong node bus connects to the main load in this area and also ties in with the large system of EGAT-R2 represented as an infinite bus. A machine connected to a large system through a transmission line may be reduced to a SMIB system, by using Thevenin's equivalent for the transmission network external to the machine. Because of the relative size of the system to which the machine is supplying power, the dynamics associated with the machine will cause virtually no change in the voltage and frequency of the Thevenin's voltage E_0 (infinite bus voltage). The Thevenin equivalent impedance shall henceforth be referred to as the equivalent impedance (i.e. $R_e + jX_e$).

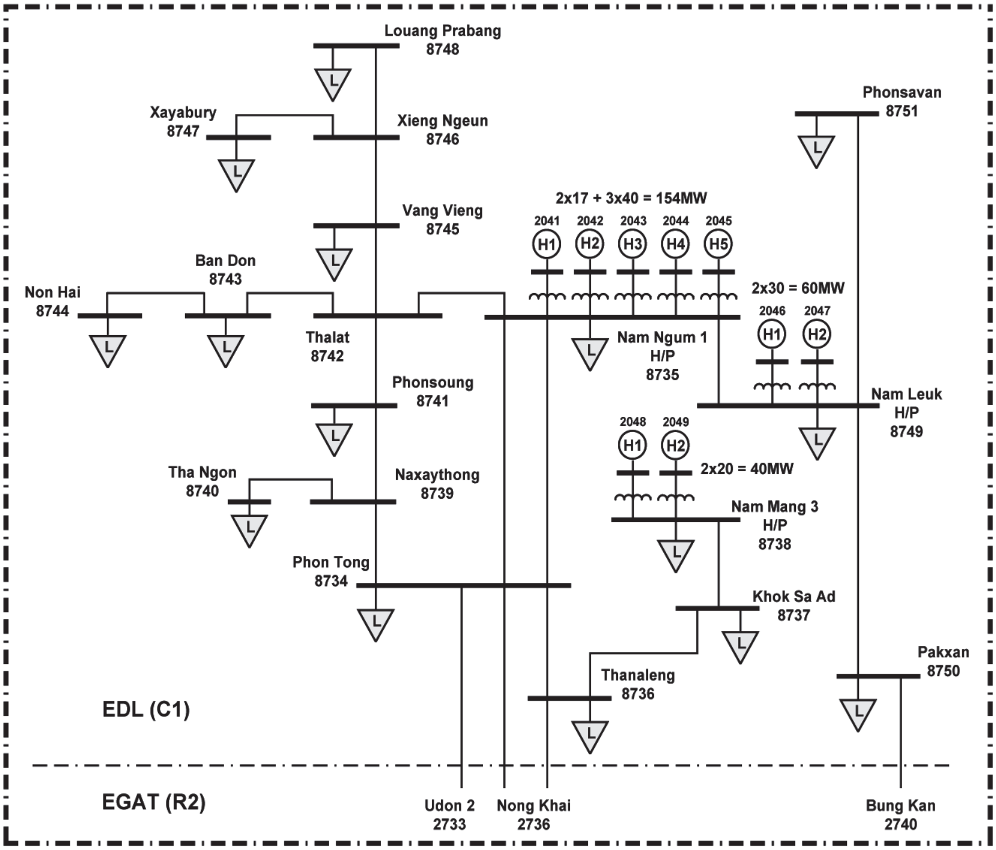

Figure 1. EDL and EGAT-R2 power system

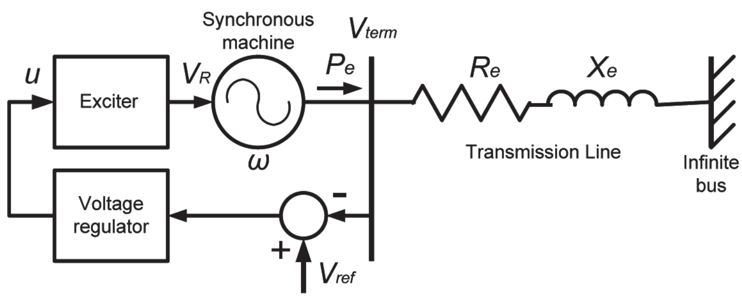

Figure 2. Single machine-infinite bus system

The nominal parameters and the nominal operating condition of the system are calculated. The Simplified Excitation System (SESX) model has been considered. A conventional PSS comprising cascade connected lead networks with generator angular speed deviation ($\Delta\omega$) as input signal had been considered.

The power system model is linearized at a particular equilibrium point to obtain the linearized system model given in the state-space form (Kundur, 1993)

$$\Delta x(t) = A\Delta x + B\Delta u, \qquad (1)$$

$$\Delta y = C\Delta x \qquad (2)$$

where Δ denotes the perturbation of the states, input and outputs from their equilibrium values, with

$$x = [\delta \quad \omega \quad E_q^{'} \quad \psi_d \quad E_q^{'} \quad \psi_q \quad V_R]^T \qquad (3)$$

$$y = [V_{term} \quad \omega \quad P_e]^T \qquad (4)$$

The constants of the linearized model of the synchronous machine are

$$K_1 = \frac{E_{q0}E_0}{A'}\left[R_e \sin\delta_0 + (X_e + X_d^{'})\cos\delta_0\right] + \frac{i_{q0}E_0}{A'}\left[(X_q - X_d^{'})(X_e + X_q)\sin\delta_0 - R_e(X_q - X_d^{'})\cos\delta_0\right] \qquad (5)$$

$$K_2 = \left[\frac{R_e E_{q0}}{A'} + i_{q0}\left(1 + \frac{(X_e + X_q)(X_q - X_d^{'})}{A'}\right)\right] \qquad (6)$$

$$K_3 = \left[1 + \frac{(X_e + X_q)(X_d - X_d^{'})}{A'}\right]^{-1} \qquad (7)$$

$$K_4 = \frac{E_0(X_d - X_d^{'})}{A'}\left[(X_e + X_q)\sin\delta_0 - R_e\cos\delta_0\right] \qquad (8)$$

$$K_5 = \frac{E_{do}}{E_{to}}X_q\left[\frac{R_e E_o \sin\delta_o + (X_e + X_d^{'})E_o\cos\delta_o}{A'}\right] + \frac{E_{qo}}{E_{to}}X_d^{'}\left[\frac{R_e E_o\cos\delta_o - (X_e + X_q)E_o\sin\delta_o}{A'}\right] \qquad (9)$$

$$K_6 = \frac{E_{qo}}{E_{to}}\left[1 - \frac{X_d^{'}(X_e + X_q)}{A'}\right] + \frac{E_{do}}{E_{to}}X_q\frac{R_e}{A'} \qquad (10)$$

where $A' = [R_e^2 + (X_e + X_d^{'})(X_q + X_e)]$ and

$$A = \begin{bmatrix} -\frac{K_D}{2H} & -\frac{K_1}{2H} & -\frac{K_2}{2H} & 0 \\ 2\pi f_o & 0 & 0 & 0 \\ 0 & -\frac{K_4}{T_{do}^{'}} & -\frac{1}{T_{do}^{'}K_3} & \frac{1}{T_{do}^{'}} \\ 0 & -\frac{K_A K_5}{T_A} & -\frac{K_A K_6}{T_A} & -\frac{1}{T_A} \end{bmatrix} \quad (11) \qquad B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{K_A}{T_A} \end{bmatrix} \quad (12) \qquad C = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} \quad (13)$$

Figure 3. Shows the small perturbation transfer function block diagram of the SMIB system relating the pertinent variables of electric torque, speed, angle, terminal voltage, field voltage and flux linkages. This linear model has been developed by linearizing the nonlinear differential equations around the nominal operating point.

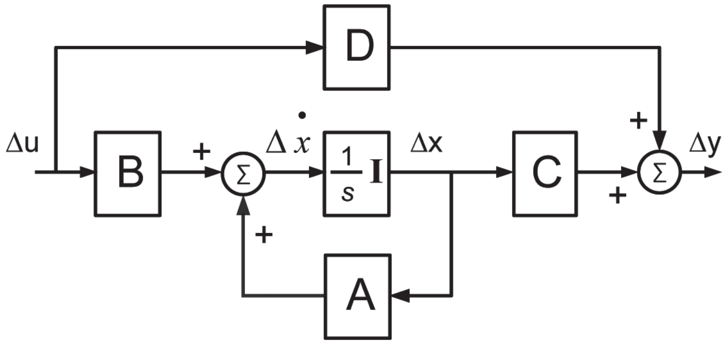

Figure. 3 Block diagram of the state-space representation

Transfer Function model of the power system stabilizer and design considerations

Figure 4. represents a transfer function block diagram of the system, through which an electrical torque is produced in response to a speed deviation signal, $\Delta\omega$, where *H*(s) is a transfer function of the system whose output is electrical torque and input is the stabilizing signal. In order to increase the damping of the rotor oscillations, a PSS utilizing shaft speed deviation as input signal must compensate for the phase-lag of H(s) to produce a component of the torque in phase with the speed deviation (Anderson and Fouad, 1977; Peerachat, 1996). The transfer function of a PSS is represented as:

$$\frac{V_S(s)}{\Delta\omega(s)} = H(s) = K_{STAB}\left[\frac{(sT_W)}{(1+sT_W)}\right]\left[\frac{(1+sT_1)(1+sT_3)}{(1+sT_2)(1+sT_4)}\right] \tag{14}$$

Modal Control theory can be well adapted for the design of the auxiliary control in a general linear system (Yao-nan Yu, 1983; Sumrit, 1990), by taking the Laplace transform of the above equations (7) and (8), and forming state space equations in the frequency domain (refer also to Figure 3.):

$$
\begin{aligned}
&\Delta \dot{x}(t) = A\Delta x + B\Delta u, \\
&\Delta y = C\Delta x \\
&sX(s) = AX(s) + BU(s) && (15) \\
&sX(s) - AX(s) = BU(s) \\
&X(s)(sI - A) = BU(s) && (16) \\
&Y(s) = CX(s) && (17)
\end{aligned}
$$

the input of the system is the PSS output signal, shown as:

$$U(s) = H(s)Y(s) \quad (18)$$

from (16)

$$
\begin{aligned}
X(s) &= (sI - A)^{-1} BU(s) \\
&= (sI - A)^{-1} BH(s)Y(s) \\
&= (sI - A)^{-1} BH(s)CX(s)
\end{aligned}
$$

then

$$H(s) = [C(sI - A)^{-1} B]^{-1} \quad (19)$$

The equations (14) and (19) must be equal, so

$$K_{STAB}\left[\frac{(sT_W)}{(1+sT_W)}\right]\left[\frac{(1+sT_1)(1+sT_3)}{(1+sT_2)(1+sT_4)}\right] = [C(sI - A)^{-1} B]^{-1} \quad (20)$$

Let λ be an eigenvalue of the poorly damped oscillation mode and replace the value of s by λ. Equations (18) and (19) become:

$$
\begin{aligned}
&H(\lambda) = [C(\lambda I - A)^{-1} B]^{-1} \\
&K_{STAB}\left[\frac{(\lambda T_W)}{(1+\lambda T_W)}\right]\left[\frac{(1+\lambda T_1)(1+\lambda T_3)}{(1+\lambda T_2)(1+\lambda T_4)}\right] = [C(\lambda I - A)^{-1} B]^{-1} \quad (21)
\end{aligned}
$$

where we know the results of matrix A, B, C and selected eigenvalue λ as required.

For conventional PSS (i.e $T_1 = T_3$ *and* $T_2 = T_4$) (Ravi, Avdhesh and Kothari, 2004), the parameters of the PSS to be calculated are K_{STAB} and T_1 , and so the equation (14) becomes

$$H(s) = K_{STAB} \frac{(\lambda T_W)}{(1+\lambda T_W)} \frac{(1+\lambda T_1)^2}{(1+\lambda T_2)^2} \tag{22}$$

$$K_{STAB} = \frac{(1+\sigma T_2 + j\omega_d T_2)^2}{(1+\sigma T_1 + j\omega_d T_1)^2} \left[1 + \frac{1}{(\sigma + j\omega_d) T_W} \right] H(\sigma + j\omega_d) \tag{23}$$

Letting

$$F\angle\theta = (1+\sigma T_2 + j\omega_d T_2)^2 \left[1 + \frac{1}{(\sigma + j\omega_d) T_W} \right] H(\sigma + j\omega_d) \tag{24}$$

$$K_{STAB} = \frac{F\angle\theta}{(1+\sigma T_1 + j\omega_d T_1)^2} \tag{25}$$

$\therefore$

$$K_{STAB} = F\left|(1+\sigma T_1 + j\omega_d T_1)^{-2}\right| \tag{26}$$

And

$$\theta = \tan^{-1}\left[\frac{2\omega_d T_1 (1+\sigma T_1)}{(1+\sigma T_1)^2 - (\omega_d T_1)^2} \right]$$

$\therefore$

$$T_1 = \frac{-(\sigma \tan\theta - \omega_d) \pm \omega_d \sqrt{1+\tan^2\theta}}{\sigma^2 \tan\theta - \omega_d^2 \tan\theta - 2\omega_d \sigma} \tag{27}$$

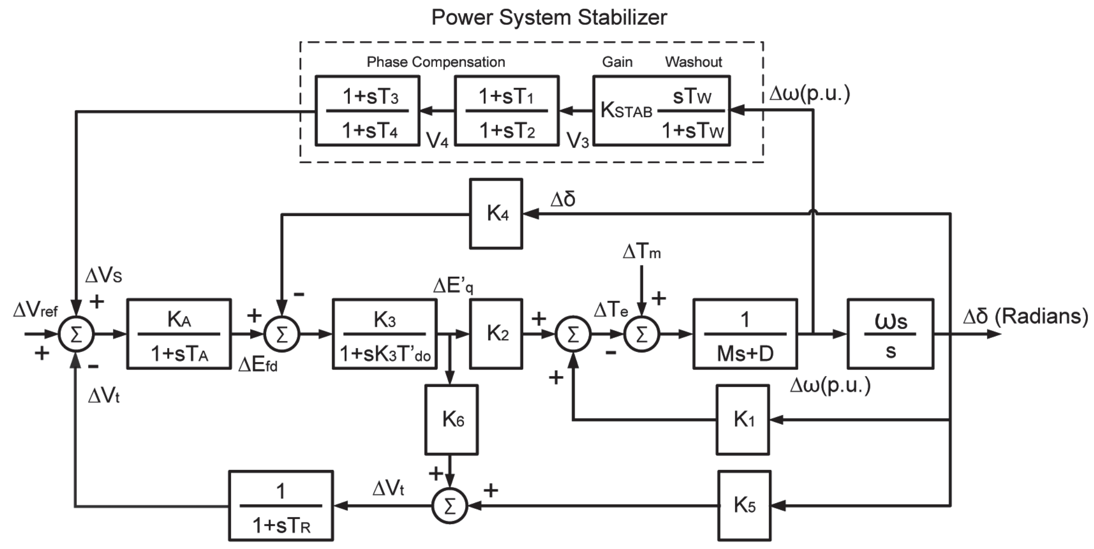

Figure 4. Small perturbation transfer function block diagram of a single machine-infinite bus associated with conventional PSS

Case study

From the small signal perturbation case study of Lao and EGAT-R2 power systems (Sadettan, 2008), the poorly damped modes were found. As mentioned in the introduction above, the strongest influences on the oscillation modes were in the EGAT-R2 system which is under EGAT responsibility. Therefore, the proposed PSS is to be designed and installed only for the machines in the EDL system. A low frequency inter-area oscillation of 0.09891 Hz is selected for the design, associated with the poor damping ratio $\zeta_{75,76} = 0.055857$, and eigenvalue with real part $\sigma_{75,76} = 0.034768$; imaginary part $\omega_{d\ 75,76} = 0.62147$.

Figure 5. shows a single line diagram of Nam Ngum 1 hydropower plant connected to the large system of the infinite bus Phonetong substation, which is further connected to the EGAT-R2 power network. The equivalent system is shown in Figure 6. as an impedance diagram of the SMIB system. The hydro generator number 2041 at Nam Ngum 1 was selected for the PSS design. All data are known in per unit of value, except that M and time constants are in seconds (EDL, 2004).

Generator	$H = 1.9313$	$T'_{do} = 5$	$D = 0$
	$x_d = 1.054$	$x'_d = 0.512$	$x_q = 0.67$
Excitation	$K_A = 300$	$T_A = 1$	

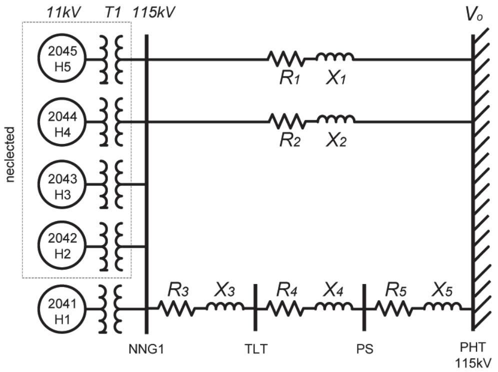

Figure 5. Single line diagram of Nam Ngum 1 H/P connected to the infinite bus at Phonetong S/S.

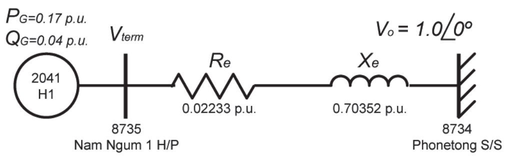

Figure 6. Equivalent system of single machine connected to a large system through a transmission line.

The values of initial operation state were calculated, giving:

$I_r = 0.1693$ p.u.	$\Phi = 13.24°$	$I_x = -0.7995$	$I_a = 0.8172$
$\Theta = -78.0395°$	$V_{tr} = 1.5586$	$V_{tx} = 0.1013$	$V_t = 1.5619$
$B = 3.7181°$	$\delta = 5.8339°$	$\gamma = 15.3563°$	$I_d = -0.2164$
$I_q = 0.7880$	$\alpha = 2.1158°$	$V_d = -0.0577$	$V_q = 1.5609$
$E_q = 1.7890$	$E_{qa} = 1.7059$		

and the constants K1 ~ K6 in p.u for the operating point to be analyzed are:

$K_1 = 1.2462$	$K_2 = 0.9132$	$K_3 = 0.6917$
$K_4 = 0.0381$	$K_5 = -0.04937$	$K_6 = 0.5788$

Calculation of parameters for PSS.

$$A=\begin{bmatrix} 0 & -1.20343 & -0.88187 & 0 \\ 314.16 & 0 & 0 & 0 \\ 0 & -0.00762 & -0.13833 & 0.2 \\ 0 & 14.81145 & -173.65298 & -1 \end{bmatrix},\quad B=\begin{bmatrix} 0 \\ 0 \\ 0 \\ 600 \end{bmatrix},\quad C=\begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

The state space to transfer function conversion is

$$H(s)=\frac{-1.0582\ s}{0.0001\ s^4+0.0001\ s^3+0.0413\ s^2+0.0428\ s+1.4001} \tag{28}$$

From the case study (Sadettan, 2008) the poorly damping ratio is $\zeta_{75,76}$ = 0.055857 and the eigenvalue $\lambda_{75,76}$ has real part $\sigma_{75,76}$ = 0.034768 and imaginary part $\omega_{d\ 75,76}$ = 0.62147. Now, the new damping ratio desired is ζ_{new} = 0.3, but the remaining natural frequency is $\omega_{n\ 75,76}$ as in equation (29). Then, the new real part σ_{new} and new imaginary part $\omega d_{.new}$ of the new eigenvalue were found as in equations (30) and (31) respectively as below.

$$\omega_n=\sqrt{\sigma^2+\omega_d{}^2} \tag{29}$$

$$\sigma_{new}=-\zeta_{new}\times\omega_n \tag{30}$$

$$\omega_{d\cdot new}=\omega_n\sqrt{1-\zeta_{new}^2} \tag{31}$$

To describe the calculation procedure, category 1 is explained as ζ_{new} = 0.3, then σ new = -0.186733, $\omega d_{.new}$ = 0.593772 and the new eigenvalue is λ_{new} = -0.186733 ± j 0.593772. For the new eigenvalue, the above transfer function *H(s)* equation (28) calculation is *H(λ)* = - 0.1372 ± j 0.4567. Washout time T_W is not critical in the range of 1- 20 s, in this case T_W = 10 s and T_2 = 0.05 s are desirable. From equation (24) F <θ= -0.5742 ± j0.2153 (0.6133<2.7829 rad). Then from the designed PSS gain equation (26), K_{STAB} = 0.8137 and from equation (27) T_1 = 3.3968 s. Table 1 shows the calculation results as below:

Table 1. PSS's Gain and time constant calculation results using Excel's solver and MATLAB

Category	Proposed Damping Ratio ζ	New Eigenvalue		K_{STAB}	T_1
		σ	ω_d		
1	0.3	- 0.186733	0.593772	0.8137	3.3968
2	0.35	- 0.217855	0.583072	0.7533	3.2124
3	0.4	- 0.248977	0.570477	0.7008	3.0407
4	0.5	- 0.311221	0.539050	0.6144	2.7296
5	0.6	- 0.373465	0.497953	0.5468	2.4553
6	0.7	- 0.435709	0.444512	0.4935	2.2105

Results and Discussions.

1. Time Domain Simulation Results

To verify the damping ratios (Florencio, Fernando, Murcia and Go'mez, 2000) Using commercial software for power system simulation for engineering (PSS/E, 2002), time domain simulations were performed as in Figure 7. to Figure. 14 which show the simulation results of rotor angle deviation in degree versus time in seconds for hydro generator number 2041 H1 at Nam Ngum 1 Hydropower Plant and combined circle thermal generator number 2024 block C21 at Nam Pong Thermal Plant.

Figure 7. shows the rotor angle (degree) versus time (second) domain curve from the previous study without PSS at machines of Nam Ngum 1 H/P, in the case of 0.1 p.u. small load rejection on 115kV line Ban Don 8743-Non Hai 8744. Figure 8. shows the curve in the case of load rejection with PSS at machine 2041 H1 Nam Ngum 1 H/P.

Figure 9. to Figure. 14 show both cases of with and without PSS at all generators 2041 H1~2045 H5 in different designed damping ratios of PSS as indicated in the above Table 1. The simulations were studied in case of line fault condition in 0.1s period in small load 115kV line Ban Don 8743-Non Hai 8744 in the EDL-C1 system.

From time domain simulation results as shown, all categories have sufficient damping. The amplitude is damped to meet the accepted ratio of 5% which means that in 3 oscillation periods about 32% of the initial value should be damped out in amplitude (Witzmann, 2001) in both cases of small signal disturbance as small load rejection and small load line fault.

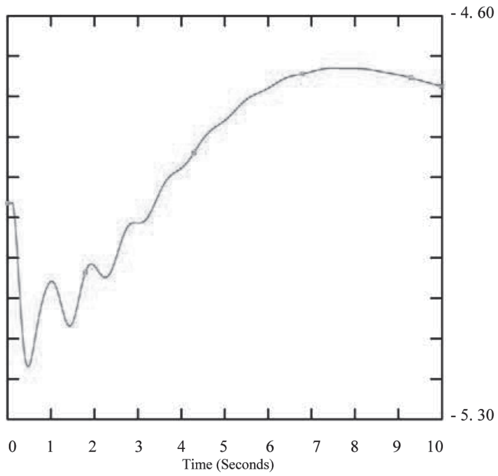

Figure 7. Rotor angle time domain without PSS from pervious study

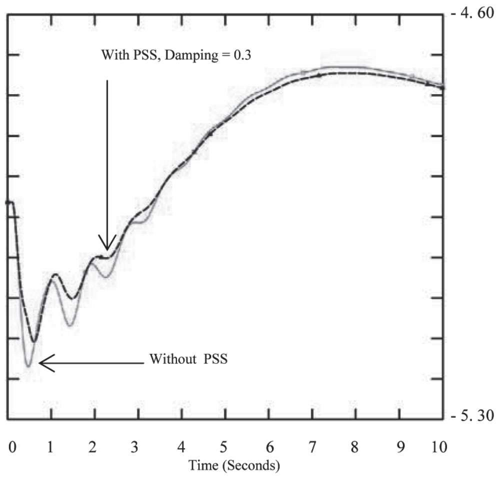

Figure 8. Rotor angle time domain with PSS at designed damping 0.3

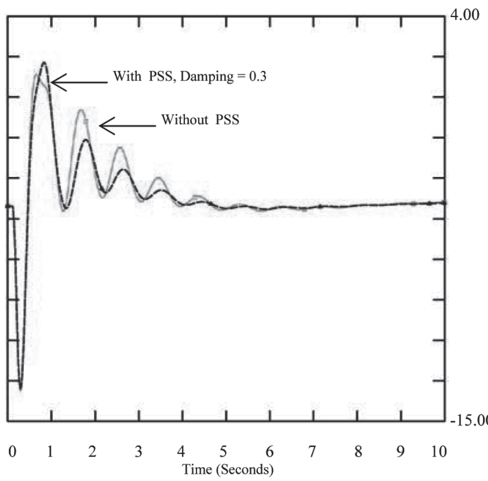

Figure 9. Rotor angle time domain with PSS at designed damping 0.3

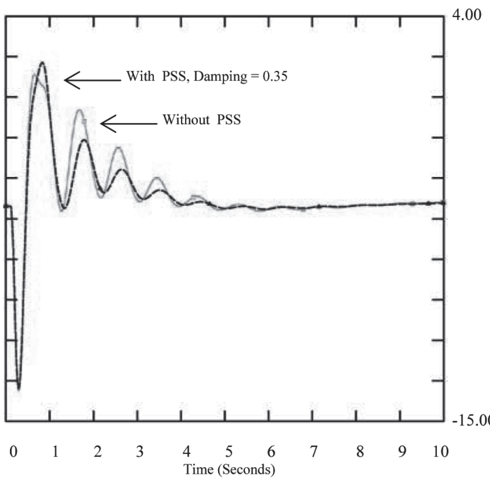

Figure 10. Rotor angle time domain with PSS at designed damping 0.35

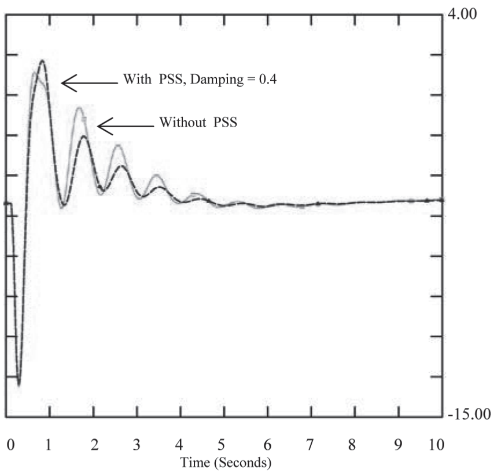

Figure 11. Rotor angle time domain with PSS at designed damping 0.4

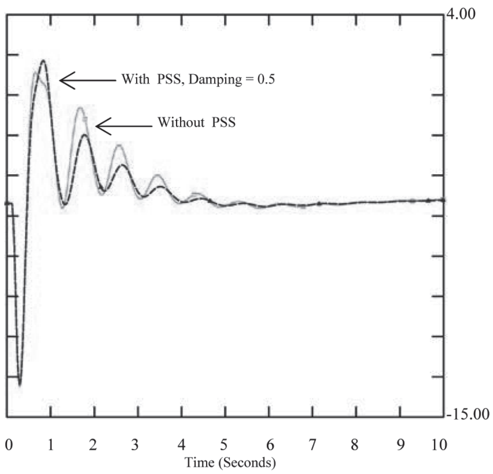

Figure 12. Rotor angle time domain with PSS at designed damping 0.5

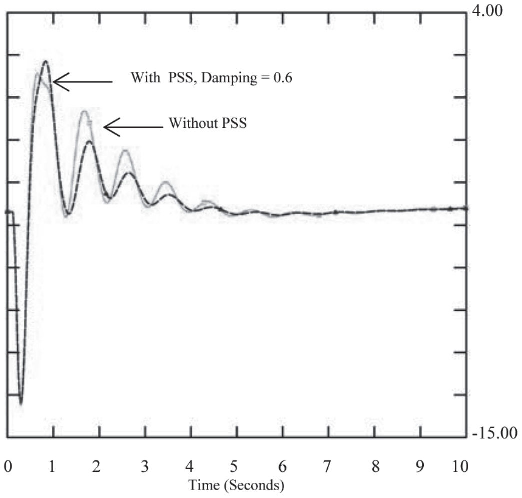

Figure 13. Rotor angle time domain with PSS at designed damping 0.6

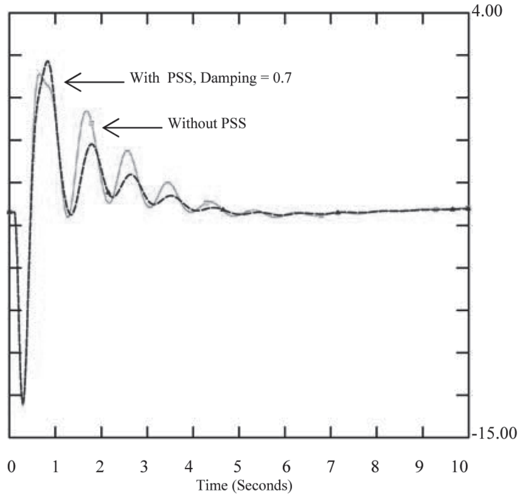

Figure 14. Rotor angle time domain with PSS at designed damping 0.7

2. Frequency Domain Simulation Results

The simulation was performed by disturbing with excitation EFD 0.01 p.u. of generator 2041 H1, with PSSs IEEE standard (IEEEST) at designed damping 0.3 at all machines of Nam Ngum Hydropower plant and the result is as shown in Table 2. The poorly damping oscillation modes were found such as eigenvalue number $\lambda_{7,8}$ with less damping in local area oscillation modes, while the eigenvalue number $\lambda_{79,80}$ has less damping in inter-area oscillation modes.

Table 2. Poorly damping oscillation modes results

EIGENVALUE					OSCILLATORY INSTABILITY
No.	Real	Imag.	Damping	Frequency	
7	**-1.1580**	**12.304**	**0.093702**	**1.9582**	Local mode
8	**-1.1580**	**- 12.304**	**0.093702**	**1.9582**	Local mode
41	-0.89546	9.3828	0.095004	1.4933	Local mode
42	-0.89546	-9.3828	0.095004	1.4933	Local mode
79	**-0.018964**	**0.68604**	**0.027632**	**0.10919**	Inter-Area mode
80	**-0.018964**	**-0.68604**	**0.027632**	**0.10919**	Inter-Area mode

Table 3 shows a summary of the normalized participation factor of elements to eigenvalue number $\lambda_{7,8}$ of local area oscillation mode. This result shows the strongly influenced hydro generators are 2048 H1 and 2049 H2 of Nam Mang 3 H/P. Considering the factor results, most of the modes of Nam Ngum 1 H/P machines 2041 H1~ 2045 H5 with PSS are not influenc to the local area oscillation modes. This means that the installation of PSS with appropriate parameters at NamNgum 1 H/P machines is able to improve local area oscillation mode under small perturbations.

Table 4 shows a summary of the normalized participation factor of elements to system eigenvalues number $\lambda_{79,80}$ of inter-area oscillation modes. This result shows only the factor of the most strongly influenced machines to the poor system damping. Considering the factor result, the strongly influenced machines are Nam Pong machines of EGAT-R2 which have large capacity in this area. Some modes of Nam Ngum 1 H/P machine with PSS influenced the inter-area oscillation modes and the machines of Nam Pong thermal plant have the strongest influence on this oscillation.

This means that the installation of PSS at Nam Ngum 1 H/P machines is most efficient for improving the local area oscillation modes. However, it is less efficient for inter-area oscillatory damping modes, due to their group total capacity being smaller compared to the Nam Pong thermal plant unit.

Table 3. The normalized participation factors for eigenvalues and localarea oscillation modes with PSS damping 0.3 at Nam Ngum machine H1~H5

Eigenvalues # 7, 8 = - 1.1580 ± j 12.3040, Damping = 0.093702, Frequency = 1.9582, Local area oscillation modes						
FACTOR	**ROW**	**STATE**	**MODEL**	**BUS**	**NAME**	**ID**
1.00000	**153**	**K+4**	**GENSAL**	**2048**	**NM3 H1 11.0**	**1**
0.99996	**158**	**K+4**	**GENSAL**	**2049**	**NM3 H2 11.0**	**2**
0.98704	**152**	**K+3**	**GENSAL**	**2048**	**NM3 H1 11.0**	**1**
0.98700	**157**	**K+3**	**GENSAL**	**2049**	**NM3 H2 11.0**	**2**
0.11339	151	K+2	GENSAL	2048	NM3 H1 11.0	1
0.11338	156	K+4	GENSAL	2049	NM3 H2 11.0	2
0.04842	103	K+4	GENSAL	2042	NNG H2 11.0	2
0.04831	102	K+3	GENSAL	2042	NNG H2 11.0	2
0.02431	154	K	GENSAL	2049	NM3 H2 11.0	2
0.02430	149	K	GENSAL	2048	NM3 H1 11.0	1
0.01759	118	K+4	GENSAL	2045	NNG H5 11.0	5
0.01759	117	K+3	GENSAL	2045	NNG H5 11.0	5
0.01753	113	K+4	GENSAL	2044	NNG H4 11.0	4

Table 4. The normalized participation factors for eigenvalues and inter-area oscillation modes with PSS damping 0.3 at Nam Ngum machine H1~H5

Eigenvalues # 79, 80 = - 0.018964 ± j 0.68604, Damping = 0.027632, Frequency = 0.10919, Inter-area oscillation modes						
FACTOR	**ROW**	**STATE**	**MODEL**	**BUS**	**NAME**	**ID**
1.00000	**62**	**K+5**	**GENROU**	**2025**	**NPO2 C22 9.90**	**22**
0.99955	**61**	**K+4**	**GENROU**	**2025**	**NPO2 C22 9.90**	**22**
0.91557	**55**	**K+4**	**GENROU**	**2024**	**NPO2 C21 9.90**	**21**
0.91540	**56**	**K+5**	**GENROU**	**2024**	**NPO2 C21 9.90**	**21**
0.76436	98	K+4	GENSAL	2041	NNG H1 11.0	1
0.67835	94	K	GENSAL	2041	NNG H1 11.0	1
0.66700	68	K+5	GENROU	2026	NPO2 C20 9.90	20
0.66548	67	K+4	GENROU	2026	NPO2 C20 9.90	20
0.61878	168	K+4	IEEEST	2041	NNG H1 11.0	1
0.59235	219	K	SEXS	2041	NNG H1 11.0	1

Table 5 shows a comparison of system eigenvalues before and after the proposed PSS sitting at a group of machines at Nam Ngum 1 H/P in both local area and inter-area oscillation modes. There are some system eigenvalues which improved as their damping ratio increased such as eigenvalues λ5,6 of local area oscillations; l75,76 for inter-area oscillation. The damping ratio of eigenvalue λ41,42 is unchanged for the local area oscillation modes, while in the inter-area oscillation the damping ratio of eigenvalue λ75,76 increased, but the damping ratio of the eigenvalue λ79,80 decreased.

Table 5. Damping improvement comparison of eignenvalues in different case studies with and without PSS at Nam Ngum 1 H/P machine

Eigenvalues						**Case**	**Oscillatio n**
Number	**Real**	**Imag.**	**Damping ratio**	**Freq.**	**Influenced machine**		**mode**
5, 6	-1.1666	± j12.324	0.094239	1.9615	NM3 H1	Without PSS,Case study*	Local
	-2.6103	± j12.411	0.20582	1.9752	NM3 H1	With PSS H1~5,Chap. V	Local
7, 8	-2.5212	± j12.266	0.20133	1.9522	NM3 H1	Without PSS,Case study*	Local
	-1.15800	± j12.304	0.093702	1.9582	NM3 H1	With PSS H1~5, Chap. V	Local
41, 42	-0.08954	± j9.3828	0.095004	1.4933	NLEK H2	Without PSS,Case study*	Local
	-0.89546	± j9.3828	0.095004	1.4933	NLEK H2	With PSS H1~5, Chap. V	Local
75, 76	- 0.0347	± j0.6214	0.055857	0.09891	NPO2 C22	Without PSS,Case study*	Inter-area
	-1.0007	± 0.7400	0.80403	0.11778	NPO2 C22	With PSS H1~5, Chap. V	Inter-area
79, 80	-0.56265	± j0.6073	0.67958	0.09666	NPO2 C22	Without PSS,Case study*	Inter-area
	-0.01896	± j0.6860	0.027632	0.10919	NPO2 C22	With PSS H1~5, Chap. V	Inter-area

Without PSS, case study* (Sadettan, 2008)

Conclusions

This paper presents a system damping improvement by using PSS at Nam Ngum 1 machines. The proposed PSS design procedure is introduced systematically.

A PPS is designed to improve the damping of the Nam Ngum 1 generator using modal control theory. Calculated lead-lag PSS parameters are used in the simulation to determine the effectiveness of the PSS. The time domain simulation results reveal the efficiency of the proposed PSS to improve system damping both of inter-area and local area oscillations as desired.

Using modal control to design the proposed PSS has been demonstrated to be very significant at helping to initiate the installed PSS with appropriate parameters before re-tuning at the actual system training stage. The methodology and the application of this study would be helpful for EDL to be able to analyze and to improve system stability on the existing and on a planning system before the system modification is undertaken.

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