Journal of Futuristic Sciences and Applications
Vol. 1(2), Jul-Dec 2018, pp. 39-51
doi: 10.51976/jfsa.121805
www.gla.ac.in/journals/jfsa

SMIB System's Ability to Deal with Low-level Signals Improved with the Implementation of PSS and TCSC

Mohan Gupta and Pankaj Kumar Singh***

ABSTRACT

The stability of the SMIB system in the presence of tiny signals is the major focus of this study. The small signal stability of SMIB is shown first by graphing the eigenvalue associated with rotor oscillations against the gain of the voltage regulator and the machine loading. Second, the very low-level signals that are sent by the SMIB system will be more reliable as a result of the incorporation of the pole placement technique and the use of TCSC in the production of PSS. A comparison is made between the impacts of PSS and TCSC on the oscillations of the rotor's speed and angle. During this last stage of the design process, consideration was given to the selection of a feedback control signal for the PSS. The amount of time it takes to reply to messages is one of the factors that determines how effective they are.

Keywords: *SSS; SMIB; FACTs Devices; Power System Stabilizer (PSS).*

1.0 Introduction

In order to perform an analysis of power systems, one must have keen perception as well as thorough thought due to the increasing complexity of the systems and the wide network of connections between them. Even a very little disruption has the ability to trigger oscillations, which, if allowed to persist, may reach levels that are potentially dangerous and wreak havoc on the electrical system. It is essential that the system be designed in such a way that these oscillations be distinguished, so preventing them from generating any serious concerns. This is because it is essential that the system be structured in such a manner that it is feasible. Because of this, it is necessary to conduct an examination into the behaviour of the system when, "Small signal stability" refers to the degree to which a power system maintains its composure even when subjected to relatively little disturbances such as those described above. This is one manner in which the concept of stability in a steady state has been developed further. Even though the transient stability limits are sometimes breached, it is common sense that a power system should never vary from the small signal stabilty constraints. This is true even if the limits on transient stability are occasionally exceeded. As a consequence of this, it is very necessary to carry out research on and make improvements to the stability of extremely tiny signals by using auxilliary controllers that are cleverly created. The stabilisation of low-frequency rotor oscillations is intimately connected to the damping of these oscillations. The eigenvalue technique, which is based on a linearized dynamic model [1, 2], is used to

**Corresponding author; Assistant Professor, Mechanical Engineering, United college of Engineering and Research, Prayagraj, U. P., India (E-mail: mohanguptaucer@gmail.com)*
***M. Tech Research Scholar, Department of Civil Engineering, KNIT Sultanpur, Uttar Pradesh, India (E-mail: pankaj02021992@gmail.com)*

conduct the analysis of this phenomenon. Establishing PSS is not only efficient in terms of meeting the aims of minimising oscillation in the power system and enhancing system stability [3-7], but it is also cost-effective in terms of accomplishing these goals. In order to achieve the objective of enhancing the system's functionality as a whole, a great number of experiments using PSS [8-14] and TCSC controllers [15-22] were conducted. One of the aspects that can be utilised to increase the stability of a power system is the ability of TCSC to control the system status in a quick way. This is one of the features that may be employed. [22] investigates the operations carried out by TCSC controllers when the oscillation of the signal is quite low.

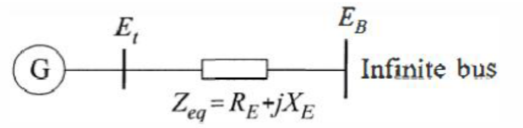
Small signal stability is the major focus of this research. First, the effect that adjusting the machine's loading and the voltage regulator's gain has on the stability of the tiny signal detected by the SMIB must be considered. Plotting the Eigen value that corresponds to rotor oscillations is required for this phenomenon's analysis. Second, to improve the SMIB power system's response to minor signals, a pole placement strategy and an application of TCSC were included into the design of the power system stabiliser. Stability in the electricity grid was a primary reason for this action. On this page, the impacts of PSS and TCSC on rotor oscillations and rotor speed will be compared. In addition, the selection of the PSS feedback signal was thoroughly researched at all phases of the design process. Different signals are compared in terms of the responses they elicit and the time it takes for those reactions to take place.

The following are the study's organisational components: Section II of this paper includes a model of the SMIB system, as well as plans for the PSS and TCSC. Finally, in the last part, we'll have a look at the findings of the study done on each event in turn In the fourth section of the essay, the conclusion is explored.

2.0 Model Formations

2.1 SMIB System[4]

Figure 1: Single Machine Infinite Bus System



The synchronous generator's output is sent to the infinite-bus through a transmission line. The machine equations are [7]:

$$\frac{d\omega}{dt}=\frac{(P_m-P_e)}{M}-\frac{K_d(\omega-\omega_o)}{M} \quad \ldots(1)$$

$$\frac{d\delta}{dt}=\omega-\omega_o \quad \ldots(2)$$

$$\frac{dI_d}{dt}=\frac{1}{T'_{do}}\,[\frac{1}{X'_{do}}\,E_{fd}\text{-}I_d\text{-}\left(\frac{x_d-X'_d}{X'_d}\right)i_d \quad \ldots(3)$$

$$\frac{dE_{fd}}{dt}=\frac{-1}{T_R}E_{fd}+\frac{K_R}{T_R}(V_{ref}-V_t) \quad \ldots(4)$$

State space model is given by:

$$p\begin{bmatrix}\Delta\omega\\ \Delta\delta\\ \Delta I_d\\ \Delta E_{fd}\end{bmatrix}=\begin{bmatrix}a_{00} & a_{01} & a_{02} & a_{03}\\ a_{10} & a_{11} & a_{12} & a_{13}\\ a_{20} & a_{21} & a_{22} & a_{23}\\ a_{30} & a_{31} & a_{32} & a_{33}\end{bmatrix}\begin{bmatrix}\Delta\omega\\ \Delta\delta\\ \Delta I_d\\ \Delta E_{fd}\end{bmatrix}+\begin{bmatrix}0\\0\\0\\b_4\end{bmatrix}\bar{u}$$

Where, $a_{00}=\frac{-K_D}{M}$, $a_{01}=\frac{-K_6}{M}$, $a_{02}=\frac{-K_5}{M}$, a_{03}=0; a_{10}= 1, a_{11}=0, a_{12} = 0, a_{13} = 0; a_{20}=0, $a_{21}=\frac{-K_4}{T'_{do}}(\frac{x_d-x'_d}{x'_d})$, $a_{22}=\frac{-1}{T'_{do}}(1+K_3(\frac{x_d-x'_d}{x'_d}))$, $a_{23}=\frac{1}{T'_{do}x'_{do}}$;a_{30}=0, $a_{31}=\frac{-K_8K_R}{T_R}$, $a_{32}=\frac{-K_7K_R}{T_R}$, $a_{33}=\frac{-1}{T_R}$, $b_4=V_{ref}$

2.2 Design of PSS [15]

In the power industry, a second-order, single-input dynamic compensator with the transfer function of is often employed as the PSS:

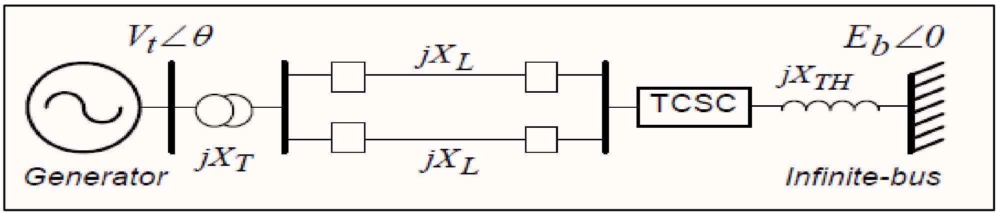
$$PSS(s)=\frac{\theta_o s^2+\theta_1 s+\theta_k}{s^2+\gamma_1 s+\gamma_k}$$

PSS is created via pole positioning method.

2.3 Design of TCSC[23]

The SMIB system with TCSC is shown in Fig 2 [8].

Fig.2 SMIB system with TCSC



Adjusting the firing angle of the thyristor is required in order to make alterations to the reactance of the TCSC. This phenomenon may be described as a rapid change in the relevant reactance that is delivered to the power system [4]. This is due to shifts in the firing angle or the conduction edge of the thyristor, both of which may induce variations. has the sort of connection that may be characterized as being in a condition that is said to be stable [9].

$$X_{TCSC}(\alpha)=X_C-\frac{X_C^2}{X_C-X_P}\frac{(\sigma+sin\sigma)}{\pi}+\frac{4X_C^2}{X_C-X_P}\frac{cos^2(\frac{\sigma}{2})}{(k^2-1)}\frac{[ktan(\frac{k\sigma}{2})-\tan(\frac{\sigma}{2})]}{\pi} \quad \ldots (5)$$

3.0 Case Study

You may find in the appendix all of the material that was taken into account for the case study that was carried out on the single machine infinite bus system. The paper has an appendix that contains this information for your convenience. The open-loop eigenvalues for the variable voltage regulator gain and the machine loads are shown in Tables 1 and 2, respectively. Both tables may be found below. Figures 3.1 and 3.2 illustrate the plots of eigenvalues that correlate to rotor oscillations

Doi: 10.51976/jfsa.121805

over a range of gain levels and machine loadings, respectively. These plots are displayed for a variety of loadings on the machine. These charts illustrate a range of different gains at a number of different scales.

Figure 3.1 illustrates that as the gain of the voltage regulator increases, the real and imaginary components of the eigen values also rise in proportion to the rotor's increasing frequency of oscillation. This is demonstrated by the fact that when the gain of the voltage regulator increases, the rotor's frequency of oscillation also increases. This illustrates that the damping coefficient reduces as KR rises, and that an increase in KR also leads in an increase in the frequency of oscillations. Additionally, this demonstrates that an increase in KR also results in an increase in the amplitude of oscillations.

Table 1: Effect of Change in Voltage Regulation Gain (Kr)

V.R. Gain (Kr)	OPEN LOOP EIGEN VALUES
20	0.0711 ± 6.3040i
30	0.1335 ± 6.3351i
40	0.1821 ± 6.3758i
50 (BASE CASE)	0.2168 ± 6.4198i
60	0.2406 ± 6.4639i
70	0.2551 ± 6.5051i
80	0.2627 ± 6.5433i

Fig.3.1: Effects of Variation in Kr on Rotor Oscillations

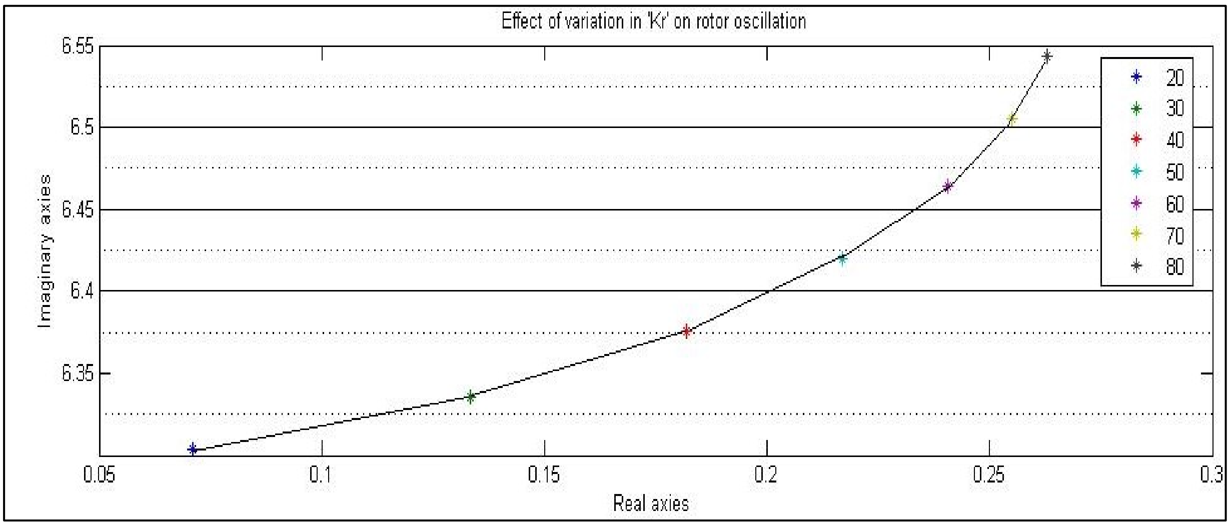


Table 2: Variation in Load Demand

LOAD in p.u.	OPEN LOOP EIGEN VALUES
0.25	0.0018±7.3698i
0.50	0.0206±7.2457i
0.75	0.0668±6.9858i
1 (BASE CASE)	0.2167±6.4196i
1.1	0.5925±5.7098i

Figure 3.2: Effects of Variation in Load on Rotor Oscillations

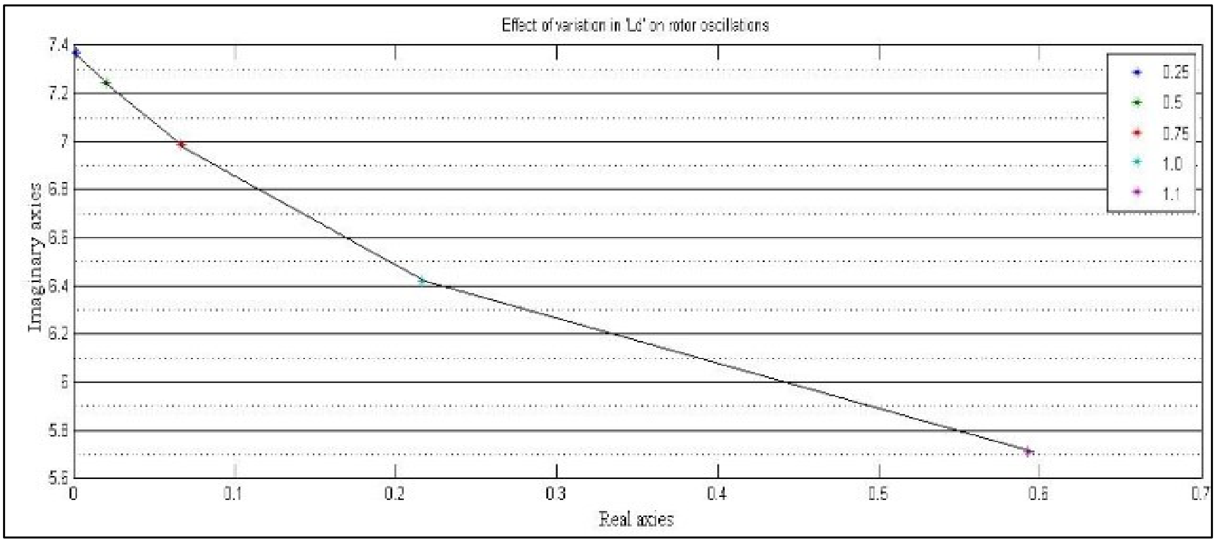
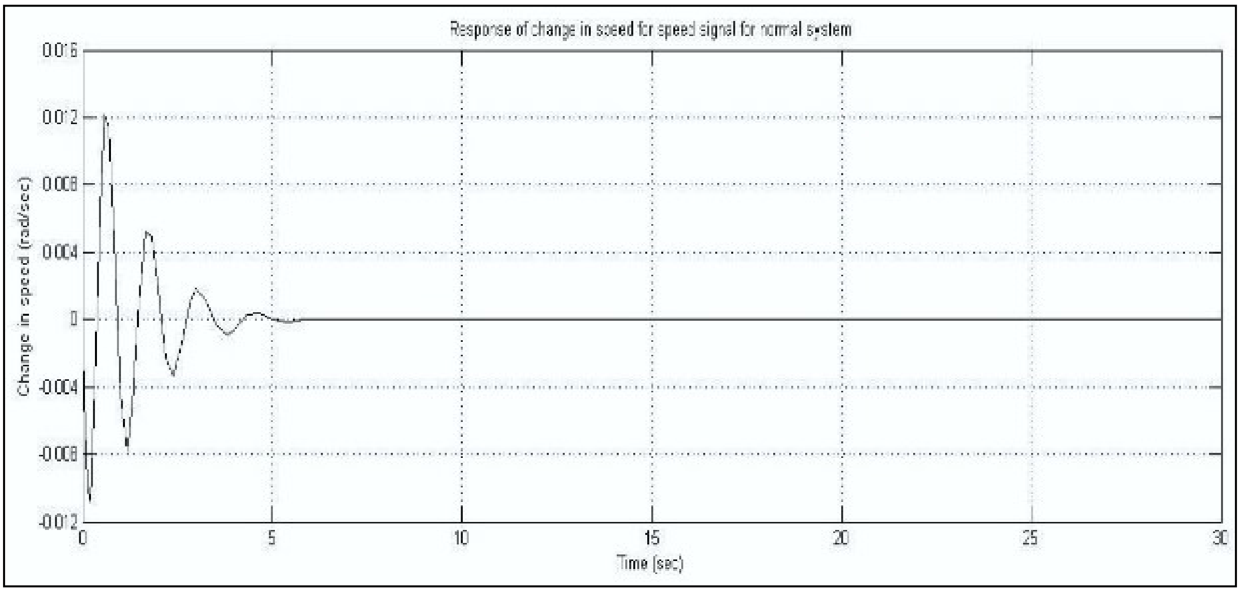


Figure 3.2 depicts how an increase in machine loading brings about a rise in the real component of eigenvalues wrt to rotor oscillations, simultaneously bringing about a reduction in the imaginary component of same values. As a result of this, it seems that the damping coefficient reduces, and along with it, the frequency of rotor oscillations also lowers, as the loading of the machine rises.

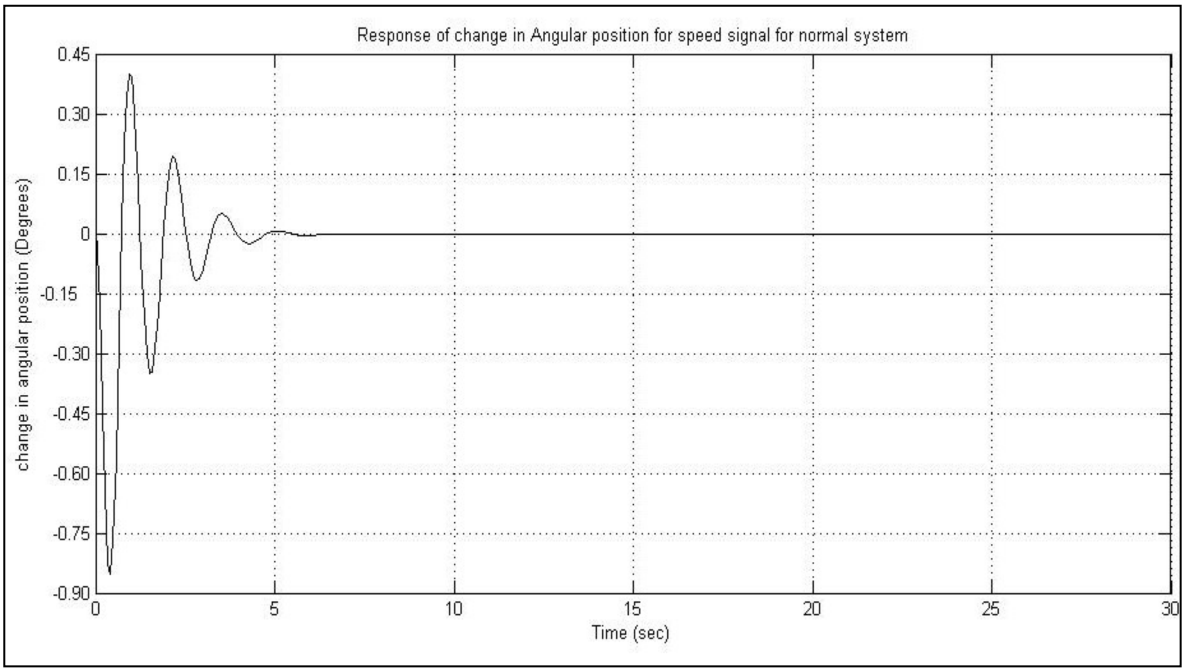
(B) The PSS was designed with the system in mind throughout its development. The speed of the rotor is what provides the input for the output feedback signal. The design goal that was taken into account was the eigenvalue assignment of the closed-loop system. As can be observed in figures 4.1 and 4.2, the temporal response of $\Delta\omega$ and $\Delta\delta$ the closed-loop system's and variables is measured by making a step change in Vref. This can be seen in the figures. It has been discovered that the introduction of PSS is what makes the system reliable once it has been deployed.

Figure 4.1: Result Shows of Change in Speed for Speed Signal for Normal System



Doi: 10.51976/jfsa.121805

Figure 4.2: Response of Change in Angular Position for Speed Signal for Normal System



(C) Figures 5.1 and 5.2 illustrate the temporal reaction of a change in rotor angular speed and Vref. This response is regulated by a TCSC controller, which is shown in the figures. It has been shown that making use of TCSC leads to a more stable operating environment for the system.

Figure 5.1: Time Response for Change in Rotor Speed (Δω)

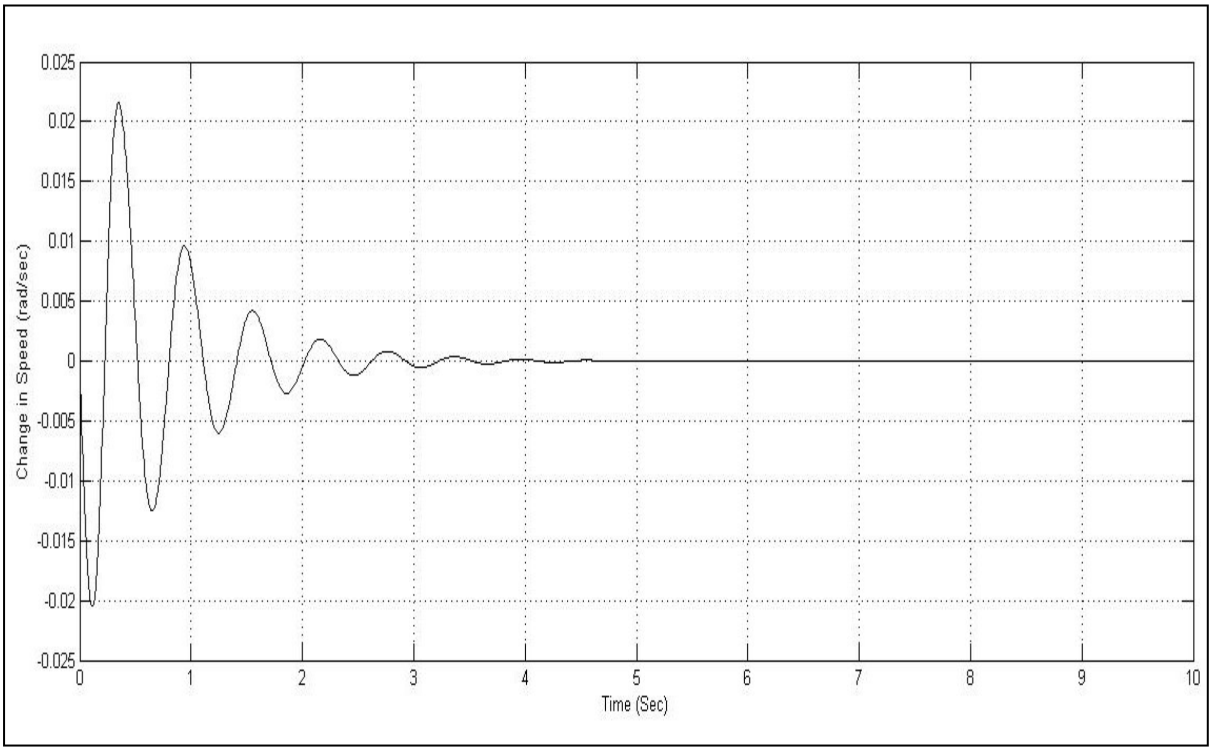
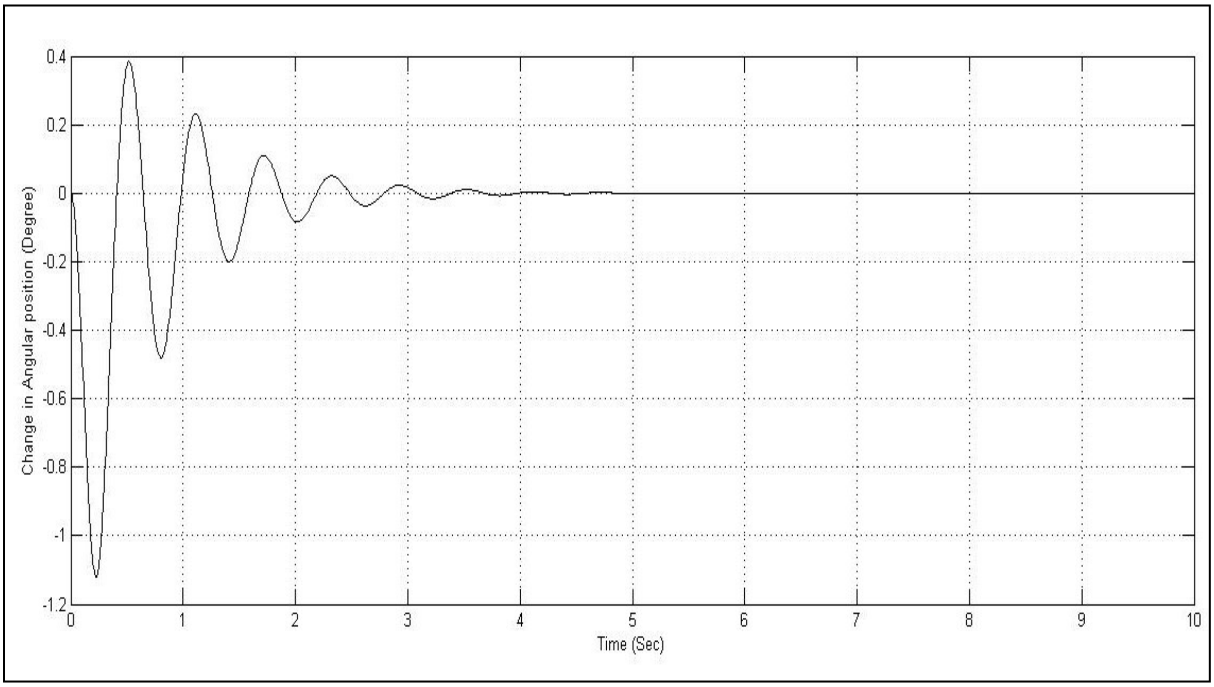


Figure 5.2: Time Response of Change in Rotor Angular Position (Δδ)



(D) PSS was developed for the three distinct situations that were thought of by using a pole assignment strategy and collecting one control signal at a time. This action was taken in order to make room for the data. Following is a selection of five closed loop Eigen values that have been made in order to examine the efficacy of control signals for a range of system strengths. These locations may be found in:

-1 ±j7, -2.0, -6.0, -1.0

The following table provides further information on the closed-loop Eigen values that were calculated for the different system strengths that were found:

Table 3: Closed loop Eigen Values for Strong System

Speed Signal	Power Signal	Frequency Signal
-47.7119	-44.1457	-45.2311
-0.7767±J8.3808	-0.8664±J7.1693	-0.8421±J7.1887
-6.1223	-6.0056	-5.9327
-2.0045	-2.0004	-2.4523
-1.0071	-0.9998	-0.9901

Table 4: Closed Loop Eigen Values for Normal System

Speed Signal	Power Signal	Frequency Signal
-46.1068	-42.2823	-40.8524
-0.9223±J7.2714	-0.7224±J6.2779	-2.2438±J4.4477
-5.9735	-5.3846	-6.4836
-2.5436	-0.9994	-1.8478
-0.8492	-2.6873	-2.8455

Doi: 10.51976/jfsa.121805

Table 5: Closed Loop Eigen Values for Weak System

Speed Signal	Power Signal	Frequency Signal
-45.0265	-44.8353	-40.8524
-0.9906±J6.2613	-0.6784±J5.5638	-2.2438±J4.4478
-0.7871	-0.4284	-1.8476
-3.7727	-3.3426	-2.8457
-5.6955	-5.7233	-6.4835

According to the data presented in Tables 3, 4, and 5, the objective of the design, which was to allot five closed loop poles to each of the instances, was successfully achieved, and the sixth eigenvalue was found to be located, a significant distance from the origin.

A analysis of time response is conducted on each unique situation while taking into consideration a step change in the reference voltage in order to explore the effectiveness of a range of control signals. This analysis is done in order to determine which control signals are most effective.

Fig. 6.1: Response of Change in Speed for Strong System

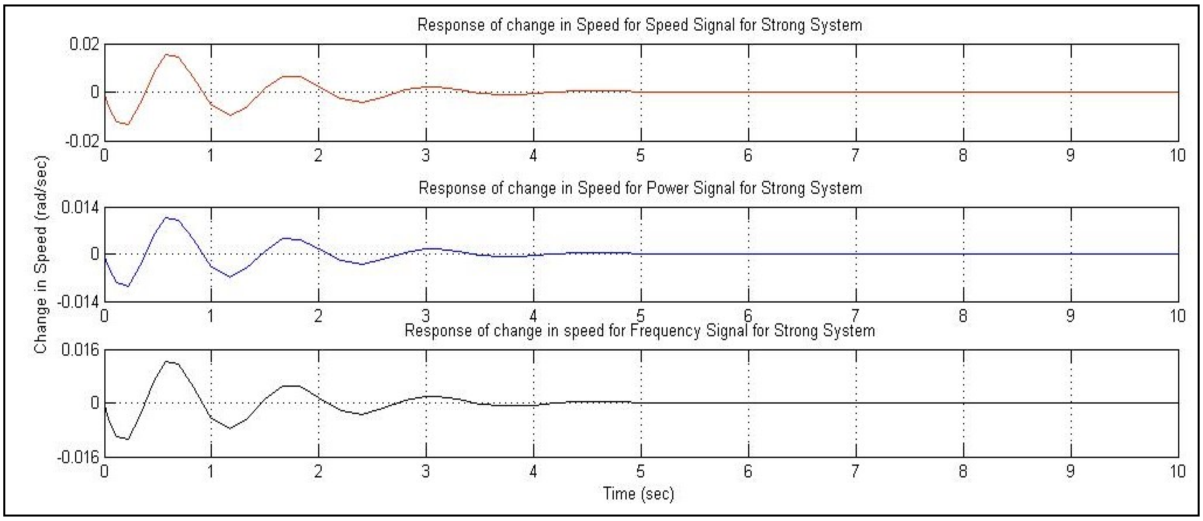


Fig. 6.2 Response of Change in Angular Position for Strong System

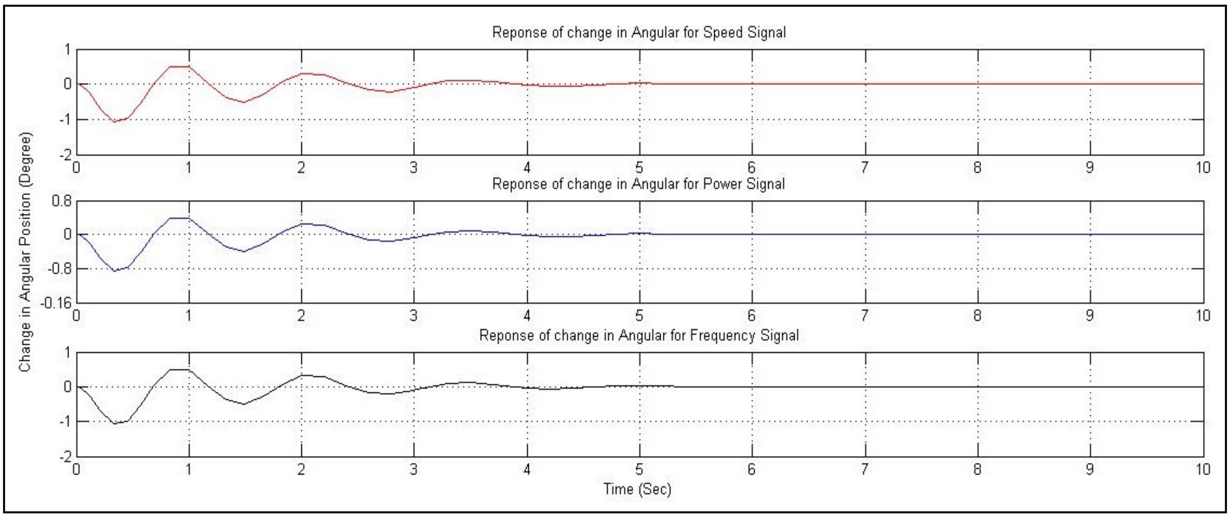


Figure 6.3: Response of Change in Speed for Normal System

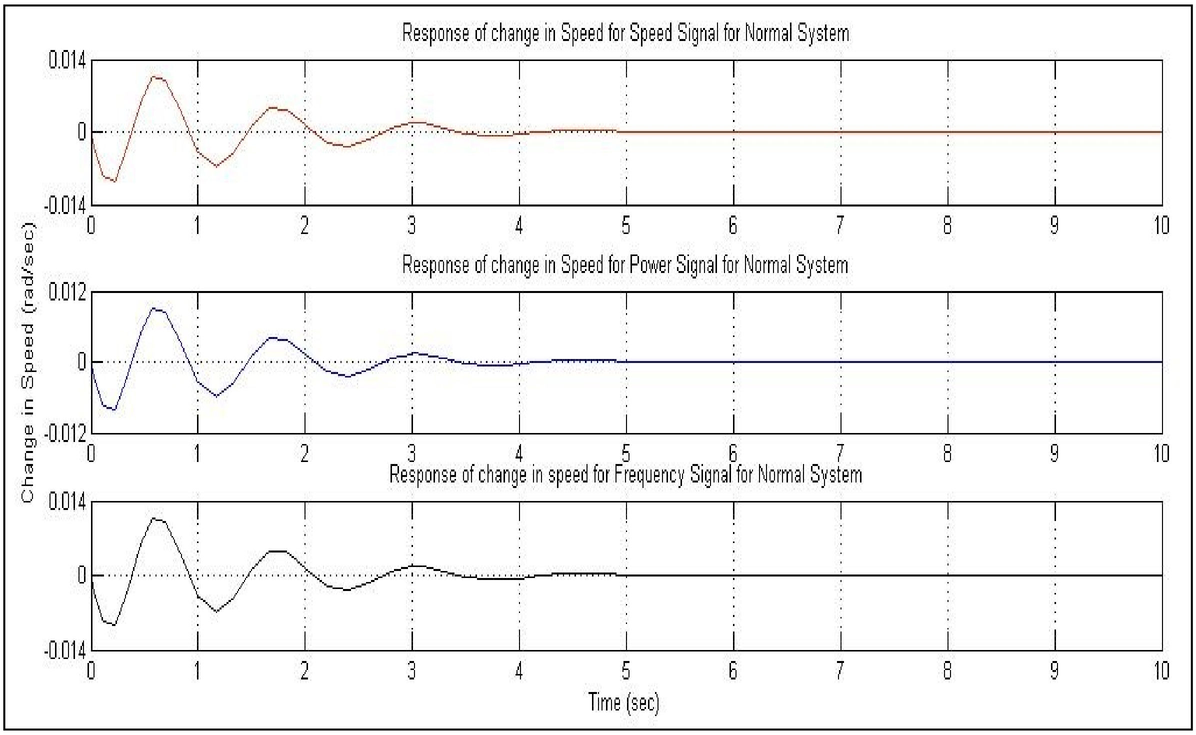
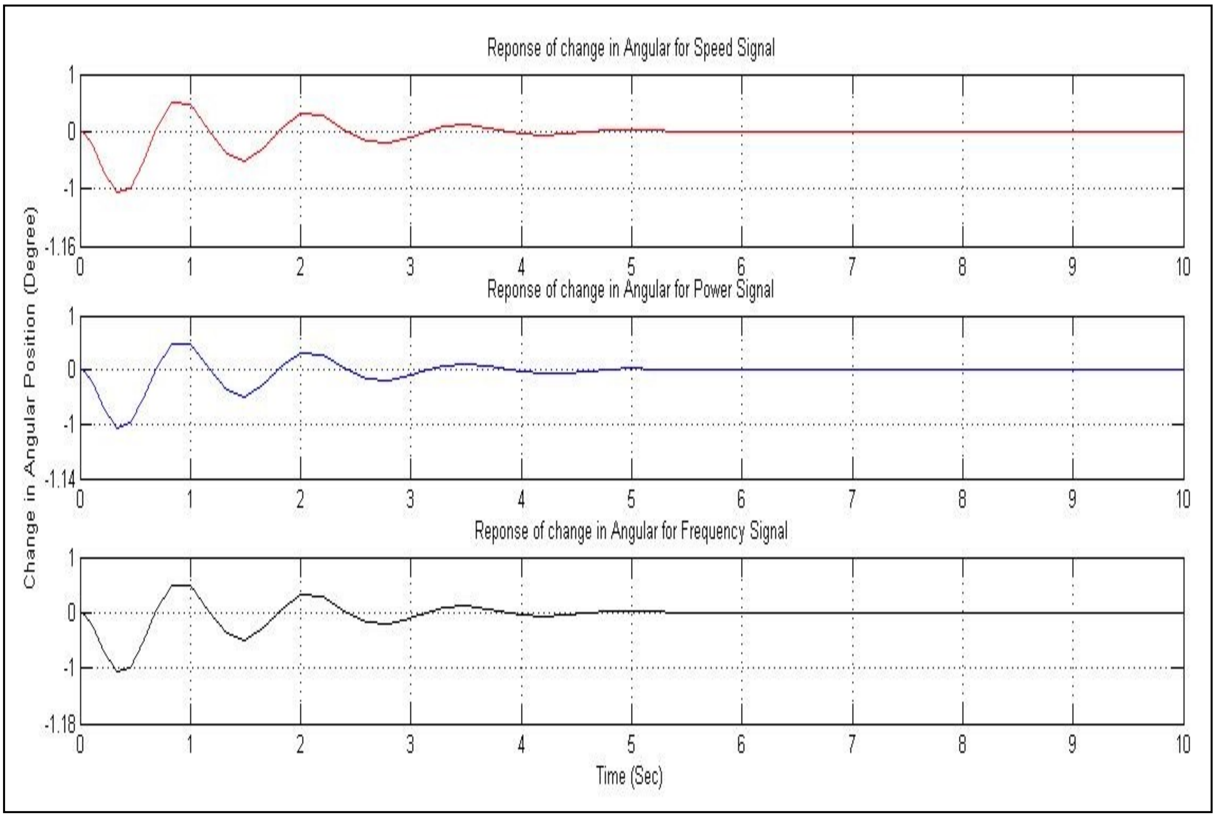


Figure 6.4 Response of Change in Angular Position for Normal System



Doi: 10.51976/jfsa.121805

Figure 6.5: Response of Change in Speed for Weak System

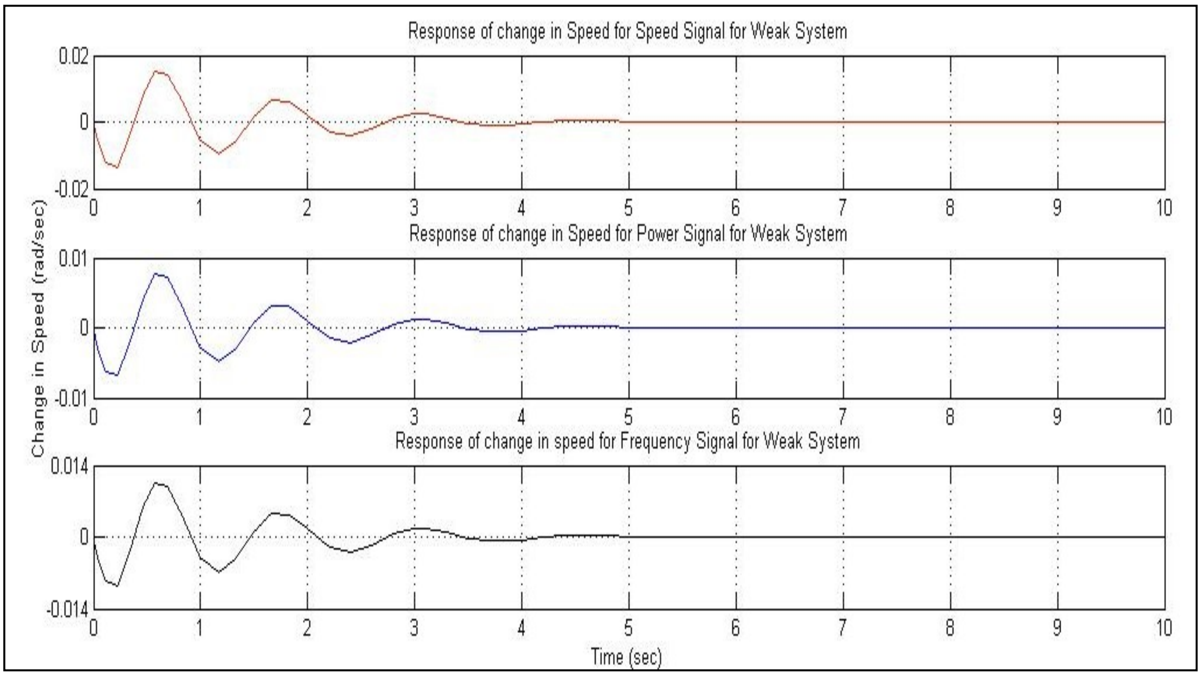
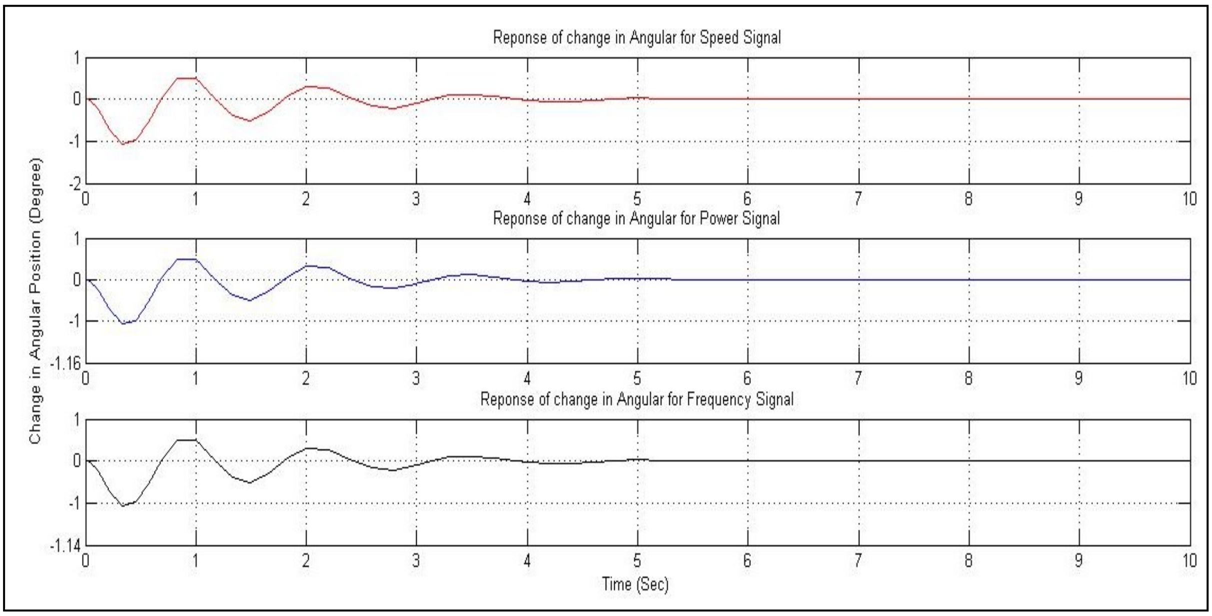


Fig. 6.6: Response of Change in Angular Position for Weak System



The temporal response of and for a step change in reference voltage demonstrates that the power signal is the most effective of the speed and frequency signals for all operating scenarios. This is the case when compared to the other two signals. This is true despite the fact that the signal might be travelling at any speed or frequency. When it comes to strong systems, efficacy is far and away the most crucial factor.

4.0 Conclusion

The results of an eigenvalue analysis may be used to determine what occurs when the load demand and voltage regulator gain change. The system will become more unstable if both values are increased, as can be seen from the eigenvalue plots for rotor oscillations. Additionally, by making use of PSS and TCSC, the SMIB system's minuscule signal stability may be improved even further. The appropriate location of the eigenvalue was given precedence over all other factors in the PSS design. Both a frequency domain and a temporal domain analysis was carried out. Even though either of these strategies may stabilise the system, using TCSC is preferable to PSS in this respect. Using the rotor's temporal response in terms of speed and angle, this may be shown. By using a variety of feedback control signals, the PSS's capacity to handle very small signals is improved. Several types of feedback control signals are used to this end. If we look at how quickly rotor speed and angle change in reaction to a step change in reference voltage, the power signal is clearly superior than the speed and frequency signals. When observing the rotor's reaction to a step change, this is the situation.

References

1) E. Larsen and D. Swann, "Applying Power System Stabilizers", Part I: General Concepts, Part II: Performance Objectives and Tuning Concept, Part III: Practical Considerations, IEEE Trans. PAS, Vol.-100, no.-6, pp. 3017–3046, 1981.

2) M.A.Pai, D.P. Sen and K.R.Padiyar, 'Topics in small signal analysis of power systems', New Delhi, India, Narosa Publishing House, 2003.

3) P.Kundur, M. Klein, G.J.Rogers, and M.S. Zywno, 'Applications of power system stabilizers for enhancement of overall system stability', IEEE Transactions on power systems, vol. 4, no. 2, pp. 614-626, 1989.

4) P.Kundur, 'Power System Stability and Control', New York, NY, McGraw-Hill, 1994.

5) P.Kundur, M. Klein, G. J. Rogers, and M.S. Zywno,'Applications of power system stabilizers for enhancement of overall system stability', IEEE Trans. on Power Systems, vol. 4, no. 2, pp. 614-626, 1989.

6) Kamwa, R. Grondin, and G. Trudel, 'IEEE PSS2B versus PSS4B:The limits of performance of modern power system stabilizers', IEEETrans. Power Syst., vol. 20, no. 2, pp. 903–915, May 2005.

7) G. E. Boukarim, S. Wang, J. H. Chow, G. N. Taranto, and N. Martins, 'A comparison of classical, robust and decentralized designs for multiple power system stabilizers', IEEE Trans. Power Syst., vol. 15, no. 4, pp. 1287–1292, Nov. 2000.

8) G. J. W. Dudgeon, W. E. Leithead, A. Dysko, J. O'Reilly, and J. R.McDonald, 'The effective role of AVR and PSS in power systems: Frequency response analysis', IEEE Trans. Power Syst., vol. 22,no. 4, pp.1986–1994, Nov. 2007.

9) K.R.Padiyar, M.A.Pai and C. Radhakrishna, 'A Versatile system model for the dynamic stability analysis of power system including HVDC links',IEEE Trans. Power Apparatus Systems,Vol.PAS-100,pp.1871-1880,April 1981.

10) Pal, B., & Chaudhuri, B. (2006). Robust control in power systems. Springer Science & Business Media.

11) J. H. Chow, J.J. Sachez Gasca, 'Pole placement design of power system stabilizers', IEEE Trans. on Power App. Syst., vol-4, pp.271-277, Feb.1989.

12) A. Ahmed, B. Muquabel, and M.A.Abido, 'Review of conventional PSS design methods', GCC Conference IEEE, 2006.

13) K.E. Bollinger, A. Laha, R. Hamilton and T. Harras, 'Power system stabilizer design using root-locus methods', IEEE Trans. PAS., Vol. PAS-94, pp.1484-1488, Sep./Oct. 1975.

14) F.P de Mello and C. Concordia, 'Concepts of synchronous machine stability as affected by excitation control', IEEE Tran. On Power apparatus and systems, Vol. PAS-88 pp.316-329, April 1969.

15) Eslami, M., Shareef, H., & Mohamed, A. (2010). Application of PSS and FACTS devices for intensification of power system stability. International Review of Electrical Engineering (IREE), 5(2), 552-570.

16) N.G. Hingorani, 'FACTS-Flexible AC Transmission System', Proceedings of Fifth International Conference on AC and DC Power Transmission- IEE Conference Publication 345, pp.1-7, 1991.

17) A. Edris, 'Proposed Terms and Definitions for Flexible AC Transmission System (FACTS)', IEEE Trans. Power Delivery, Vol-12, no-4, pp. 1848-1852, 1997.

18) Singirikonda, S., Sathishgoud, G., & Harikareddy, M. (2014). Transient stability of AC generator controlled by using fuzzy logic controller. Int J Eng Res Appl, 4(3).

19) S. Panda and N. P. Padhy, 'MATLAB/SIMULINK Based Model of Single-Machine Infinite-Bus with TCSC for Stability Studies and Tuning Employing GA,' *International Journal of Energy and Power Engineering,* Vol-1(3), 2007.

20) S. Akhtar, A. Saha and P. Das, 'Modeling, Simulation and Comparison of Various FACTS Devices in Power Systems, '*International Journal of Engineering Research & Technology (IJERT),* Vol.-1(8), October 2012.

21) D. Mohanty, A. Ahamad and M. A. Khan, 'Modeling, Simulation and Performance Analysis of FACTS Controller in Transmission line,' *International Journal of Emerging Technology and Advanced Engineering,* Volume 3, Issue 5, May 2013.

22) B.S. Nitve, 'Modeling, Simulation and Analysis of the Thyristor-Controlled Series Capacitor (TCSC)' *Journal of Smart Grid Technology*, Vol-2, Issue 2, 2017.

23) S. Sharma, 'Modeling & Simulation Study of TCSC based Damping Controller for Power System'*, International Journal of Engineering Research & Technology (IJERT),*Vol. 6 Issue 04, April 2017.