International J. of Recent Trends in Engineering and Technology, Vol. 3, No. 3, May 2010

Signals Selection of TCSC Device for Damping Oscillation

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***Abstract*—This paper proposes Eigen value analyses to assess the most appropriate input signals (stabilizing signal) for supplementary damping control of TCSC. The Right-Half Plane zeros (RHP-zeros) and Hankel Singular Value (HSV) is used as tools to select the most receptive signal to a mode of the Interarea oscillation. The effectiveness of the proposed method of selection of signals is demonstrated on practical network of 25 bus south Malaysian Power system**

***Index Terms*: TCSC, Power system oscillations, linear models, eigenvalues, HSV, and RHP zeros**

I. INTRODUCTION

Damping of electromechanical oscillations between interconnected synchronous generators is necessary for a secure system operation. Power system stabilizers (PSSs) are effective for controlling system oscillations but are usually designed for damping local electromechanical oscillations. The behaviour of low frequency inter-area oscillations is generally determined by global parameters of larger parts of the power system. The limited influence on inter-area modes, however, leads us to the fact that they may not be considered as the only solution to damp inter-area oscillations. Flexible AC Transmission Systems are being increasingly used to improve the utilization capacity of the existing transmission systems.

Flexible AC Transmission System (FACTS) is a technology based solution to help the utility industry deal with changes in the power delivery business. A major thrust of FACTS technology is the development of power electric based systems that provide dynamic control of the power transfer parameters transmission voltage, line impedance and phase angle [1].

The thyristor Controlled Series Capacitor (TCSC), which is a series device, provides dynamically variable series impedance to regulate the power at a line where it is connected [1, 2]. Application of TCSC device for evaluating system damping using various techniques are reported in the literature [3-9], and the usefulness of damping the oscillations depend on the location of TCSC controllers and signal selection.

The selection of appropriate feedback signal to FACTS controllers and effective tuning for improving the damping controls is an important consideration. According to [3, 10, 11] the most suitable supplementary input signals are locally measured transmission line-current magnitude or locally measured active power. In [12, 13] used generator angular speed as a supplementary input signal.

Farsangi et al [14, 15] proposed a method for selecting suitable feedback signal to FACTS controllers for improving the damping. She used the Minimum Singular Values (MSV), the Right-Half Plane zeros (RHP-zeros), the Relative Gain Array (RGA) and the Hankel Singular Values (HSV) as indicators to find stabilizing signals in the single-input single-output (SISO) and multi-input-multi-output (MIMO) systems. But she did not suggest any criterion for placing FACTS controllers.

In this paper, the best selection of the input signals for TCSC device proposed by [14, 15] has also been applied in this paper and extended to practical system that is TNB 25 bus system.

II SELECTION OF FEEDBACK SIGNALS FOR TCSC DEVICE

A. Right Hand Plane (RHP) Zeros

Consider an open loop system with a transfer function from output yi to input ui as G(s).

Where

$$G(s)=\frac{b(s)}{a(s)} \quad (1)$$

There may be a finite values of s for which b(s)=0 and these are called the zeros of G(s),likewise the values of s that make a(s)=0 are called pole of G(s), let these zeros be donated as z_i and poles be p_i.

If the open loop system is applied, a constant controller Kp, the closed loop system with negative feedback can be express as

$$G_{closed}(s)=\frac{K_p b(s)}{a(s)+b(s)K_p} \quad (2)$$

From equation (2) the locations of zeros that is zi is maintained while poles location change from a(s)=0 that is pi to [a(s)+b(s)Kp]=0 by the feedback signal. From the same equation (2) we have the following observations:

i) If the feedback gain increases, the closed loop poles will moved from open loop poles to open loop zeros, this may lead to instability [15, 16].

ii) If the feedback gain decreases, the closed loop poles will move to open loop poles.

DOI: 01.IJRTET.03.03.158
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From observation number one, if the open loop zeros are in right half plane then the closed loop poles can change from stable pole to unstable and can lead to pole zero cancellation. Therefore, the selection of feedback signal should be made in such a way that the closed loop system has a minimum number of the RHP-zeros, which are required not to lie within the closed loop bandwidth [14, 16]

B. *Hankel singular values*

The controllability of the input signal and the observability of the feedback signal are very important factors in determine the combination of input-output signals. Application of modal controllability, Observability index of the combination of input –output signals will determine which combination will give more information to internal states of the system.

Consider a stable linear time-invariant model (A, B, C, D) of the standard form from equation in (3) as

$$\dot{x}(t) = Ax(t) + Bu(t),$$
$$y(t) = Cx(t) + Du(t) \qquad (3)$$

Where $x(t) \in R^n, u(t) \in R^m$ and $y(t) \in R^p$ are the state vectors, the input vector and the output vector at time *t*, respectively? The solution P and Q of the system of equations (4) and (5) are known as controllability and observability grammian respectively[11].

$$PA^T + AP + BB^T = 0 \qquad (4)$$
$$QA + A^TQ + C^TC = 0 \qquad (5)$$

The singular value of the product of controllability and observability grammian is

$$\sigma(PQ) = \Sigma = diag[\sigma_1, \sigma_2, ..., \sigma_n] \qquad (6)$$

The $\boldsymbol{\sigma_i}$ is called the Hankel Singular Values (HSV) of the system ordered as $\sigma_1 \geq \sigma_2 \geq .....\sigma_n > 0$. In other words $\sigma_i = \lambda_i (PQ)^{1/2}$, the largest singular value σ_1 by definition is the Henkel norm of the system, that is $\|G\|_H = \sigma_1$.

For choosing input and output signals, the HSV can be calculated for each combination of inputs and outputs, the candidate with the largest HSV shows better controllability and observability properties [11, 14].

III CRITERIA FOR SIGNAL SELECTION

A. *Selecting Stabilizing Input Signals*

In this section the following signals will be taken into accounts which include local and global signals such as *real power*, *reactive power*, and *magnitude of current* in lines, *bus voltages* and *angular speed of the generators*.

The procedure to follow in selecting stabilizing signal for damping controller of the TCSC devices includes Right-Half Plane Zeroes (RHP zeros) and Hankel Singular Value (HSV) and can be described below [17, 18]

Step 1: After placing TCSC, select the stabilizing signal candidates for supplementary control.

Step 2: Check input/output controllability of the signals using the HSV. The candidate with the largest HSV for the same type candidate is more preferred, which shows that the corresponding signal is more responsive to the mode of oscillation.

Step 3: For each chosen candidate for each category of the same type signals, calculate the RHP-zeros. If any RHP-zeros are encountered in the frequency range of 0.1-2 Hz that is undesirable, then the corresponding candidate should be discarded [17].

IV RESULTS AND DISCUSSION

The effectiveness of the proposed method was tested on TNB 25 bus system of south Malaysian network. The results for the system are presented as follows:

A. TNB 25 Bus System

The system consists of 12 generators, five consumers and 37 branches with generator 3 taken as reference generator. The equivalent power system of south Malaysian peninsular is depicted in Figure.1. Modal analysis shows that, in the base case, the critical mode

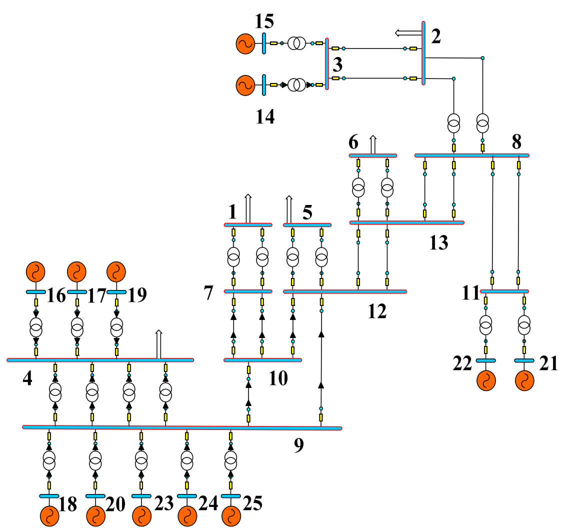

Figure.1 25 Bus equivalent of South Malaysian Peninsular Power System

that is an inter-area mode has an eigenvalues of -0.34325±j5.5454 and damping ratio of 0.06178, which is relatively low. Analysis of phase angle of right eigenvectors and participations factor shows in Figure. 2 and Table 1 respectively that in this inter-area mode, generators G14,G15, G21and G22 oscillates against a group of generators G16, G17,G18,G19 and G25.

B. *Feedback Signal selections*

The choices of feedback signals for the TCSC could be group as follows:

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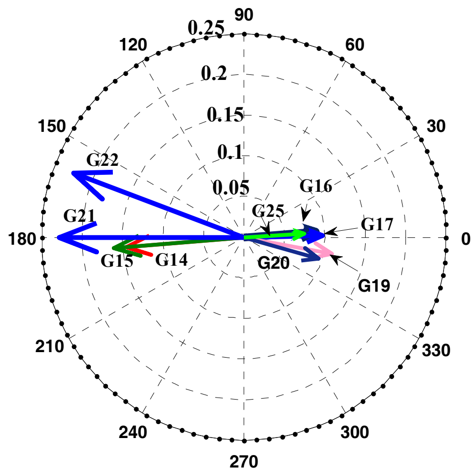

Figure. 2 Interarea mode shapes of rotor angles for TNB 25 Bus

TABLE I
PARTICIPATING FACTORS OF TNB 25 BUS SYSTEM

GROUP 1		GROUP2	
GENERATORS.	NPF	GENERATORS.	NPF
G21	0.21514	G17	0.0518
		G20	0.0493
G22	0.19232	G19	0.04906
		G16	0.03536
G15	0.16216	G25	0.03506
		G23	0.03054
G14	0.09512	G24	0.0304
		G18	0.02268

NPF=Normalized Participation *Factor*

TABLE II
SIGNALS THAT DO NOT ENCOUNTER RHP ZEROS FOR 145-BUS SYSTEMS WITH TCSC DEVICE

Group	Free fault TCSC	Post fault TCSC
1	I2-6 ,I33-49, I3-33 and I9-6	I2-6 ,I33-49, I3-33 and I9-6
2	P1-6, P6-7,P2-6, P33-49 P3-33 and P9-6	P1-6,P6-7 ,P2-6 and P3-33 and P9-6
3	Q1-6,Q6-7,Q2-6 Q33-49 andQ3-33	Q1-6,Q6-7 and Q2-6
4	W_1 W_2 and W_4	W_1 W_2 and W_4
5	V1,V2,andV18	V_1,V_2·V3 andV_{18}

P10-7, P9-12, P12-13, P13-8 and P2-3
I10-7, I9-12, I12-13, I13-8 and I2-3
Q10-7, Q9-12, Q12-13, Q13-8 and Q2-3
W14, W15, W21 and W22

The RHP-zeros of free fault and post fault system are calculated for each group of the selected signals, after discarding all signals that had RHP zeros, the remaining signals in each group are listed in Table2.

To select the best signal among the remaining signals, we next consider the Hankel singular values analysis for each sets and Hankel singular values reflect the joint controllability and observability of the states of a balanced realization as explained in Section IIB. The Henkel singular values are invariant under state transformations but they do depend on scaling.

From Figure. 3 to Figure . 7 and Table 2, the signal that has highest HSV and does not encounter RHP zero is reactive power between bus3 and bus 2. In other word reactive power Q32 contains more information about the system internal states than other output signals therefore it is the final selection of the best signal.

Figure 3 HSV of selected line current signals

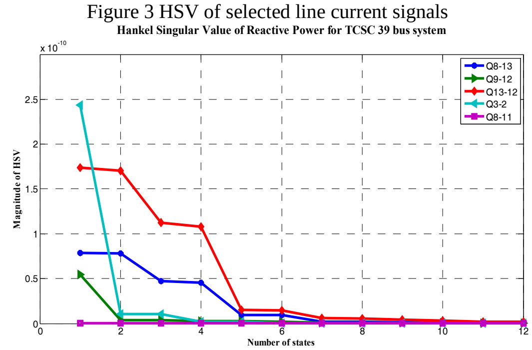

Figure.4 HSV of selected Reactive Power signals

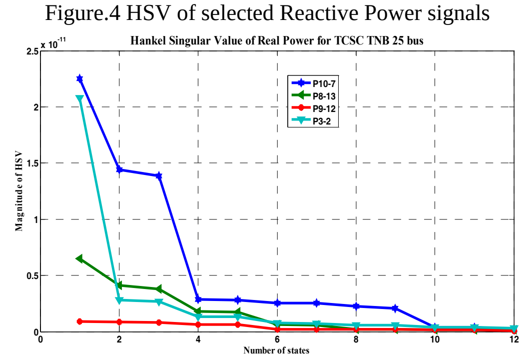

Figure 5 Real Power Response as feedback signal

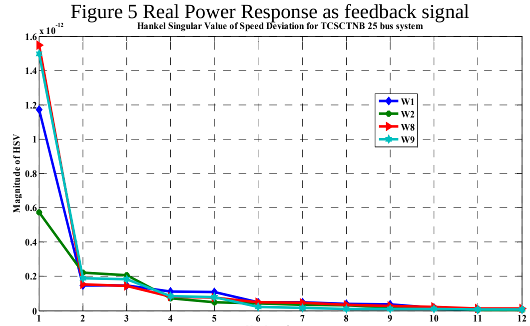

Figure. 6 HSV of selected rotor Speed signal

DOI: 01.IJRTET.03.03.158

V CONCLUSION

The significance of identifying efficient feedback signals for the TCSC device in a power system is highlighted. The selection of signals was carried out based on detailed input-output controllability analysis using RHP zeros and the HSV techniques. From the analysis mentioned above it is concluded that the technique of controllability and observability alone as an analytical tool is not enough to identify the most effective feedback signals.

ACKNOWLEDGMENT

The authors would like to express their appreciation to the Universiti Teknologi Malaysia (UTM) and Ministry of Science Technology and Innovation (MOSTI) for funding this research.

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DOI: 01.IJRTET.03.03.158