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# Dynamic Stability Enhancement of Power System Using Fuzzy Power System Stabilizer Under Different Loading Conditions

Chandrashekhar P K*, Srivani S G**, Shyam Sundar S*** and Rashmi ****

*The power system is dynamic in nature and is constantly being subjected to disturbances. It enters into dynamic instability when there is an imbalance between generation and varying load demand which calls for use of Power System Stabilizer (PSS). PSS is a device which provides additional signal to the voltage regulator derived from speed deviation, excitation deviation and accelerating power for damping critical oscillations. The PSS used should be capable to produce appropriate stabilizing signals against a wide range of operating conditions and disturbances. For this purpose, a PSS based on fuzzy logic control under multi-operating conditions is proposed in this paper. The performance of Fuzzy Logic based PSS(FLPSS) applied to Single Machine Infinite Bus (SMIB) system is studied for three different operating conditions; nominal load, heavy load and fault condition in transmission line. For Fuzzy PSS, speed deviation and acceleration are taken as input. The system is simulated in SIMULINK platform and its dynamic response is analyzed for system without PSS and with PSS. The results are compared for system with Conventional PSS and Fuzzy Logic PSS.*

***Keywords:*** *Automatic Voltage Regulator (AVR), Fuzzy Logic Controller (FLC), Power System Stabilizer (PSS), Single Machine Infinite Bus (SMIB)*

## 1.0 INTRODUCTION

Stability of synchronous generators is influenced by a number of factors such as the setting of the generator's automatic voltage regulator (AVR). Many generators are equipped with high gain, fast acting AVR's to enhance large scale stability by holding the generator in synchronism with the power system during large transient fault conditions. However, these high gain excitation systems can decrease the damping torque of the generators, leading the system to become vulnerable due to oscillatory instability. Improved performance has been achieved by damping the oscillations of the system by employing PSS. The conventional PSS (CPSS), which uses lead-lag compensation, might exhibit poor performance under different loadingconditions [1].

The dynamic stability of a system can be improved by providing suitably tuned PSS on selected generators to provide damping to critical oscillations. Suitably tuned PSS will introduce a component of electrical torque in phase with generator rotor speed deviations resulting in damping of low frequency power oscillations. The input signal to stabilizer may be one of the locally available signals such as changes in rotor speed, rotor frequency, accelerating power or any other suitable signal. This stabilizing signal

* Senior Research Fellow, Power Systems Division, Central Power Research Institute, Bangalore – 560 080, Karnataka.
Email: pkcsmce@gmail.com, Mob: +91 9611783356
** Associate Professor, Dept. of Electrical & Electronics Engg., R V College of Engineering, Bangalore – 560 059, Karnataka.
Email: srivanisg@rvce.edu.in, Mob: +91 9844327829
*** Engg. Officer. Gr.-4, Power Systems Division, Central Power Research Institute, Bangalore – 560 080, Karnataka.
Email: shyamsundar@cpri.in, Mob: +91 9449057569
**** Associate Professor, Dept. of Electrical & Electronics Engg.,Siddaganga Institute of Technology, Tumkur - 572 103, Karnataka.
Email: rash_mysore@yahoo.com, Mob: +91 9740110576

is compensated for phase and gain to result in adequate component of electrical torque that results in damping of rotor oscillations and thereby enhancing power transmission and generation capabilities.

A generalized neuron (GN) that requires much smaller training data and shorter training time has been developed and by taking benefit of these characteristics of the GN, a new adaptive fuzzy logic power system stabilizer is proposed [2]. The design of PSS for single machine connected to an infinite bus has been described using fast out-put sampling feedback [3]. A modified self-organizing Fuzzy Auto-Regressive Moving Average (FARMA) controller is proposed in [4] to enhance the low frequency damping of the SMIB under different operating conditions. An auto tuning fuzzy logic PSS based on real coded genetic algorithm is proposed in [5]. The methods used foradaptive PSS design corresponding to the varying operating conditions require extensive knowledge of dynamics of the power system and long processing time [5]. The fuzzy logic based PSS possess lesser computational time and its performance is robust over different operating conditions.The performance of SMIB system with fuzzy PSS using different membership functions for input and output variables is investigated in [6] [7], which lead to the choice of triangular membership function for the proposed FLC. Further various applications of fuzzy logic to power system control are described in [8].

Keeping the above aspects in mind, the performance of SMIB system with FLC based PSS is presented in this paper. The performance of the controller is studied for three different operating conditions; nominal load, heavy load and fault condition in transmission line.The performance of SMIB system is studied for a step change in 5% of input torque and the results arecompared with CPSS.

## 2.0 POWER SYSTEM STABILIZER

Traditionally the excitation system is used for regulation of the generated voltage and thereby helping to control the system voltage. As compared to ammortisseur winding and governor controls the AVRs are found extremely suitable for the regulation of generated voltage through excitation control. Many generators in power system are provided with high gain, fact acting AVRs for improving stability. But use of these high gain AVRs can decrease the damping torque of generators. These AVRs have detrimental effect on the dynamic stability or steady state stability of the power system as oscillations of low frequencies (typically in the range of 0.2 to 3 Hz) persist in the power system for a long period and sometimes affect the power transfer capabilities of the system [10]. PSSs were developed to aid in damping these oscillations by providing additional stabilizing signal to the AVR and by this supplement stability to the system. The basic operation of PSS is to apply a signal to the excitation system that creates damping torque which is in phase with the rotor oscillations.

The basic function of CPSS is to damp electromechanical oscillations. To achieve the damping, the CPSS proceeds by controlling the AVR excitation using auxiliary stabilizing signal. The parameters of CPSS are determined based on a linearized model of the power system around a nominal operating point where they can provide good performance [9]. The transfer function of CPSS used forcomparison is:

$$G_{PSS}(S) = (K_{STAB})\left[\frac{sT_w}{1+sT_w}\right]\left[\frac{1+sT_1}{1+sT_2}\right] \quad ....(1)$$

The PSS as shown in Figure 1 has three components, the phase compensation block, the signal washout block and gain block. The phase compensation block provides the appropriate phase lead characteristics to compensate for the phase lag between exciter input and generator electrical torque.

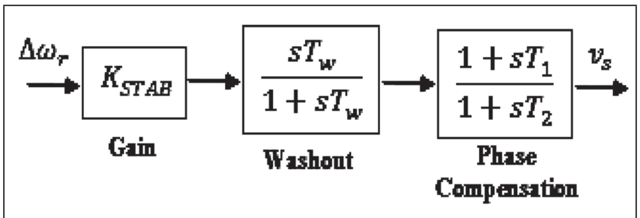


FIG. 1 CONVENTIONAL LEAD-LAG PSS [9]

The signal washout block serves as high pass filter, with time constant *Tw* high enough to allow signals associated with oscillations in $\omega_r$ to pass unchanged and its value ranges from 1 to 20 seconds. The stabilizer gain $K_{STAB}$ determines the amount of damping introduced by PSS [9].

## 3.0 SYSTEM MODELING

The SMIB system considered for study is having a synchronous machine (generator) connected to an infinite bus through a transformer and two parallel transmission lines as shown in Figure 2. The synchronous machine is represented with classical fourth order model of voltage behind the transient reactance. The block diagram representation of the SMIB system with constant field voltage is as shown in Figure 3. The linearized system considered for simulation with AVR and PSS blocks included is as shown in Figure 4. The system dynamics of the synchronous machine can be expressed as a set of first order differential equations [9].

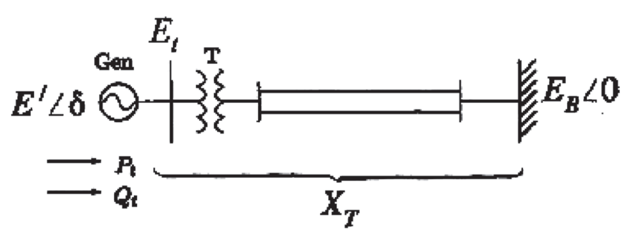


FIG. 2 SCHEMATIC OF THE SINGLE MACHINE POWER SYSTEM CONNECTED TO AN INFINITE BUS (SMIB)

$$\Delta T_e = \frac{\partial T_e}{\partial \delta}\Delta\delta = \frac{E' E_B}{X_T}\cos\delta\,(\Delta\delta) \quad \text{....(2)}$$

$$\Delta T_e = K_1\Delta\delta + K_2\Delta\psi_{fd} \quad \text{....(3)}$$

$$\Delta\psi_{fd} = \frac{K_3}{1 + sT'_{d0}}\left(\Delta E_{fd} - K_4\Delta\psi_{fd}\right) \quad \text{....(4)}$$

$$\Delta E_t = K_5\Delta\delta + K_6\Delta\psi_{fd} \quad \text{....(5)}$$

Where $\Delta T_e$ is the change in electrical torque

$\Delta\,\psi_{fd}$ is the change in field winding flux linkage

$E'$ is the voltage behind transient reactance of the machine

$E_B$ is infinite bus voltage

$\delta$ is the angle by which $E'$ leads $E_B$

$\Delta\,\delta$ is the rotor angle deviation

$\Delta E_{fd}$ is the change in field voltage

$\Delta E_t$ is the change in terminal voltage

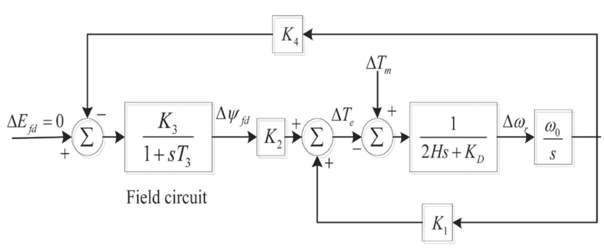


FIG. 3 BLOCK DIAGRAM REPRESENTATION WITH CONSTANT $E_{FD}$[9]

In the above expressions (2) to (5), the dynamic characteristics of the system are expressed in terms of the Heffron-Phillips constants (K-constants). These constants are dependent on the machine parameters and the operating condition considered. The constants $K_1$ to $K_6$ shown in block diagram describe internal influence factors within the system and can be found by a comparison of coefficients with the equations governing the synchronous machine dynamics [9]. While $K_1$ and $K_2$ are derived from the computation of the electric torque, $K_3$ and $K_4$ have their origin in the field voltage equation. $K_5$ and $K_6$ come from the equation governing the terminal voltage magnitude.

The basis for the block diagram and expressions for the associated constants and the detailed derivation of constants is discussed in [9]. The description of the K-constants is given below.

- $K_1$ - Influence of torque angle on electric torque
- $K_2$ - Influence of internal Voltage on electric torque
- $K_3$ - Field winding constant
- $K_4$ - Influence of torque angle on field voltage
- $K_5$ - Influence of torque angle on terminal voltage
- $K_6$ - Influence of internal voltage on terminal voltage

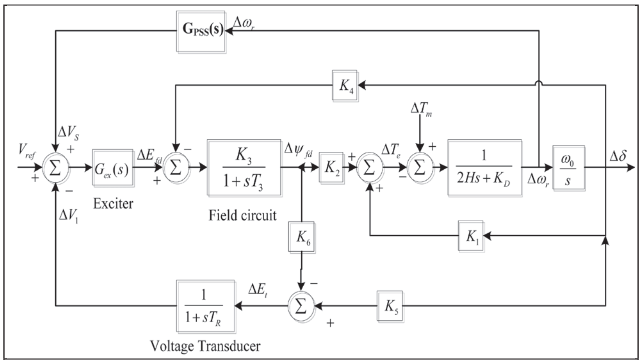

FIG. 4 LINEARIZED BLOCK DIAGRAM OF SMIB WITH AVR AND PSS [9]

## 4.0 FUZZY LOGIC

Fuzzy logic is based on the theory of fuzzy sets, where an object's membership of a set is gradual rather than just member or not a member. Fuzzy logic uses the whole interval of real numbers between zero (False) and one (True) to develop logic as a basis for rules of inference [11]. Fuzzy logic controllers are model-free rule-based controllers. They do not require an exact mathematical model of the control system. Fuzzy logic, unlike Boolean or crispy logic, deals with problems deals with vagueness, uncertainty, imprecision or qualitativeness. The membership functions map each element of the fuzzy set to a membership grade. Fuzzy sets are characterized by several linguistic variables. Each linguistic variable has its unique membership function which maps the data accordingly. Fuzzy rules are also provided along with to decide the output of the fuzzy logic based system.

## 5.0 PROPOSED FUZZY LOGIC CONTROLLER

The design of the fuzzy logic controller (FLC) has five steps:

- Selection of the fuzzy control variables
- Membership function definition
- Rule creation
- Inference engine
- Defuzzification strategies

To design the FLC, variables which can represent the dynamic performance of the plant to be controlled should be chosen as the inputs to the controller. In addition to the proper input signals, signal gains and fuzzy subsets should be defined. Speed deviation and its derivative (acceleration) are used as inputs to the FLC. Voltage signal is the output of the controller. Out of different types of membership functions available in MATLAB, because of simplicity and being more efficient [7] triangular membership functions are used for both input and output. There are seven fuzzy sets chosen for each of the three fuzzy variables. 49 rules have been generated corresponding to seven membership functions NB-Negative Big, NM-Negative Medium, NS-Negative Small, ZE-Zero, PS-Positive Small, PM-Positive Medium, PB-Positive Big. These membership functions for the input and output variables used are as shown in Figure 5.

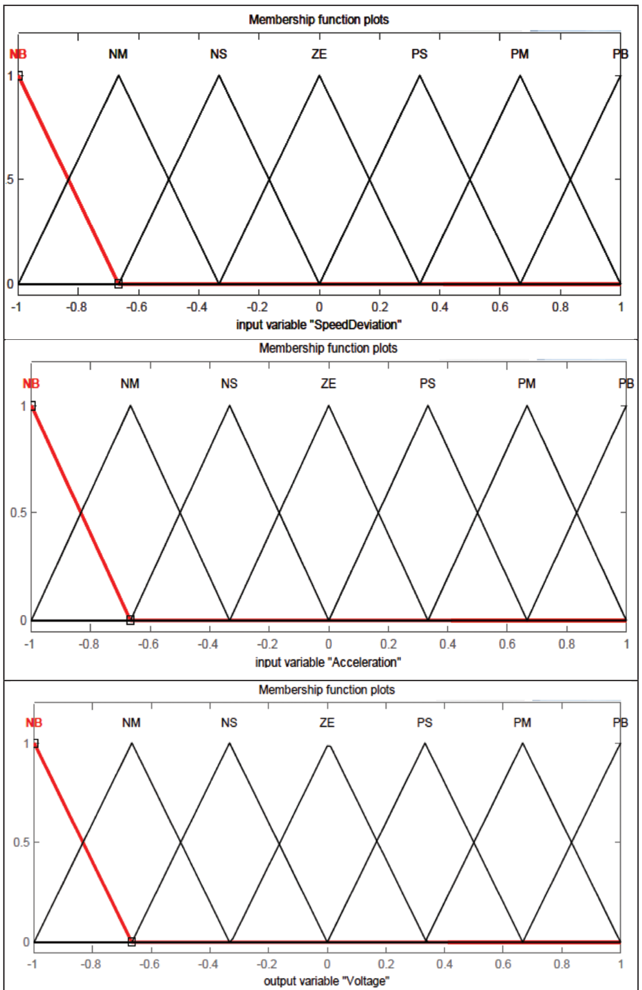


FIG. 5 MEMBERSHIP FUNCTIONS OF INPUT AND OUTPUT VARIABLES

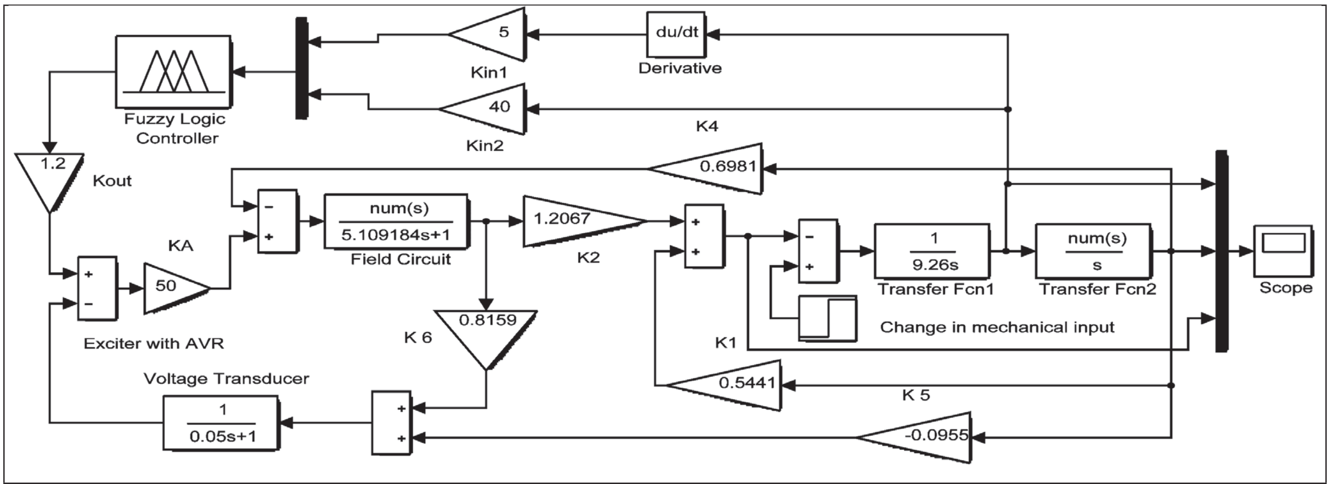


FIG. 6 SIMULINK MODEL WITH FLPSS CONTROLLER

These membership functions are symmetrical and each one overlaps with the adjacent functions by 50%. The membership functions are normalized in the interval [-1, 1], which is symmetrical around zero. Thus, control signal amplitudes (fuzzy variables) are expressed in terms of controller parameters (gains). The rule table for the FLC is as given in Table 1 [8].

The FLC is designed by using fuzzy logic toolbox (GUI) in Matlab. For the fuzzy inference system design Mamdani type of rule-base model is used. The centroid method is used for defuzzification.

## 6.0 SIMULATION AND RESULTS

The performance of FLPSS applied to the SMIB system has been studied for three different cases; nominal load, heavy load and fault condition in transmission line. The Simulink model of the system used for study is as shown in Figure 6.

TABLE 1

RULE TABLE USED FOR FLPSS

| Speed Deviation | Acceleration | | | | | | |
|---|---|---|---|---|---|---|---|
| | **NB** | **NM** | **NS** | **ZE** | **PS** | **PM** | **PB** |
| **NB** | NB | NB | NB | NB | NM | NM | NS |
| **NM** | NB | NM | NM | NM | NS | NS | ZE |
| **NS** | NM | NM | NS | NS | ZE | ZE | PS |
| **ZE** | NM | NS | NS | ZE | ZE | PS | PM |
| **PS** | NS | ZE | ZE | PS | PS | PM | PM |
| **PM** | ZE | PS | PS | PM | PM | PM | PB |
| **PB** | PS | PM | PM | PB | PB | PB | PB |

The performance is studied for a variation of 5% increase in torque (mechanical input) [1].

The result of the performance of single machine infinite bus systemis presented for the following cases.

- without excitation system
- with excitation system
- with conventional PSS (lead-lag)
- with FLC based PSS

The initial values for nominal load condition and K constants of the related system, which are used in the simulations, are summarized in Table 2 and 3 respectively [5].

TABLE 2

INITIAL VALUES FOR NOMINAL LOAD CONDITION

| | |
|---|---|
| **Generator Constants** | $M = 9.26$, $D = 0$, $T_{do}' = 7.76$ s, $X_d = 0.973$p.u., $X_d' = 0.19$p.u., $X_q = 0.55$p.u. |
| **Exciter Constants** | $K_A = 50$, $T_A = 0.05$ s |
| **Line Constants** | $R_1 = 0.051$, $X_1 = 1.49$, $R_2 = 0.102$, $X_2 = 2.99$, $G = 0.249$, $B = 0.262$ |
| **Initial Constants** | $P_{e0} = 1.0$p.u., $Q_{e0} = 0.015$p.u. $V_{t0} = 1.05$ p.u. |

TABLE 3

HEFFRON-PHILLIPS COEFFICIENTS OF THE SMIB SYSTEM FOR DIFFERENT OPERATING CONDITIONS

| Operating Conditions | Nominal Load | Heavy Load | Fault in the Line |
|---|---|---|---|
| $K_1$ | 0.5441 | 0.4563 | 0.4007 |
| $K_2$ | 1.2067 | 1.4477 | 1.1404 |
| $K_3$ | 0.6584 | 0.6584 | 0.7095 |
| $K_4$ | 0.6981 | 0.8706 | 0.6834 |
| $K_5$ | -0.0955 | -0.1675 | -0.1207 |
| $K_6$ | 0.8159 | 0.7747 | 0.8348 |

Figure. 7 gives the plot of speed deviation, angular position and torque variation for a 5% change in input mechanical torque of the SMIB system with constant field voltage. The plot of system response with excitation system included for a 5% step change in mechanical torque is as shown in Figure 8.

The system responses with CPSS included for 5% step change in mechanical torque is as shown in Figure 9. Figure 10 gives the plot of speed deviation, angular position and torque variation for a 5% change in input mechanical torque of the SMIB system with CPSS replaced by proposed FLPSS for nominal loading condition.

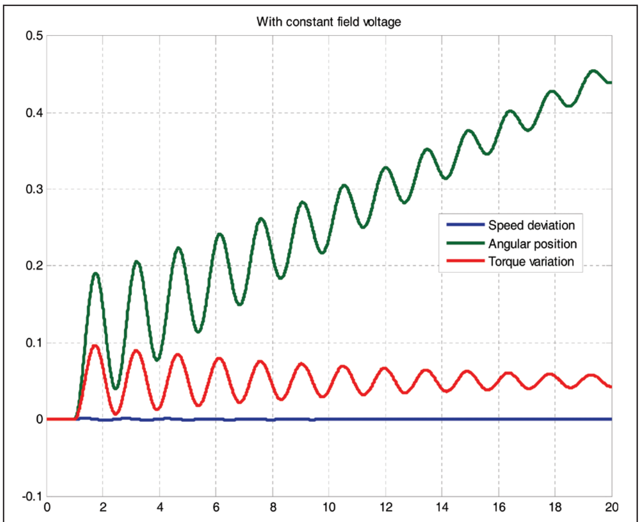


FIG. 7 SYSTEM RESPONSE FOR A 5% CHANGE IN MECHANICAL INPUT WITH CONSTANT FIELD VOLTAGE

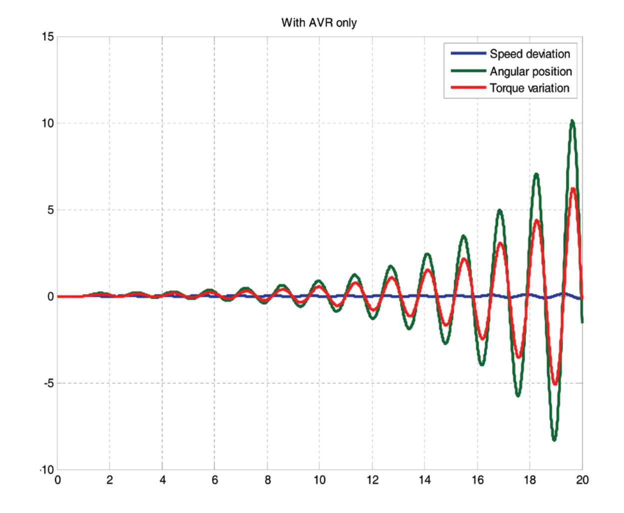


FIG.8 SYSTEM RESPONSE FOR A 5% CHANGE IN MECHANICAL INPUT WITH EXCITATION SYSTEM

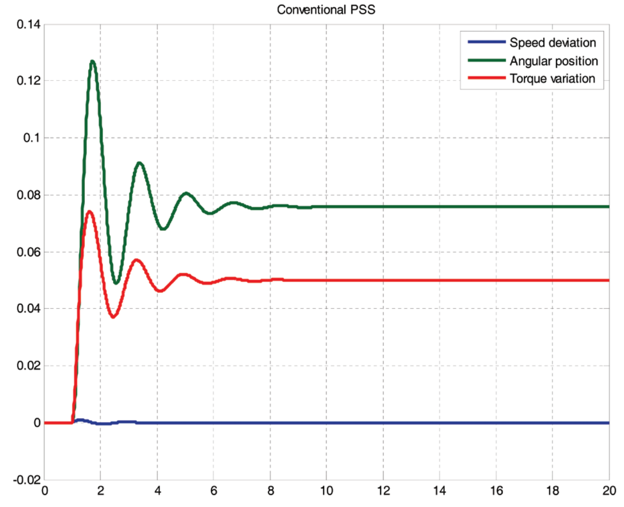


FIG. 9 SYSTEM RESPONSE FOR A 5% CHANGE IN MECHANICAL INPUT WITH CPSS

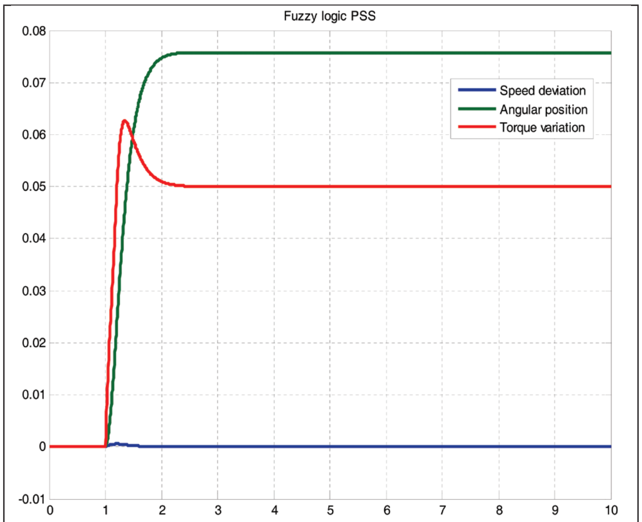


FIG. 10 SYSTEM RESPONSE FOR A 5% CHANGE IN MECHANICAL INPUT WITH FL PSS FOR NOMINAL LOAD

Angular position, speed deviation and torque variation plots for three different operating conditions of nominal load, heavy load and fault condition in transmission line are given in Figure 11, 12 and 13 respectively. From Figure 12 it can be observed that deviation in speed for different operating conditions is small with FLPSS.

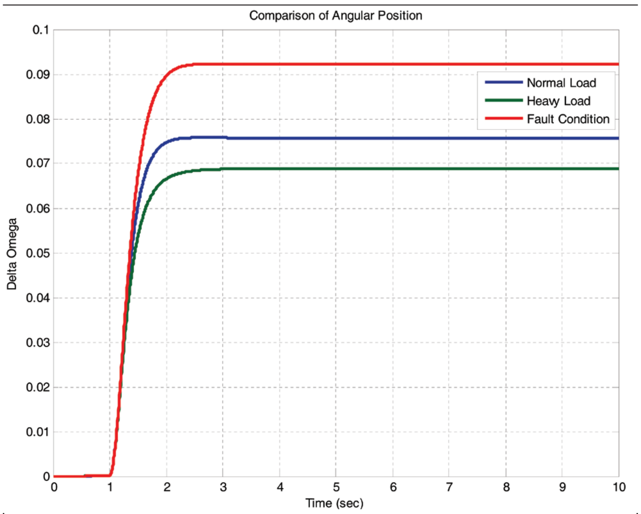


FIG. 11 ANGULAR POSITION PLOT FOR 5% CHANGE IN MECHANICAL INPUT FOR DIFFERENT OPERATING CONDITIONS

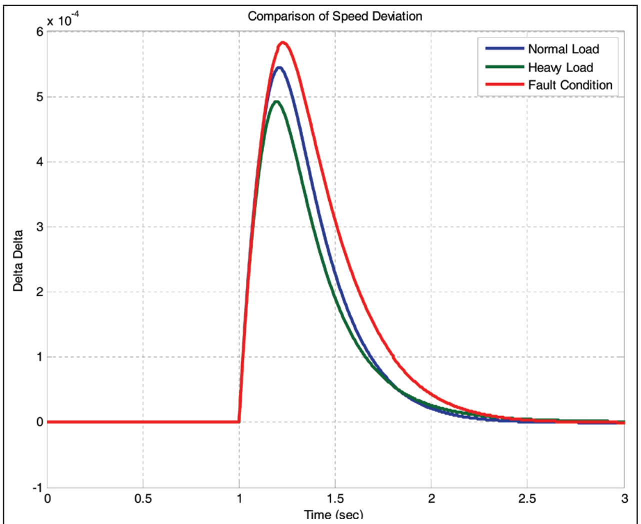


FIG. 12 SPEED DEVIATION PLOT FOR 5% CHANGE IN MECHANICAL INPUT FOR DIFFERENT OPERATING CONDITIONS

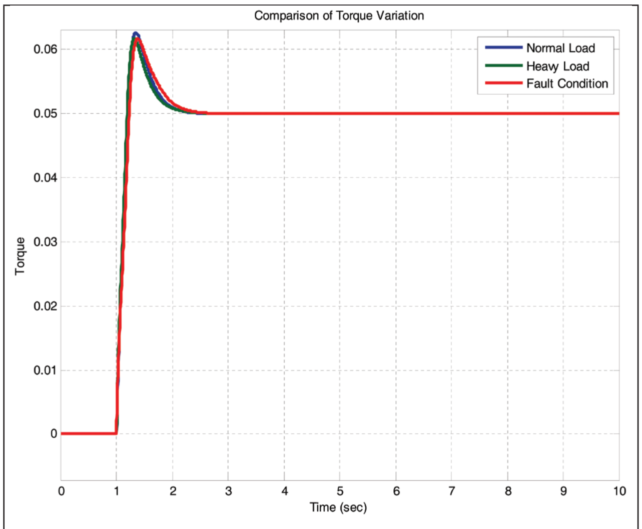


FIG. 13 TORQUE VARIATION FOR 5% CHANGE IN MECHANICAL INPUT FOR DIFFERENT OPERATING CONDITIONS

## 7.0 CONCLUSION

The simulation studies shows that the FLPSS provides better damping for oscillations as compared to conventional PSS. From the comparison of the results of the performance of FLPSS and CPSS for various operating conditions and disturbances, it can be seen that with the application of the Fuzzy Logic the rise time and the settling time decreases due to which system reaches its steady state much earlier with Fuzzy Logic power system stabilizer as compared to conventional power system stabilizer. The proposed stabilizer is able to provide good damping over a wide range and improves the overall system performance. Therefore it can be inferred that with FLPSS controller without any complex mathematical support the response is much improved.

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