PERFORMANCE ANALYSIS OF MULTI-BAND PSS IN MODERN LOAD FREQUENCY CONTROL SYSTEMS

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Abstract

The large-scale power systems are subjected to continuous disturbance due to the existence of sudden load perturbations, parameter uncertainties, basic variation etc. The Load Frequency Control (LFC) is a part of the power system stability for controlling power interchange and frequency deviation. In this paper, the LFC problem is analyzed with various types of Power System Stabilizers (PSSs) like PSS2B, PSS3B and PSS4B, to overcome the effect of load disturbance. Performance of PSSs, with and without notch filter, is examined. Further, the PSSs are designed to operate in both continuous and discrete mode for the given test LFC system. The continuous mode PSS4B having notch filter connected in cascaded, gives better time domain response among other types of PSSs. The proposed approach is simulated in MATLAB/Simulink environment for a five-area test power system consisting of five generating units having a non-reheated turbine, to highlight the efficacy in terms of robustness.

Keywords: Load Frequency Control, MB-PSS, Five-Area Power System, Notch Filter, Power System Stabilizers

I. Introduction

The successful operation of interconnected power system shows that there is necessary generation available to meet the total load demand, with least system losses. In Single area LFC system having the primary loop, a change in the load condition will result in steady state frequency deviations, based on governor speed regulation. For reducing this deviation, a reset action is required. This is achieved through an integral controller, which change the speed set point. At last, it will turn the final frequency deviation to zero [1], [2]. For determining the power in Automatic Generation Control (AGC), an economic dispatch process and gain insights into the economic characteristics of the generating units are taken into consideration to formulate the real time value [3]. The LFC of two area thermal power plants, with Generation Rate Constraint (GRC) and integral controller are demonstrated in [4]. The authors in [5], develop a control strategy to consider the DFIG. As per [6], Integral-Double Derivative Controllers shows the better dynamic responses among the Integral, Proportional-Integral, and Integral-Double Derivative controllers in the automatic generation of multi area interconnected thermal system. Similarly, a Sliding Mode Load Frequency Control strategy is designed in [7]. Design of the fuzzy gain scheduling controllers is presented in [8]. Tilt Integral Derivative Controller with Filter in [9]. The tunings of a PID controller by Ziegler-Nichols Methods or Simplex Search Method shows the far better performance than the conventional controllers [10]. In [11], A fractional order fuzzy proportional-integral-derivative controller is presented for LFC of 4-area interconnected power systems [12]. A two-level coordinated control frame based on multi-agent system is presented in [13]. The work in [14] deals with the unequal multi-area AGC with integral derivative along with filter and proportional derivative secondary controllers. In [15], a two-level coordinated control frame based on multi-agent system is proposed. Four area power system is designed in [16. In [17], cascade combination of integer order integral-derivative with filter and fractional order proportional derivative is considered as a secondary controller. The [18], presents the impact of Demand Response(DR) control loop with communication delay. an adaptive control strategy [19], [20], Multi-Band Stabilizers [21], Analysis of noise extenuation techniques [22], Discrete time mode PSS controller [23], Robust LQG [24], WADC [25], Discrete and continuous mode PSS [26] are presented.

The main objective of this paper is to compare the performance of various types of MB-PSS (PSS 2B, PSS 3B, PSS 4B) in both continuous and discrete mode of operation, in given LFC system. The time domain performance of complete system is compared with conventional and MB-PSS system. The performance is also evaluated with various frequency bands {i.e. Low (L), intermediate (I) and high (H)}, with cascaded connected notch filter and without any notch filter in the corresponding band. In next step of analysis, the time domain response is compared for the given Load Frequency Control (LFC) system with continuous and discrete mode operation of MB-PSS. Further, the effect of using speed transducer in cascaded with continuous and discrete mode MBPSS, is also analyzed.

II. Five Area Systems for Load Frequency Control

In this paper, five area systems are considered with a number of generators and loads as illustrated in Fig. 1. The transfer function for the plant model is given by eq. (1), when droop characteristics are neglecting,

$$G = G_g G_t G_p \tag{1}$$

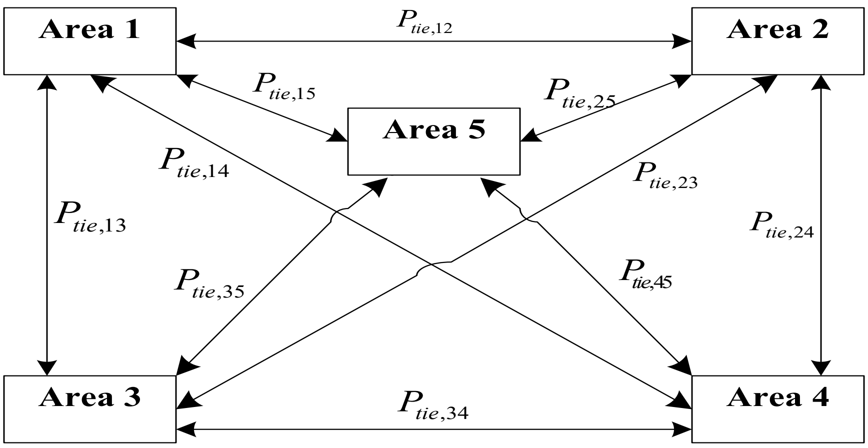

Figure 1: *Block diagram of five area interconnected system*

Where, $G_g = 1/(1+T_g s)$ is the transfer function of governor, $G_t = (1+K_r T_r s)/(1+T_t s)(1+T_r s)$ is the turbine transfer function, $Gp = K_p/(1+T_p s)$ is the power system transfer function which represents the load and machine dynamics. Since the reheat turbine used has different stages of low and high pressures of steam, it is modelled as a second-order unit. The transfer function for the plant model considering droop characteristics is given by eq. (2),

$$G = \frac{G_g G_t G_p}{1 + G_g G_t G_p \left(\frac{K_I}{s} + \frac{1}{R} \right)} \tag{2}$$

Power transported in ith area is given by eq. (3),

$$P_{tie,i} = \frac{|V_i| * |V_j| * \mathrm{Sin}(\delta_i - \delta_j)}{X_{ij}}, (i, j = 1, 2, ..., 5) \tag{3}$$

During normal condition, the active power of ith control areas,

$$ACE_i = B_i \Delta F_i + \Delta P_{tie,i}, (i = 1, 2, ..., 5) \tag{4}$$

Where, B_i = biasing factor, ACE_i = area control error of i^{th} area and $\Delta P_{tie,i}$ = tie line power of i^{th} area. The control inputs for the five area systems is given by eq. (5),

$$u_i = -k_{ij} \int ACE_i dt = \Delta P_{ci}(S), (i, j = 1, 2, ..., 5) \tag{5}$$

III. Multi-Band Power System Stabilizers (MB-PSS)

The MB-PSS is used to achieve the precise compensation over a wide range of frequencies of oscillations, as it may difficult to control a wide range of oscillations using conventional lead-lag compensator. Further, the system experiences low and high frequency oscillation too, the tuning strategy of the single-band stabilizers need to trade off and won't accomplish optimal damping in any of the oscillation [27]. The MB-PSS considered here are PSS2B [28], PSS3B [29] and PSS4B [30].

IV. Simulation Results

The five-area interconnected reheat thermal power system investigated in this paper is modelled and implemented in MATLAB/Simulink environment. Following 10 different cases are considered for analysis purpose:

- Case I. Performance with various types of MB-PSSs only.
- CASE II: Performance with MB-PSSs considering notch filter.
- CASE III: Performance with Low, Intermediate and High band pass of PSS4B.
- CASE IV: Performance considering Low-Intermediate (LI) Band and Low Intermediate High (LIH) Band, with notch filter of PSS4B.
- CASE V: Performance comparison of PSS4B and Low-Intermediate (LI) band MBPSS only.
- CASE VI: Performance comparison of PSS4B with and without notch filter.
- CASE VII: Comparison of various types of MB-PSSs in continuous and discrete mode.
- CASE VIII: Performance analysis with notch filter in cascaded with discrete mode MB-PSSs.

I. Performance analysis of Various types of MB-PSS (PSS2B, PSS3B, PSS4B)

The PSS2B, PSS3B and PSS4B are implemented in the given LFC test system. Figure 2 and figure 3 show the speed deviation and power deviation with respect to time respectively, after perturbation in the system. The time domain responses are improved with the application of PSS4B as compared to PSS3B and PSS2B, as reflected from figure 2 and 3.

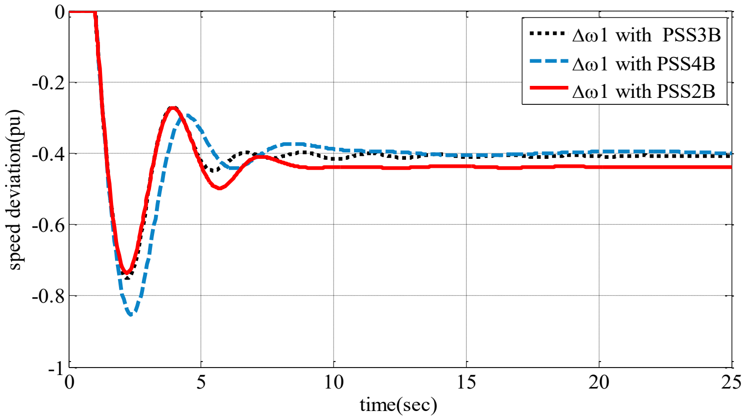

Figure 2: *Speed deviation (in pu) of area 1 with different types of MBPSSs*

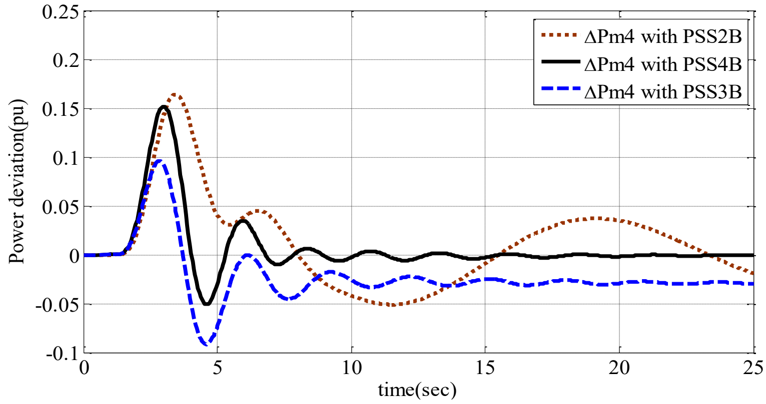

Figure 3: *Power deviation (in pu) of area 4 with different types of MBPSS*

II. Performance with MB-PSSs considering notch filter

Various types of MBPSSs with notch filter connected in cascaded, is used for the analysis purpose. Notch Filter is attenuating signal within a very narrow band of frequency. Here 6th order notch filter with 0.5 Hz center frequency and 0.25 quality factor is used in the test system. Speed deviation of area 2, using various types of MBPSSs with notch filter, are demonstrated in figure 4. It can be observed that the settling time and peak overshoot magnitude is reduced with application of PSS4B having notch filter.

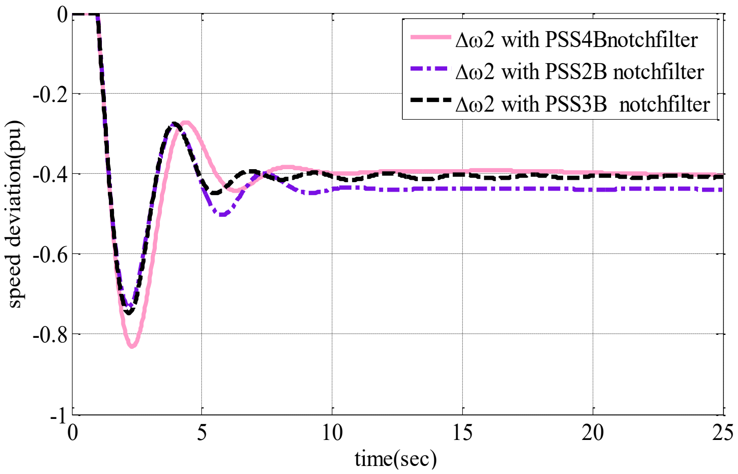

Figure 4: *Speed deviation (in pu) of area 2 with different types of MBPSS with notch filter*

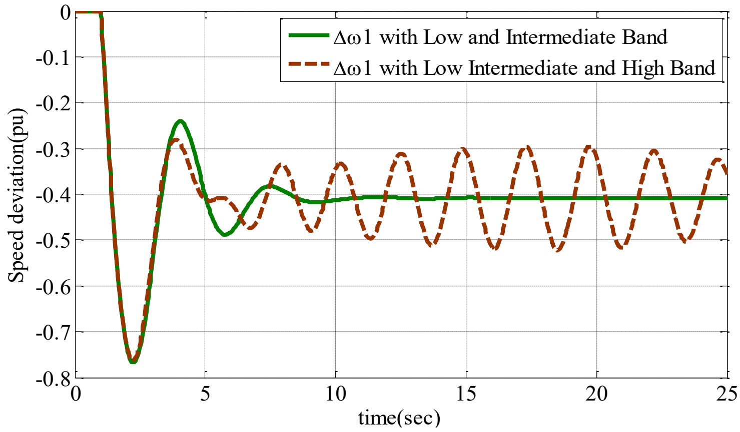

Figure 5: Speed deviation of generator in area 1 without speed

III. Performance with Low, Intermediate and High band pass of PSS4B

PSS4B has a separate differential filter as a band, to provide phase lead at low (0.01-0.1 Hz), intermediate provides (0.1-1Hz), and high frequency (1-4Hz) bands. Low and intermediate band filter getting it's input signal as speed deviation and high frequency band filter receiving it's input signal as electrical power deviation. Without speed transducer, low and intermediate band or low intermediate and high band filter are given in figure 5. The figure 6 shows that the change in power in area 3, , with low intermediate (LI) and Low-Intermediate-High (LIH) Band. It shows that LI Band has lower damping as compared to LIH Band for given LFC test system.

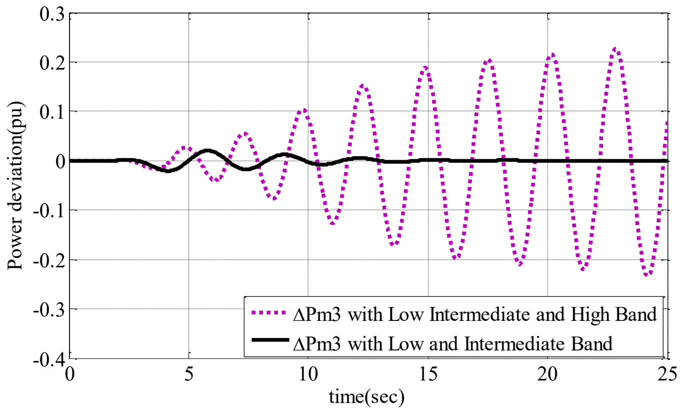

Figure 6: *Power deviation response of area 3 without speed transducer cascaded with PSS4B*

IV. Performance considering Low-Intermediate (LI) Band and Low Intermediate High (LIH) Band, with notch filter of PSS4B

Fig. 7 shows the frequency deviation of area 3 with LI or LIH band PSS having notch filter. From the plot obviously the settling time and oscillation magnitude is reduced by LI with notch filter. It has effectively reduced the peak overshoot. The figure 8 shows, the change in power in area five, with LI and LIH band having notch filter. It shows LI band with notch filter has lower damping as compare to LIH Band with notch filter.

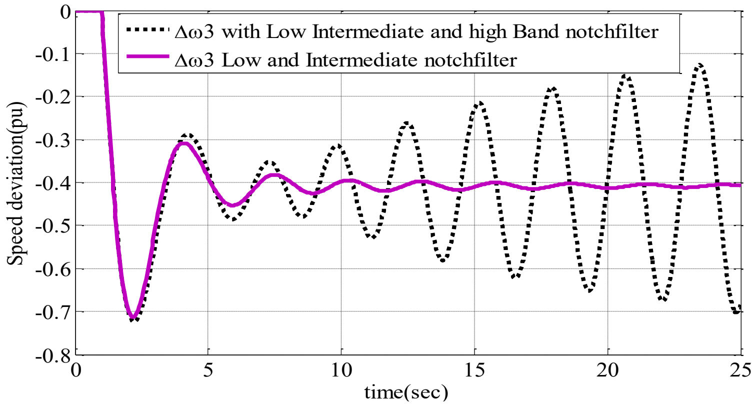

Figure 7: *Speed deviation response of area 3 without considering speed transducers but having notch filter with PSS4B*

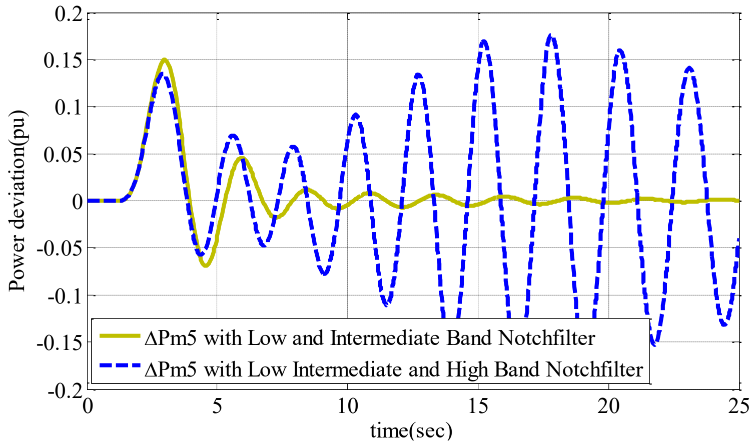

Figure 8: *Speed deviation response of area 5 without speed transducers but having notch filter with PSS4B*

V. Performance comparison of PSS4B and Low-Intermediate (LI) band MBPSS only

It can be seen from Fig. 9, 10, and 11, that with complete PSS4B, there is lower damping as compared to LI band in both cases having notch filter for given LFC system.

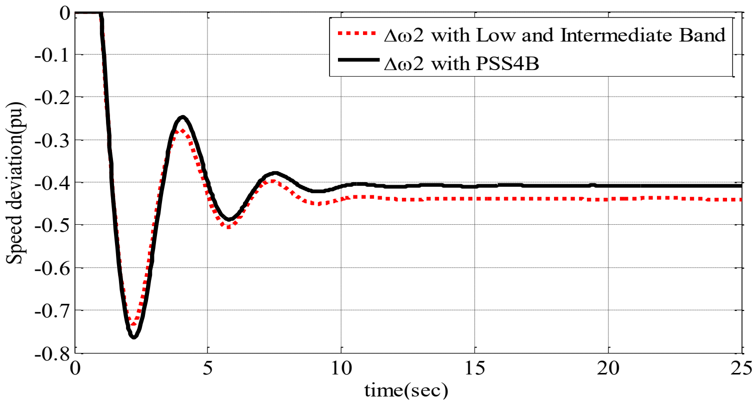

Figure 9: *Comparison of speed deviation in area 2 with PSS4B or Low and intermediate filter*

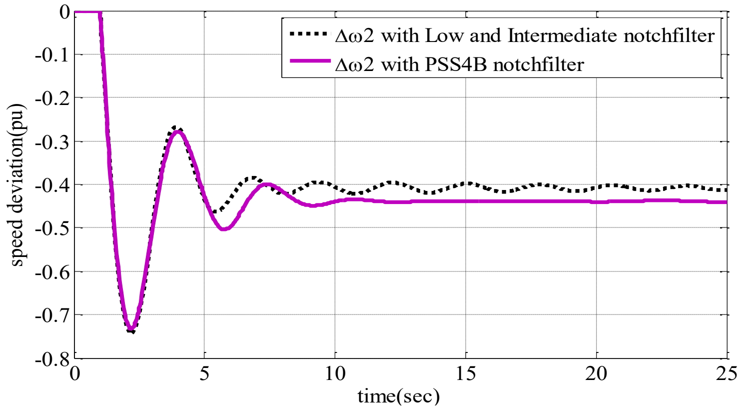

Figure 10: *Comparison of speed deviation in area 2 with Low and intermediate (LI) band having notch filter in PSS4B*

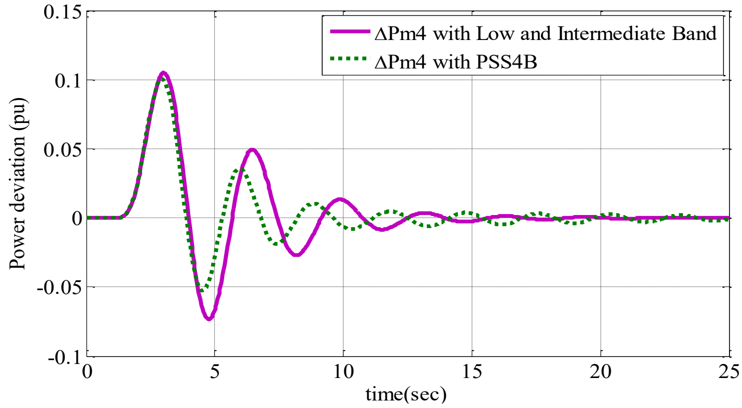

Figure 11: *Comparison of Power deviation response of area 4 with complete PSS4B and with LI Band PSS only*

VI. Performance comparison of PSS4B with and without notch filter

Critical analysis of Fig.12, and Fig.13 shows that PSS4B with notch filter have transient response. From the plot it can be derived that the settling time and oscillation magnitude is reduced. The designed PSS4B with notch filter mitigates the oscillation time and amplitude and brings the system again into the stable operation.

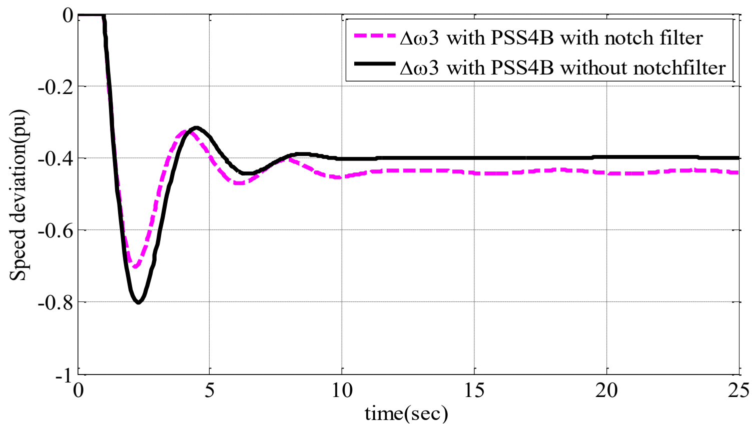

Figure 12: *Comparison of speed deviation in area 3 of PSS4B with or without notch filter*

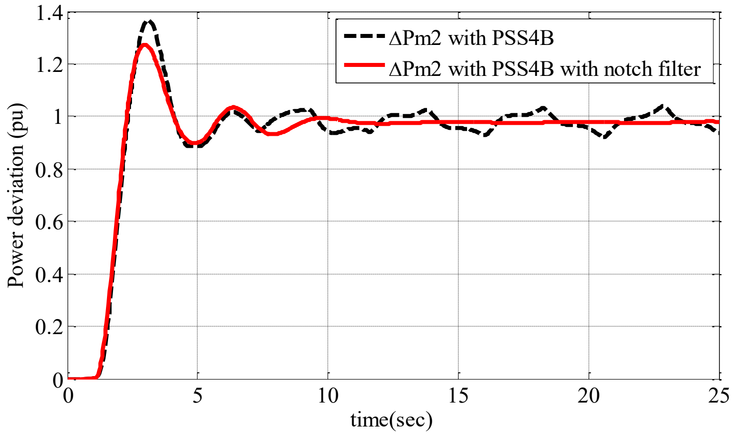

Figure 13: *Comparison of power deviation in area 2 of PSS4B with or without notch filter*

VII. Comparison of various types of MB-PSSs in continuous and discrete mode

PSS2B, PSS3B, PSS4B are studied for both continuous and discrete signal. Comparison of these things are shown below. The sampling time of discrete function is 0.04 Hz. Discrete time shows better accurate than continuous time signal. From the Fig.14, Fig.15, Fig.16, and Fig. 17 analyzed that the different type of MBPS in discrete and continuous (PSS 2B, 3B, 4B), conclusion drawn from plots is continuous mode shows better performance than discrete mode.

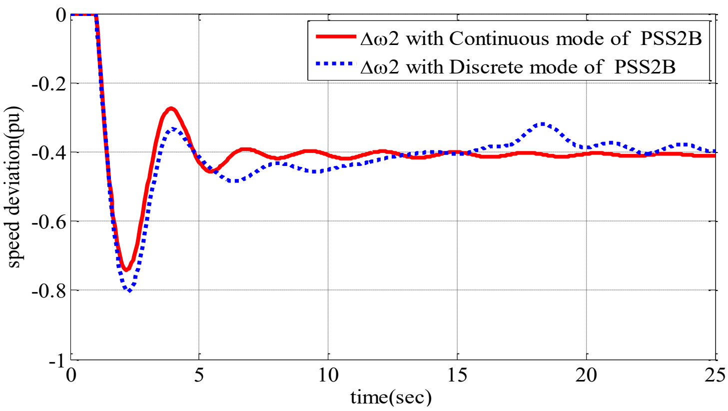

Figure 14: *Comparison between speed deviation of area 2 with discrete and continuous and discrete PSS2B*

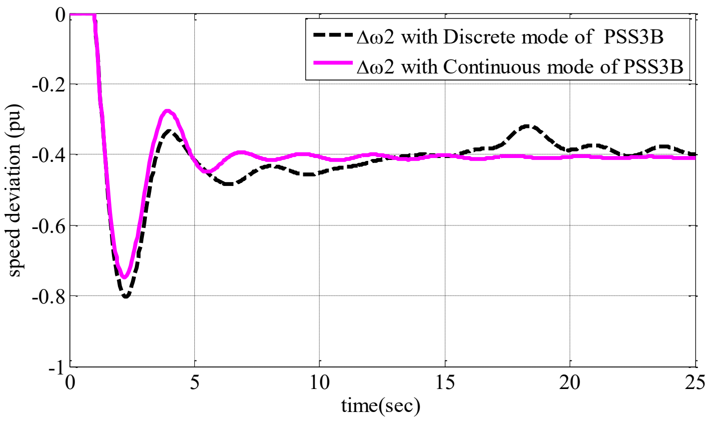

Figure 15: *Comparison between speed deviation of area 2 with discrete and continuous and discrete PSS3B*

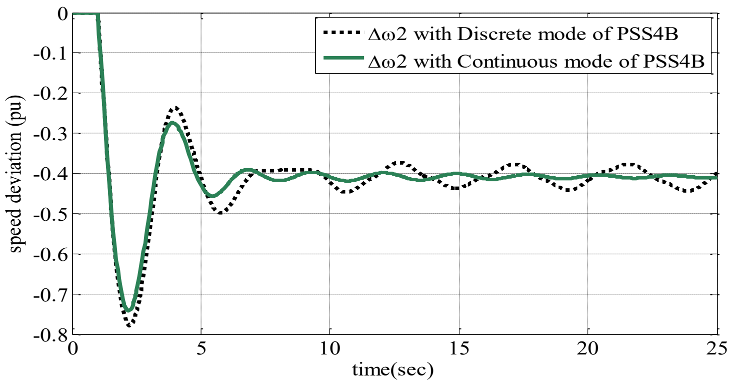

Figure 16: *Comparison b/w frequency deviation step responses of area 2 continuous and discrete mode of PSS4B*

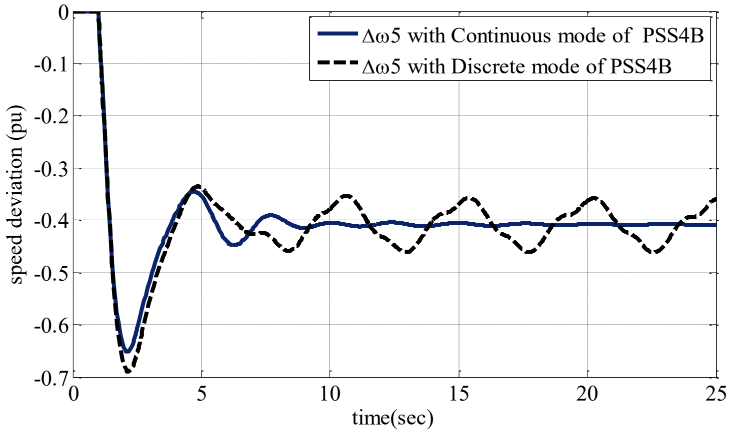

Figure 17: *Comparison between frequency deviation of area 5 with continuous and discrete mode of PSS4B*

VIII. Performance analysis with notch filter in cascaded with discrete mode MB-PSSs

Critical analysis of Fig. 18, Fig. 19, and Fig. 20 shows that the settling time and oscillation magnitude is reduced by PSS4B with notch filter in discrete time signal.

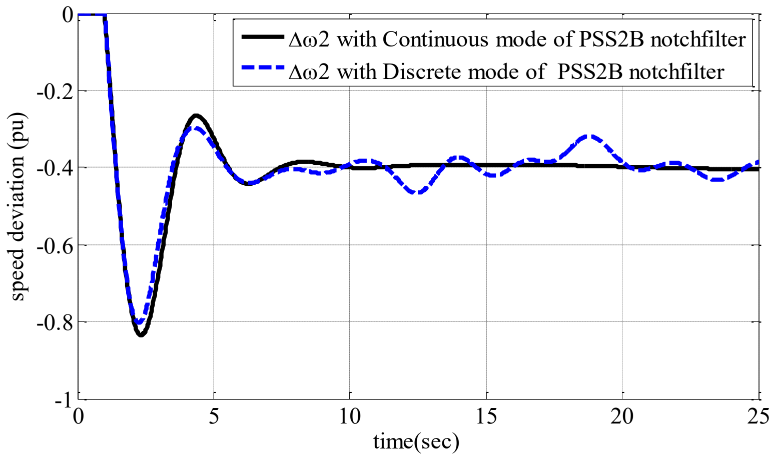

Figure 18: *Comparison between speed deviation of area 2 with continuous and discrete mode of PSS2B having notch filter*

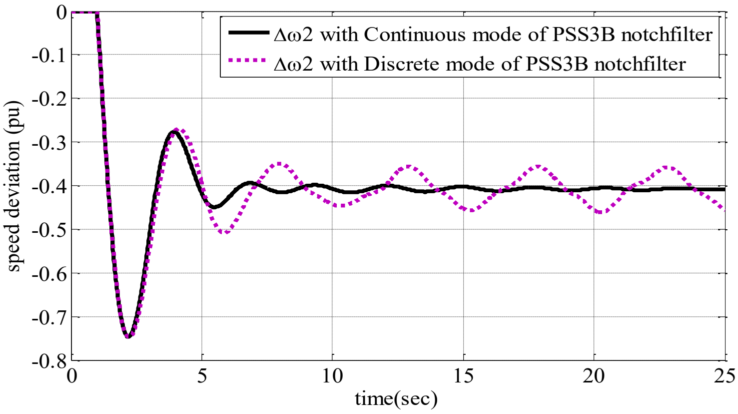

Figure 19: *Comparison between speed deviation of area 2 with continuous and discrete mode of PSS3B with Notch Filter*

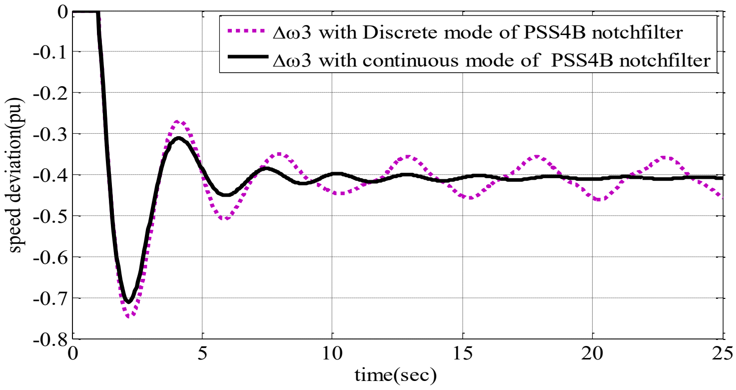

Figure 20: *Comparison between speed deviation of area 3 with continuous and discrete mode of PSS4B with Notch Filter*

V. Conclusion

This work gives a comparative performance analysis between the various types of MB-PSS along-with continuous and discrete mode MB-PSSs. The 5-area reheat thermal power system is taken for complete analysis purpose. For this test system, it has been observed that PSS4B gives better load frequency control performance as compared to PSS2B and PSS3B, both with and without notch filter consideration. Particularly in PSS4B, LI band of MB-PSS gives improved time domain performance as compared LIH band of MB-PSS. The discrete mode MB-PSSs are analyzed at sampling time of 0.04 sec, for given test system. It has been found that continuous mode MB-PSSs gives better time domain performance corresponding to their discrete counterpart. Along-with time domain response, a comparative time domain specifications are also mentioned to verify the performance

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