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Performance Evaluation of Power System Stabilizer

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Abstract
A power system stabilizer (PSS) installed in the excitation system of the synchronous generator improves the small-signal power system stability by damping out low frequency oscillations in the power system. It does that by providing supplementary perturbation signals in a feedback path to the alternator excitation system. Many different methods and approaches have been investigated to design PSS. In this paper a comprehensive study of the PSS designing methods is presented. For simulations, we use three different design of PSS, multiband PSS (MB-PSS), conventional delta w PSS (Delta w) and conventional acceleration power PSS (Delta Pa). The MATLAB package with Control System Toolbox and SIMULINK is used for the design and simulations for symmetrical and asymmetrical faults analysis of the proposed system.

Keywords: Power system stabilizers; Symmetrical fault; Asymmetrical fault; dynamic stability.

Introduction
Power system stabilizers have been used for many years to add damping to electromechanical oscillations. Essentially, they act through the generators excitation system in such a way that a component of electrical torque proportional to speed change is generated (an addition to the damping torque) [1]-[2]. Of course, it is easy to say that this is done, and the mechanism varies depending on whether the mode is a local mode or an inter-area mode [3]. Never the less, an effective stabilizer does produce a damping torque over a wide range of input frequencies [4]. Less effective stabilizers may only produce a damping torque over a very small frequency range, which leads to problems when system changes cause the system's oscillatory modes to change.
The power frequency and the tie-line power deviations persist for a long duration. In these situations, the governor system may no longer be able to absorb the frequency fluctuations due to its slow response [5]. To stabilize power oscillation, PSS is often used as an effective device to enhance the damping of electromechanical oscillations in power systems. The power system stabilizer is a supplementary control system, which is often applied as part of excitation control system. The basic function of the PSS is to apply a signal to the excitation system, creating electrical torques to the rotor, in phase with speed variation, that damp out power oscillations.
In the past decades, the utilization of supplementary excitation control signals for improving the dynamic stability of power systems has received much attention. Extensive research has been conducted in many fields such as the effect of PSS on power system stability, PSS input signals, PSS optimum locations, and PSS tuning techniques. In [6], the concept of synchronous machine stability as affected by excitation control has been examined. This work developed insights into effects of excitation systems and requirement of supplementary stabilizing action for such systems based on the concept of damping and synchronizing torques. These stabilizing requirements included the adjustment of voltage regulator gain parameters as well as the PSS parameters.
Since the primary function of the PSS is to add damping to the power oscillations, basic control theories have been applied to select the most suitable input signal of PSS. Some readily available signals are generator rotor speed, calculated bus frequency, and electrical power. In [7], the application of PSS utilizing either of speed, frequency or power input signals has been presented. Guidelines were presented for tuning PSS that enable the user to achieve desired dynamic performance with limited effort. The need for torsional filters in the PSS path for speed input PSS was also discussed. The most PSS controls today use the generator rotor speed as the feedback input signal. They would provide robust damping over a wide range of operating conditions with minimum interaction [8].
Simulation studies of PSS effects on inter-area and local modes of oscillations in interconnected power systems have been presented by [9]-[10]. It was shown that the PSS location and the voltage characteristics of the system loads are significant factor in the ability of a PSS to increase the damping of inter-area oscillations. The procedures for the selection of the most effective machines for stabilization have been proposed.

Power System Model
A two-area four-machine interconnected power system with wind farms in Fig.1 is used to design PSS. Each generator is represented by a 5th-state transient model [11].

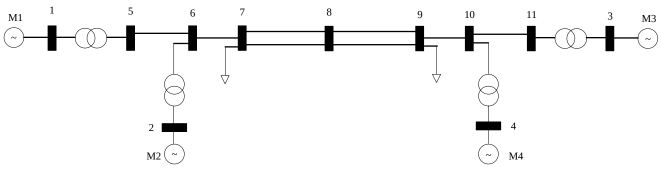

Fig. 1. Two area four machines power system

The system consists of two similar areas connected by a weak tie. Each area consists of two coupled units, each having rating of 900 MVA and 20 kV. The generator parameters in per unit on the rated MVA and kV base are as follows.

$$X_d = 1.8$$
$$X_q = 1.7 \quad X_l = 0.2$$
$$X_d^{'} = 0.3 \quad X_q^{'} = 0.55 \qquad (1)$$
$$X_d^{''} = 0.25$$
$$X_q^{''} = 0.25 \quad R_a = 0.0025$$
$$T_{d0}^{'} = 8.0s \quad T_{q0}^{'} = 0.4s \qquad (2)$$
$$T_{d0}^{''} = 0.3s$$
$$T_q^{''} = 0.05s \quad A_{Sat} = 0.015$$
$$B_{Sat} = 9.6 \quad \psi_{T1} = 0.9 \qquad (3)$$

H = 6.5 (for M1 and M2) H=6.175
(for M3 and M4)
K_D=0 (4)

Each step –up transformer has an impedance of 0+j0.15 per unit on 900 MVA and 20/230kV base, and has an off-nominal ratio of 1.0. The transmission system nominal voltage is 230kV. The line lengths are identified in Fig.1. The parameters of the line in per unit on 100 MVA, 230 kV base are,

R=0.0001 pu/km
x_l = 0.001 pu/km
b_C = 0.00175 pu/km (5)

The system is operating with area 1 exporting 400 MVA to area 2, and the generating units are loaded as,

M1: P = 700 MW, Q = 185 MVAr, $E_t = 1.03\angle 20.2°$
M2: P = 700 MW, Q = 235 MVAr, $E_t = 1.01\angle 10.5°$
M3: P = 719 MW, Q=176MVAr, $E_t = 1.03\angle -6.8°$
M4: P = 700 MW, Q=202MVAr, $E_t = 1.03\angle -17.0°$ (6)

Proposed System Description

The test system consists of two fully symmetrical areas linked together by two 230 kV lines of 220 km length. It was specifically designed in [10]-[11] to study low frequency electromechanical oscillations in large interconnected power systems. Despite its small size, it mimics very closely the behaviour of typical systems in actual operation. Each area is equipped with two identical round rotor generators rated 20 kV/900 MVA. The synchronous machines have identical parameters [1,2], except for inertias which are H = 6.5s in area 1 and H = 6.175s in area 2 [11]. Thermal plants having identical speed regulators are further assumed at all locations, in addition to fast static exciters with a 200 gain [10]-[11]. The load is represented as constant impedances and split between the areas in such a way that area 1 is exporting 413MW to area 2. Since the surge impedance loading of a single line is about 140 MW [11], the system is somewhat stressed, even in steady-state. The reference load-flow with M2 considered the slack machine is such that all generators are producing about 700 MW each. The results can be seen by opening the Powergui and selecting Machine and Load-Flow Initialization. They are slightly different from [11], because the load voltage profile was improved (made closer to unity) by installing 187 MVAr more capacitors in each area. In addition, transmission and generation losses may vary depending on the detail level in line and generator representation.

Three different design of PSS, multiband PSS (MB-PSS), conventional delta w PSS (Delta w) and conventional acceleration power PSS (Delta Pa). The MATLAB package with Control System Toolbox and SIMULINK is used for the design and simulations for symmetrical and asymmetrical faults analysis of the system. Fig.2 shows the Simulink representation of two area four machine power system implemented with different PSS.

A. Symmetrical Fault Analysis of two area four machine power system

Figs.3-22 show the simulated responses of four machine power system with symmetrical fault analysis. Figs.3-7 show the symmetrical fault analysis of the proposed system without the PSS implementation. Figs.8-12 show the symmetrical fault analysis of the four machine two area power system with multiband PSS, Figs.13-17 show with delta w PSS and Figs.18-22 show with delta Pa PSS respectively. From the reflection of the three PSS, the multiband PSS responses are superior to other two.

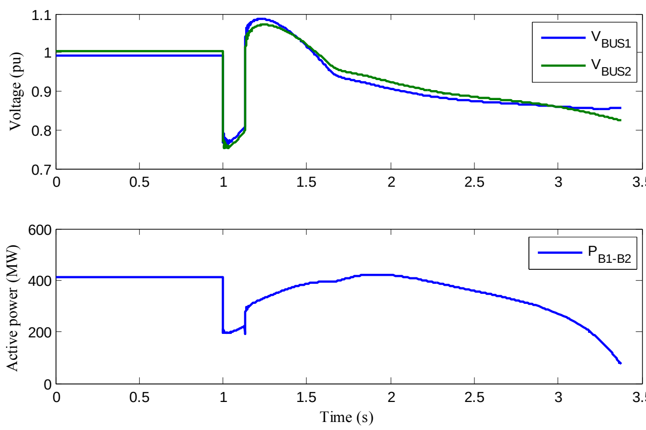

Fig.3 Simulated response of active power and voltage for bus 1 and 2 without PSS

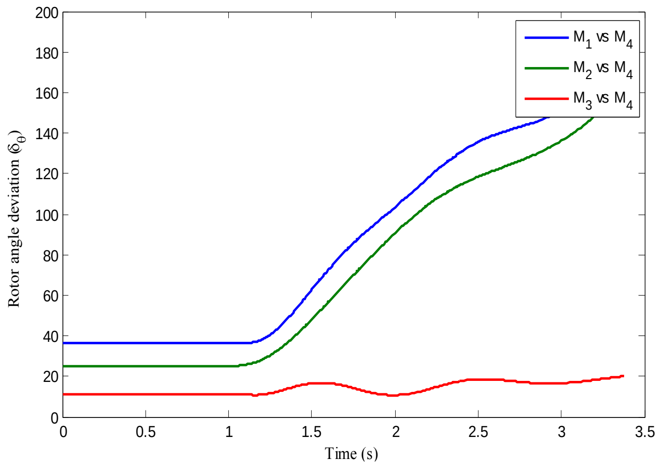

Fig.4 Simulated response of rotor angle deviation for two area four machine power system without PSS

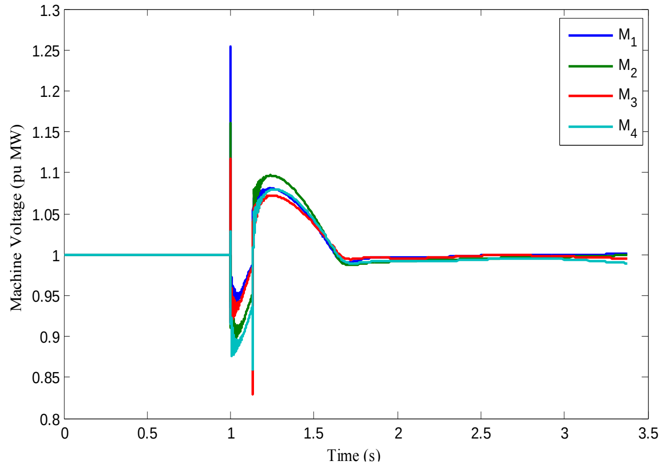

Fig.7 Simulated response of machine voltage for two area four machine power system without PSS

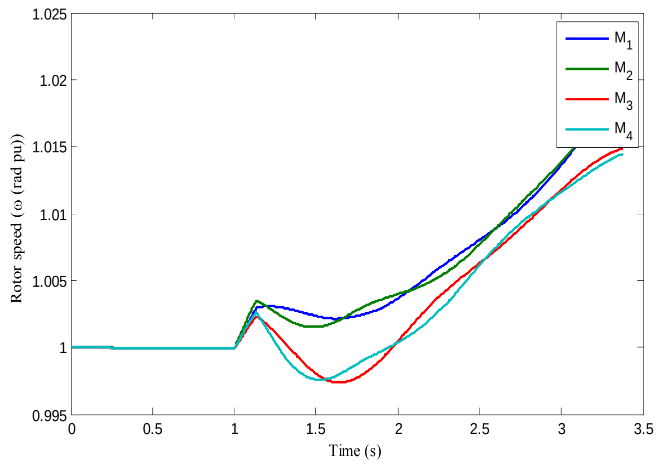

Fig.5 Simulated response of rotor speed for two area four machine power system without PSS

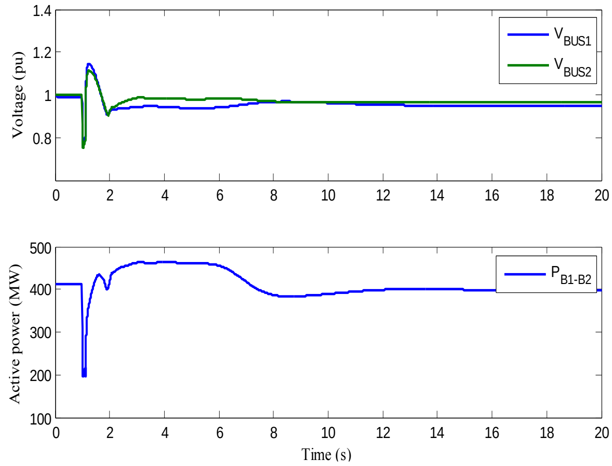

Fig.8 Simulated response of active power and voltage for bus 1 and 2 with multiband PSS

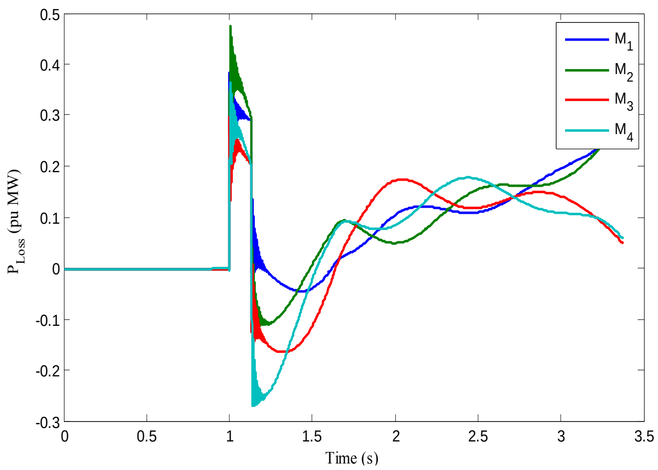

Fig.6 Simulated response of power loss for two area four machine power system without PSS

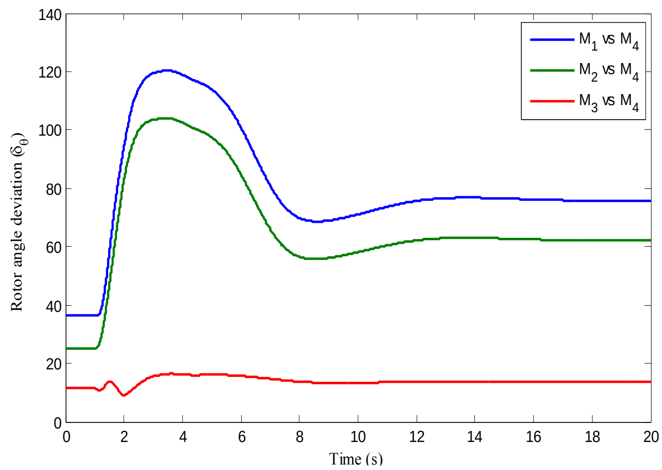

Fig.9 Simulated response of rotor angle deviation for two area four machine power system with multiband PSS

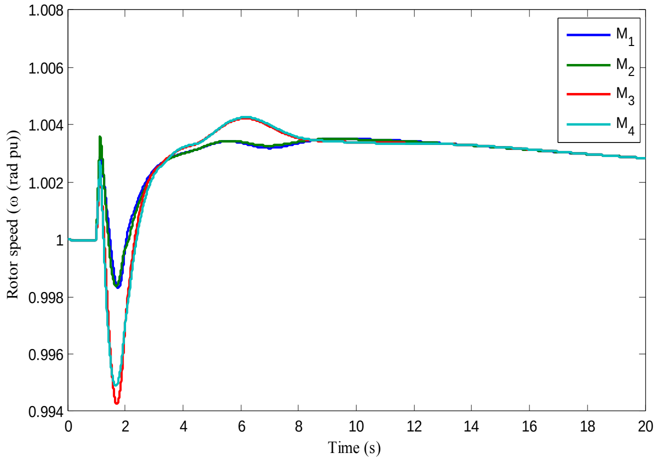

Fig.10 Simulated response of rotor speed for two area four machine power system with multiband PSS

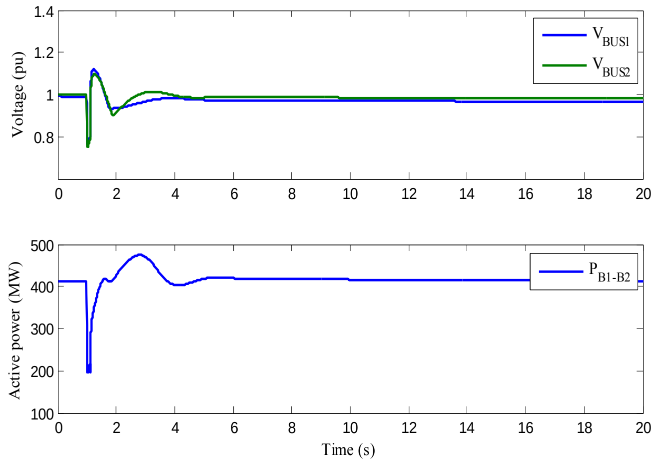

Fig.13 Simulated response of active power and voltage for bus 1 and 2 with delta w PSS

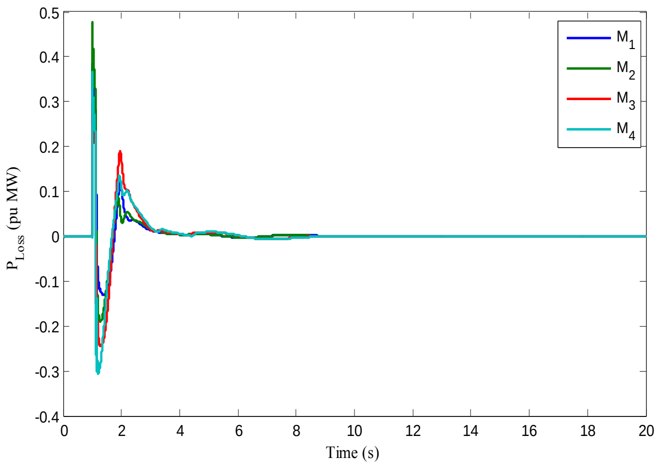

Fig.11 Simulated response of power loss for two area four machine power system with multiband PSS

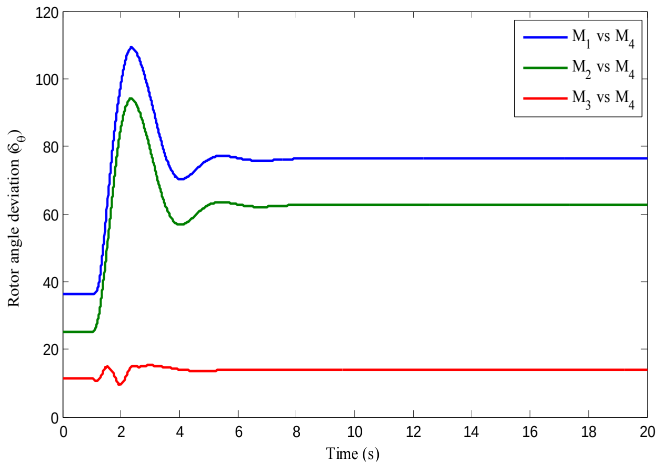

Fig.14 Simulated response of rotor angle deviation for two area four machine power system with delta w PSS

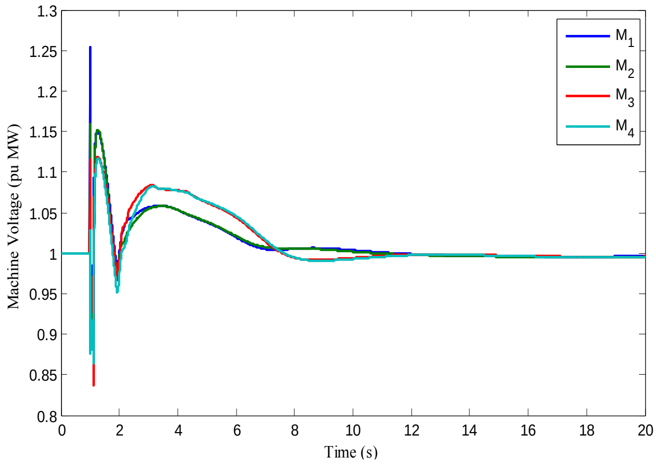

Fig.12 Simulated response of machine voltage for two area four machine power system with multiband PSS

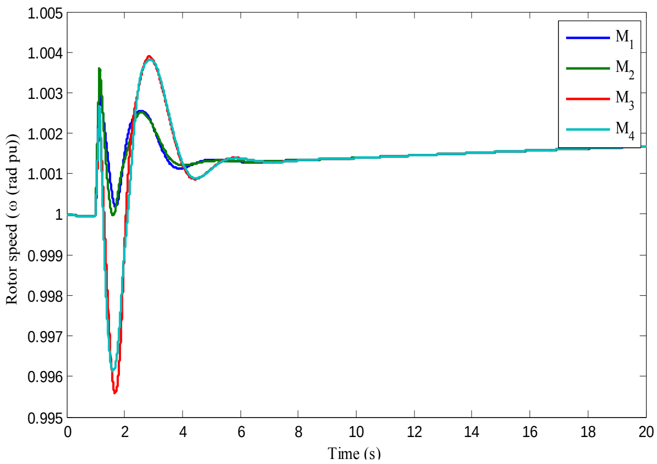

Fig.15 Simulated response of rotor speed for two area four machine power system with delta w PSS

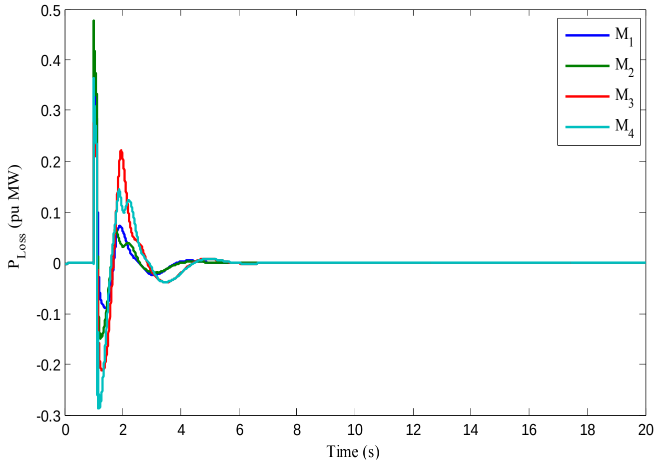

Fig.16 Simulated response of power loss for two area four machine power system with delta w PSS

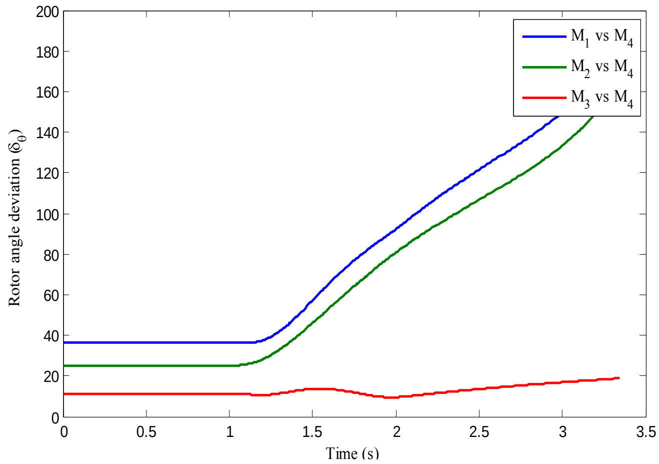

Fig.19 Simulated response of rotor angle deviation for two area four machine power system with delta Pa PSS

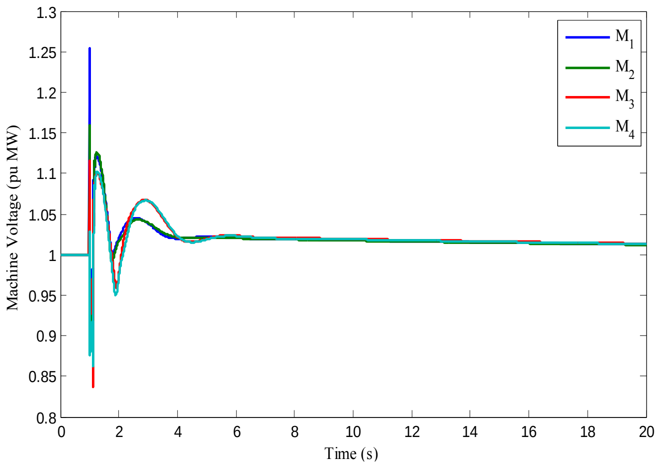

Fig.17 Simulated response of machine voltage for two area four machine power system with delta w PSS

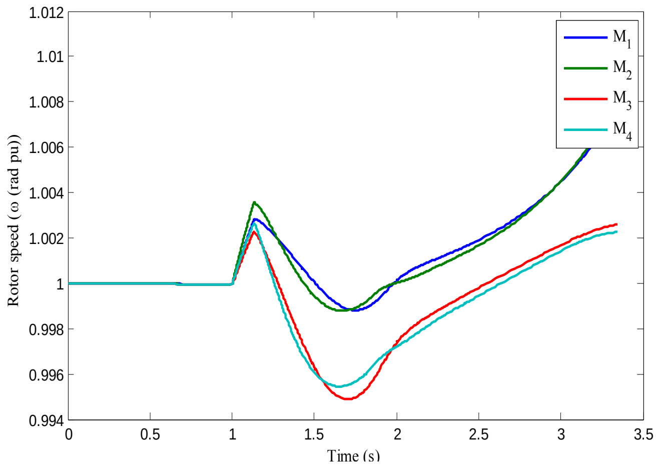

Fig.20 Simulated response of rotor speed for two area four machine power system with delta Pa PSS

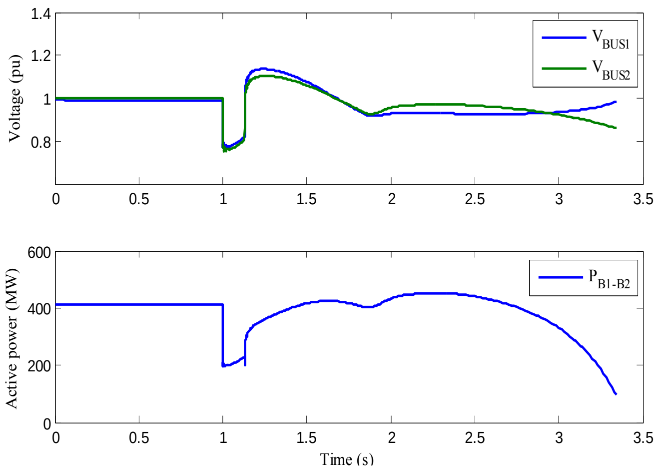

Fig.18 Simulated response of active power and voltage for bus 1 and 2 with delta Pa PSS

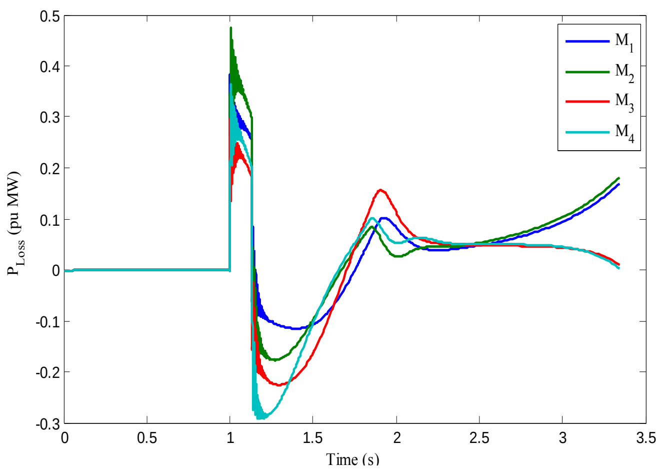

Fig.21 Simulated response of power loss for two area four machine power system with delta Pa PSS

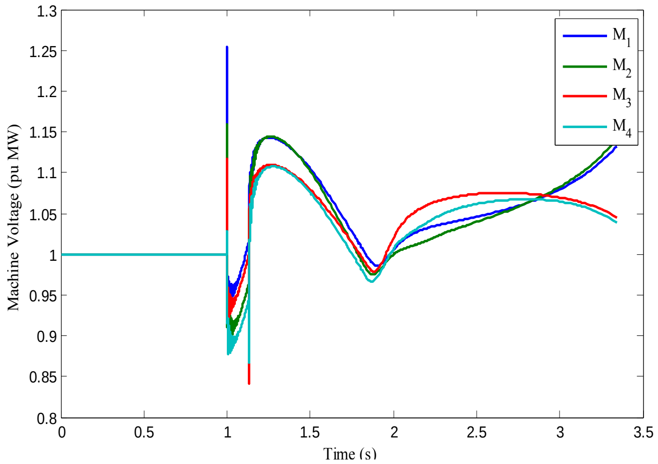

Fig.22 Simulated response of machine voltage for two area four machine power system with delta Pa PSS

B. Asymmetrical Fault Analysis of two area four machine power system

Figs.23-62 show the simulated responses of four machine power system with asymmetrical fault analysis such as L-G and LL-G fault. Figs.23-27 show the L-G fault analysis of the proposed system without the PSS implementation. Figs.28-32 show the L-G fault analysis of the four machine two area power system with multiband PSS, Figs.33-37 show with delta w PSS and Figs.38-42 show with delta Pa PSS respectively. From the simulation of the three PSS, the multiband PSS responses are superior to other two. Similarly for the LL-G fault analysis the multiband PSS is superior to others. The simulated responses of single line to ground fault analysis is shown in Figs.43-62.

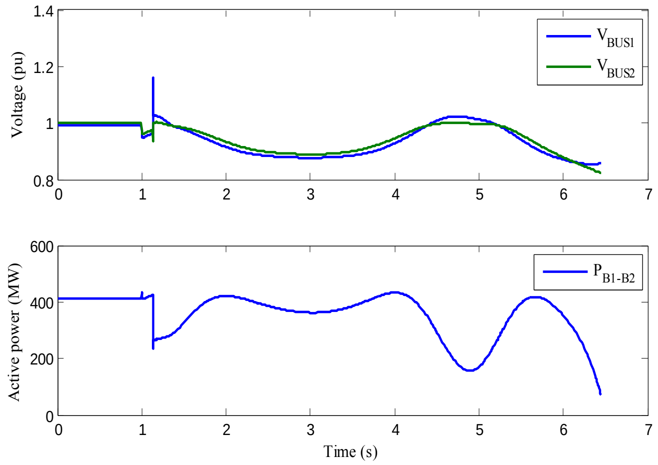

Fig.23 Active power and voltage for bus 1 and 2 without PSS during L-G fault

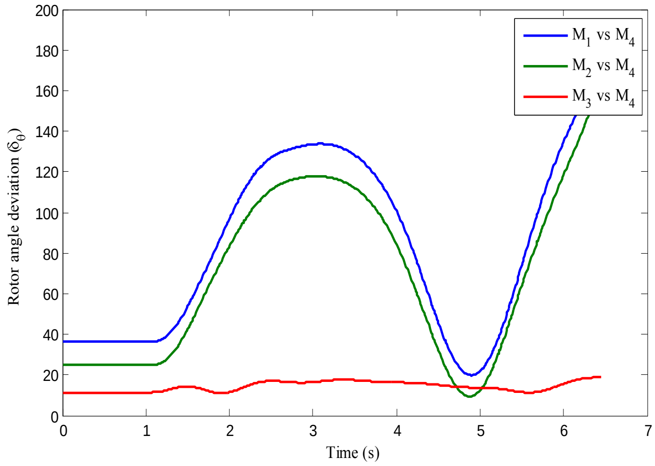

Fig.24 Rotor angle deviation for two area four machine power system without PSS during L-G fault

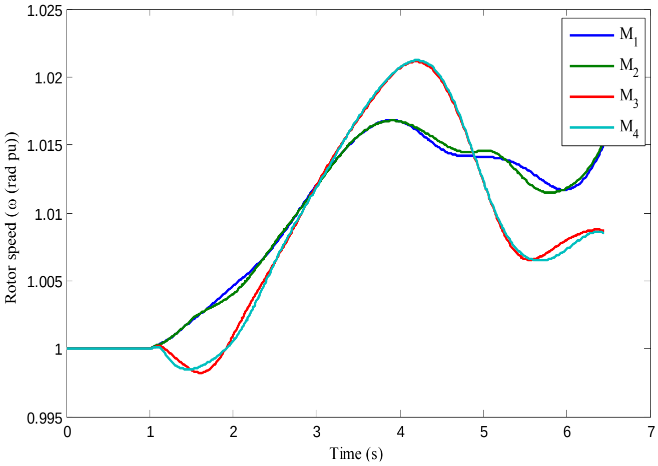

Fig.25 Rotor speed for two area four machine power system without PSS during L-G fault

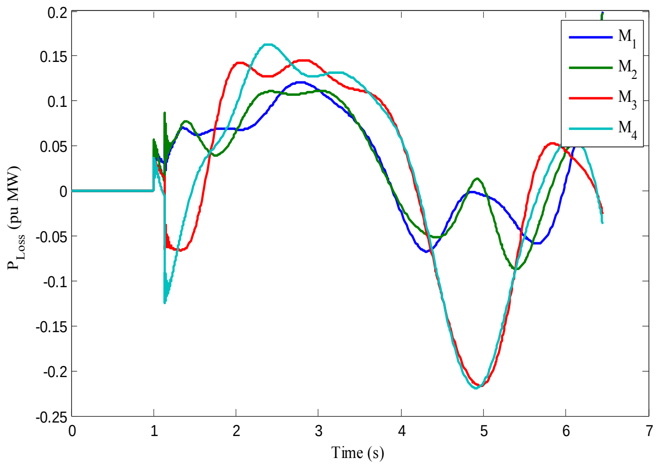

Fig.26 Power loss for two area four machine power system without PSS during L-G fault

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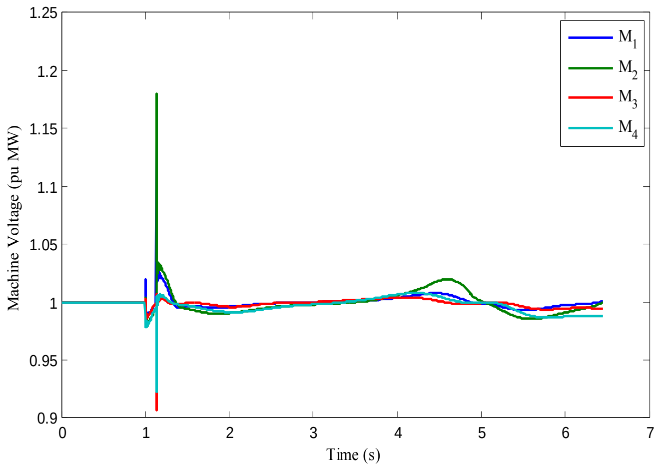

Fig.27 Machine voltage for two area four machine power system without PSS during L-G fault

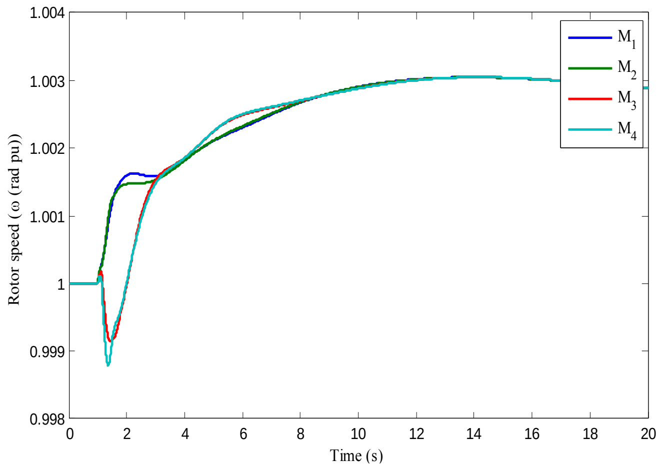

Fig.30 Rotor speed for two area four machine power system with multiband during L-G fault

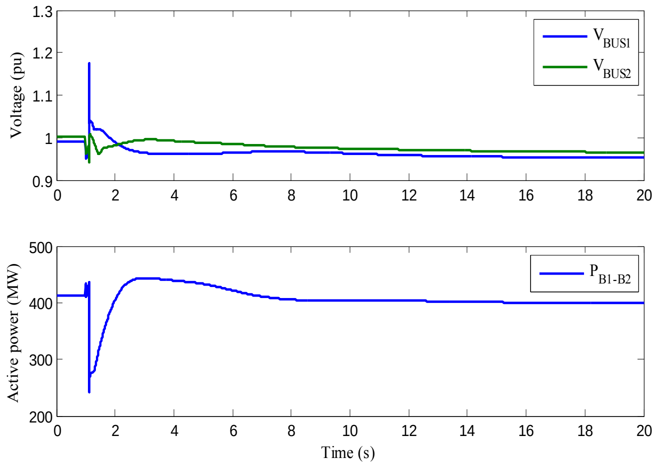

Fig.28 Active power and voltage for bus 1 and 2 with multiband PSS during L-G fault

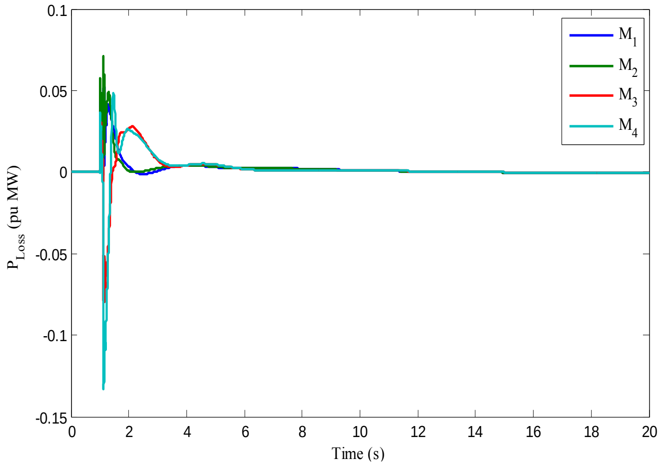

Fig.31 Power loss for two area four machine power system with multiband PSS during L-G fault

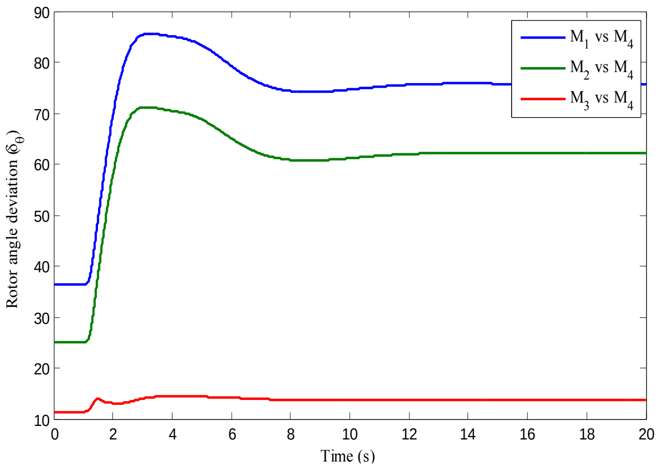

Fig.29 Rotor angle deviation for two area four machine power system with multiband PSS during L-G fault

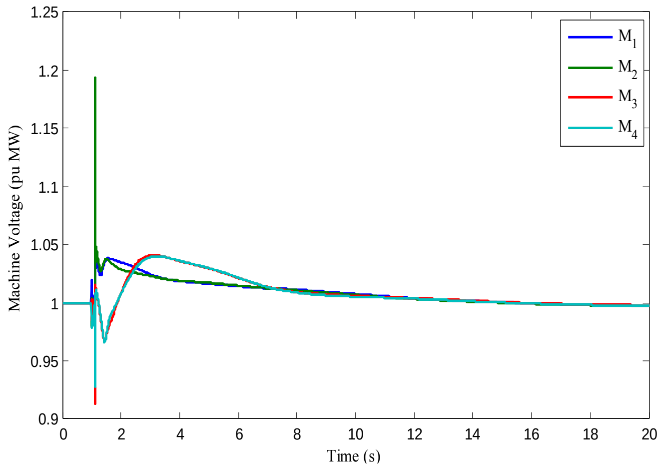

Fig.32 Machine voltage for two area four machine power system with multiband during L-G fault

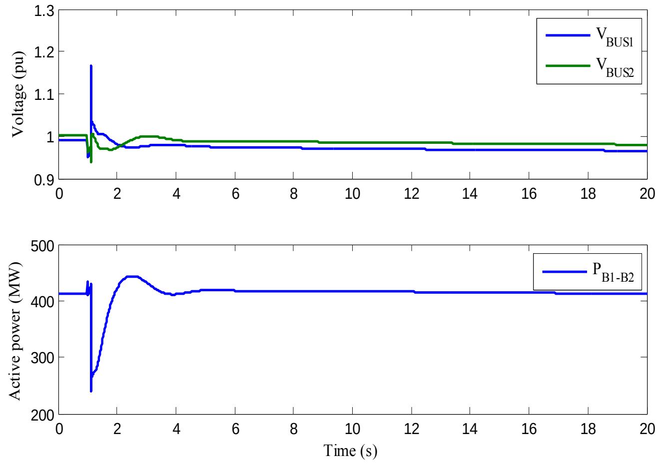

Fig.33 Active power and voltage for bus 1 and 2 with delta w PSS during L-G fault

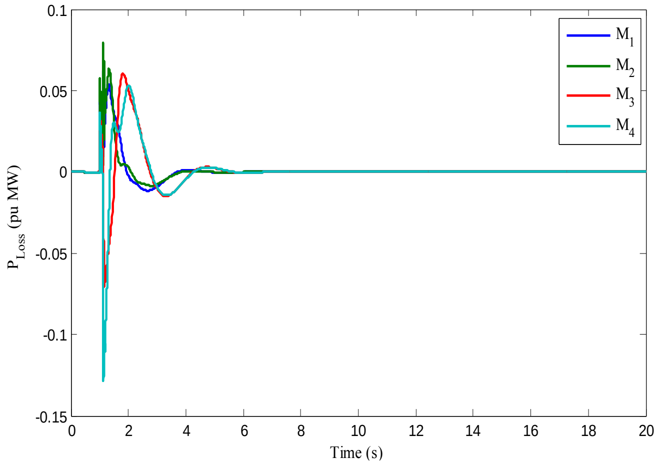

Fig.36 Power loss for two area four machine power system with delta w PSS during L-G fault

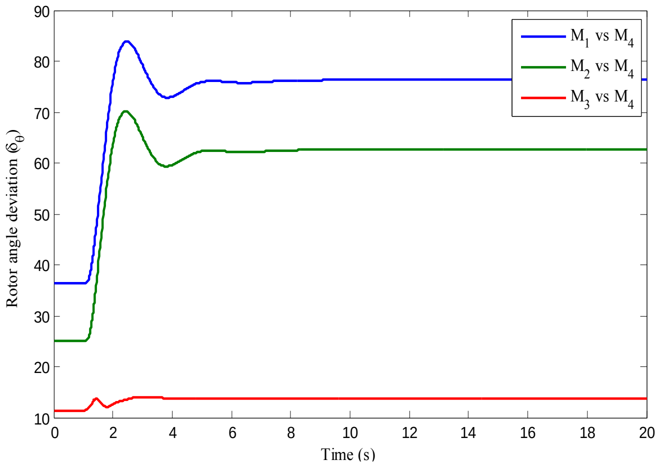

Fig.34 Rotor angle deviation for two area four machine power system delta w PSS during L-G fault

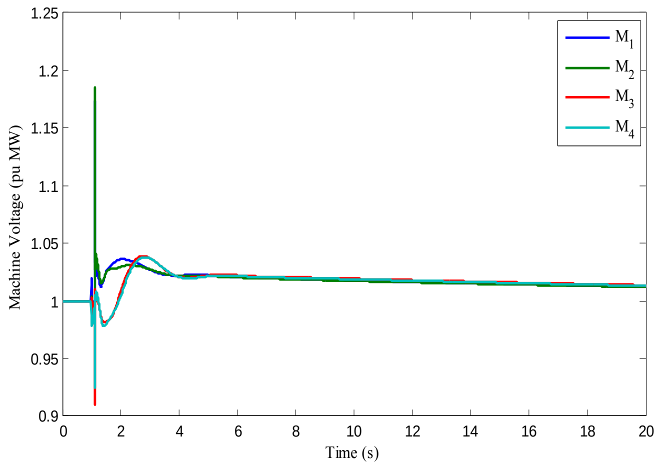

Fig.37 Machine voltage for two area four machine power system with delta w PSS during L-G fault

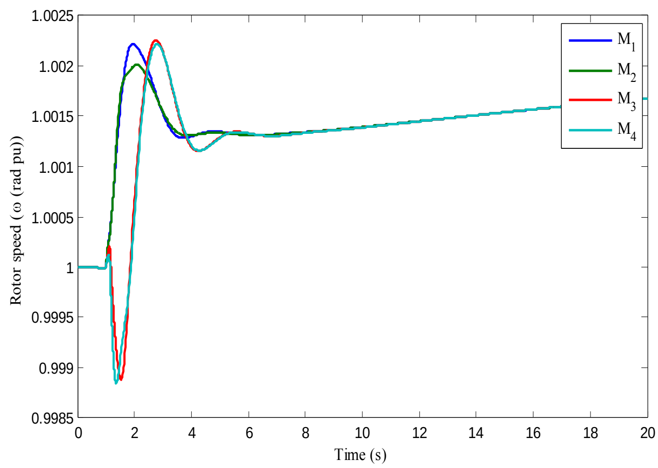

Fig.35 Rotor speed for two area four machine power system with delta w PSS during L-G fault

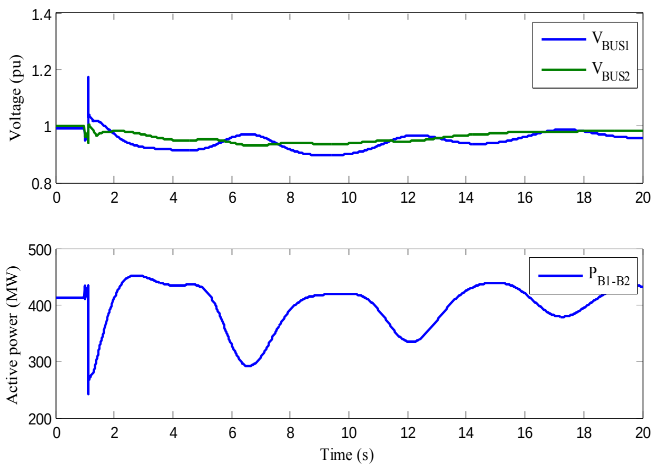

Fig.38 Active power and voltage for bus 1 and 2 with delta Pa PSS during L-G fault

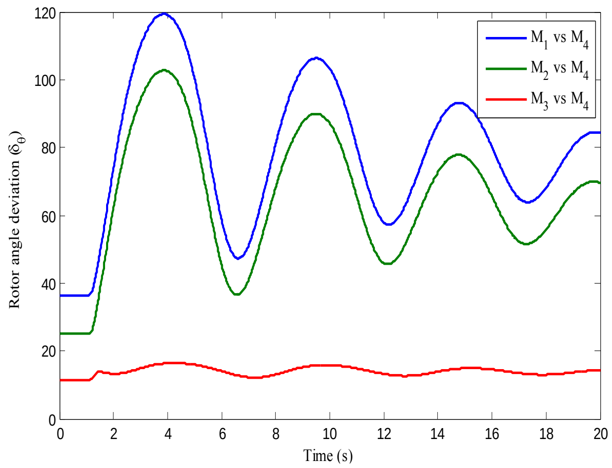

Fig.39 Rotor angle deviation for two area four machine power system delta Pa PSS during L-G fault

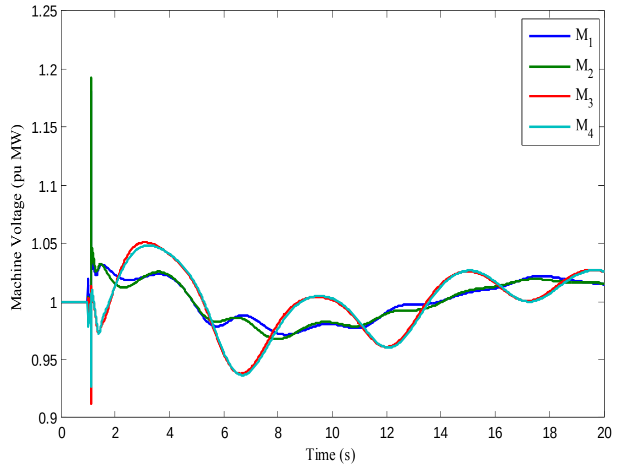

Fig.42 Machine voltage for two area four machine power system with delta Pa PSS during L-G fault

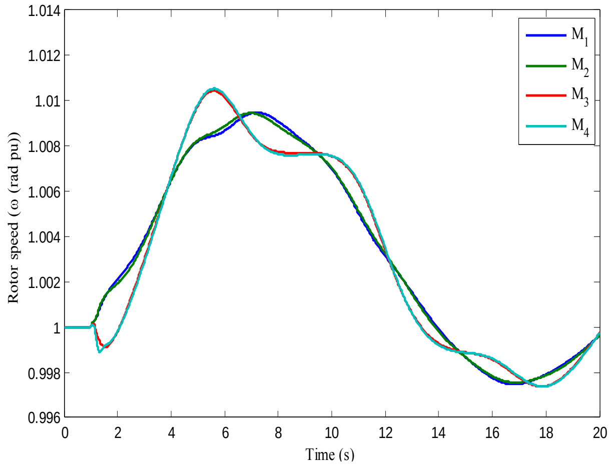

Fig.40 Rotor speed for two area four machine power system with delta Pa PSS during L-G fault

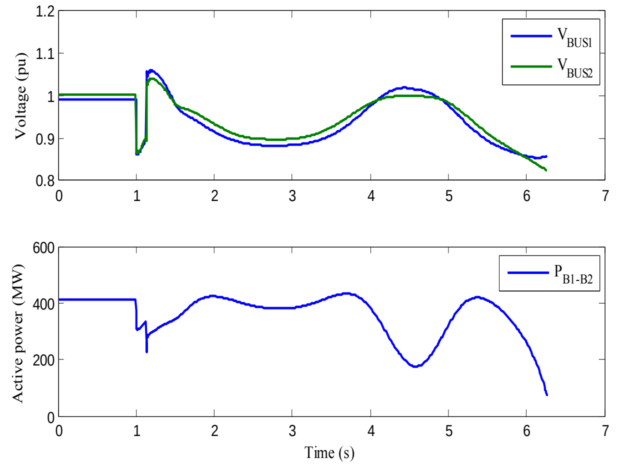

Fig.43 Active power and voltage for bus 1 and 2 without PSS during LL-G fault

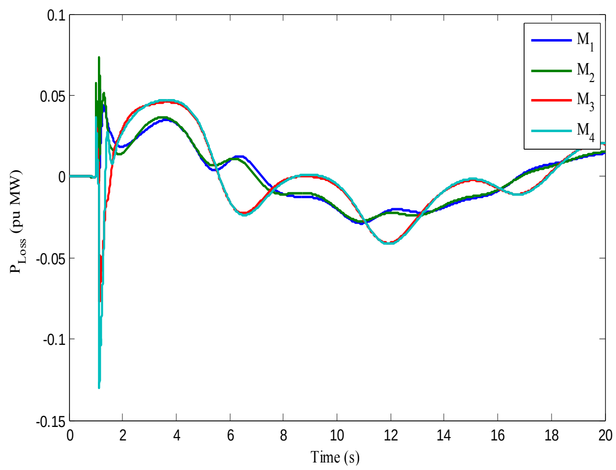

Fig.41 Power loss for two area four machine power system with delta Pa PSS during L-G fault

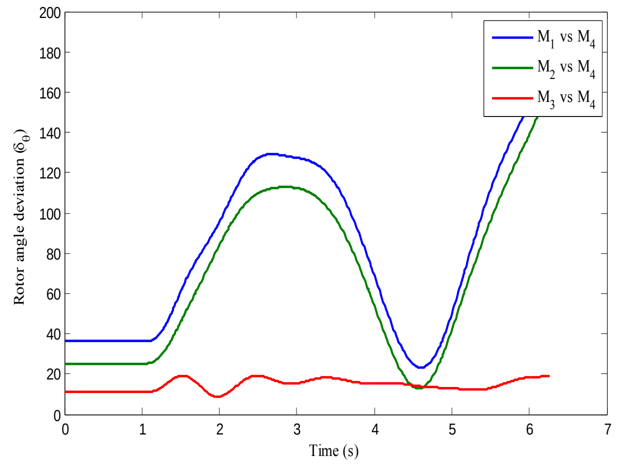

Fig.44 Rotor angle deviation for two area four machine power system without PSS during LL-G fault

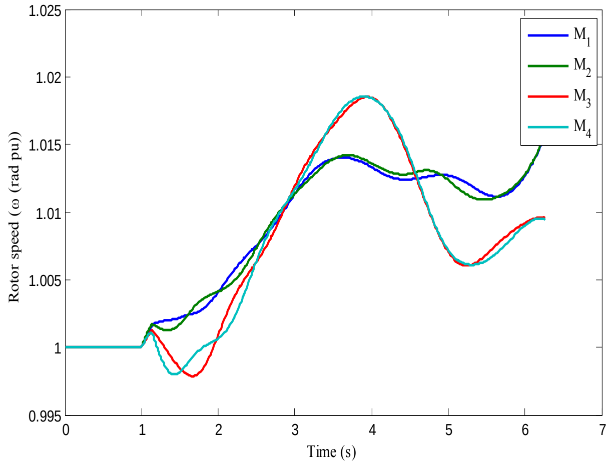

Fig.45 Rotor speed for two area four machine power system without PSS during LL-G fault

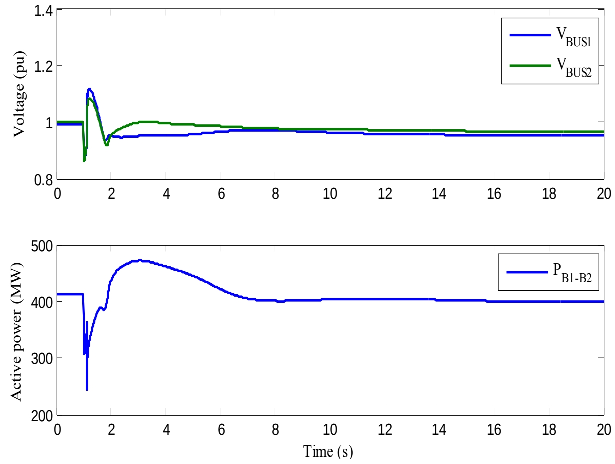

Fig.48 Active power and voltage for bus 1 and 2 with multiband PSS during LL-G fault

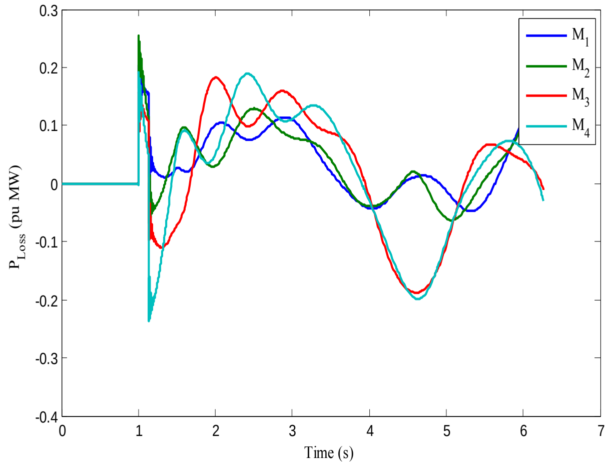

Fig.46 Power loss for two area four machine power system without PSS during LL-G fault

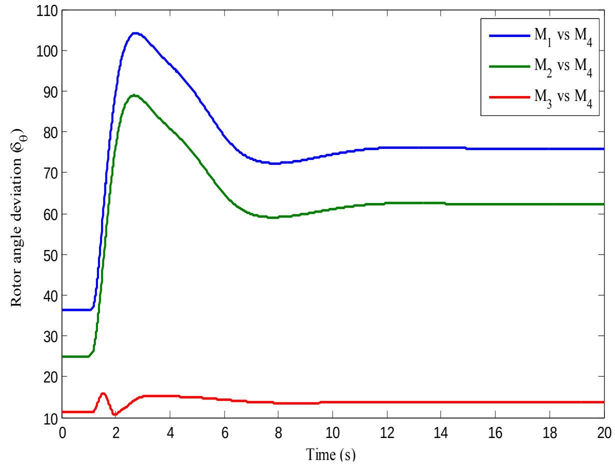

Fig.49 Rotor angle deviation for two area four machine power system with multiband PSS during LL-G fault

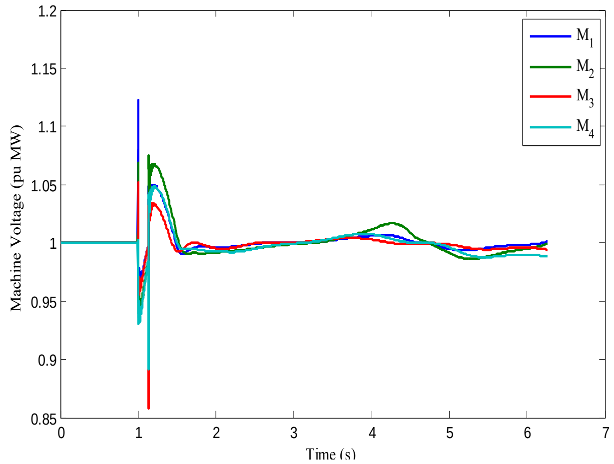

Fig.47 Machine voltage for two area four machine power system without PSS during LL-G fault

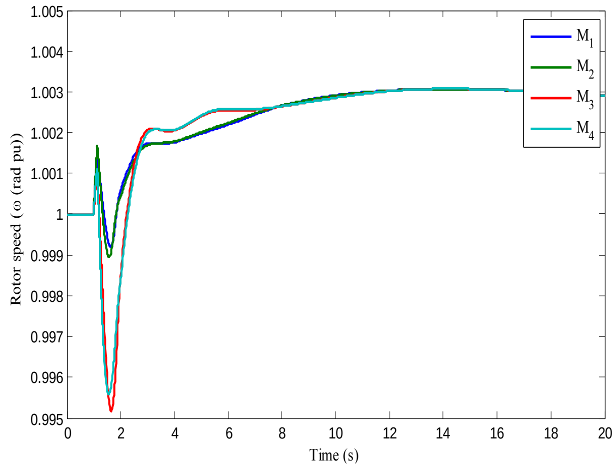

Fig.50 Rotor speed for two area four machine power system with multiband during LL-G fault

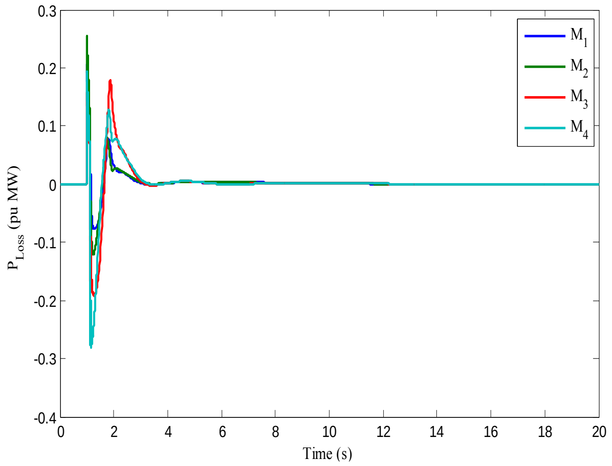

Fig.51 Power loss for two area four machine power system with multiband PSS during LL-G fault

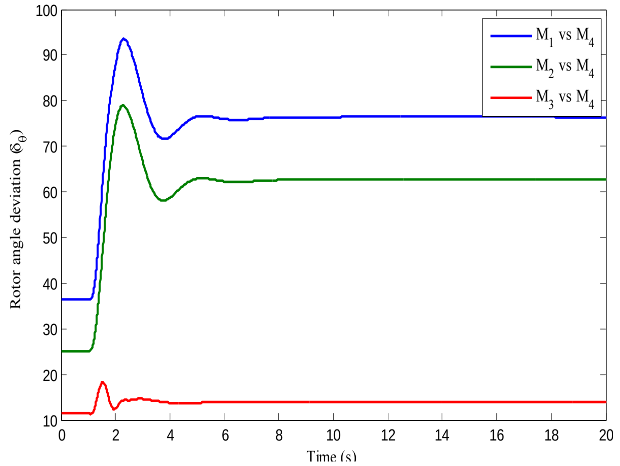

Fig.54 Rotor angle deviation for two area four machine power system delta w PSS during LL-G fault

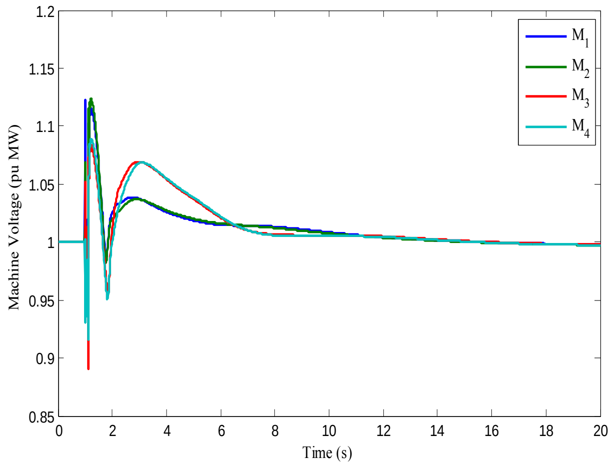

Fig.52 Machine voltage for two area four machine power system with multiband during LL-G fault

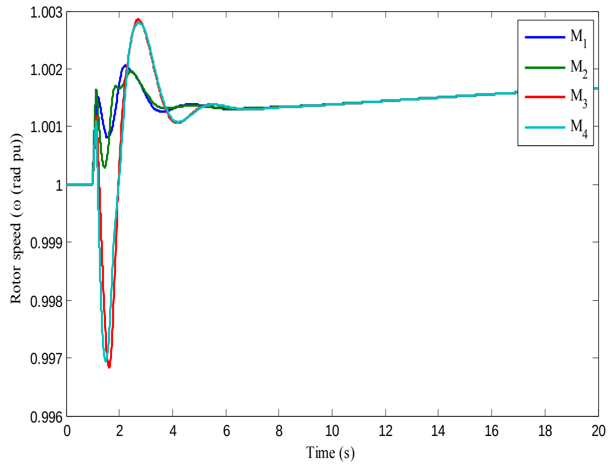

Fig.55 Rotor speed for two area four machine power system with delta w PSS during LL-G fault

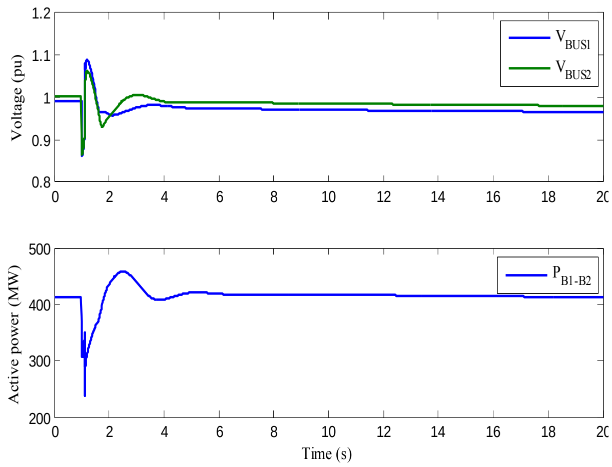

Fig.53 Active power and voltage for bus 1 and 2 with delta w PSS during LL-G fault

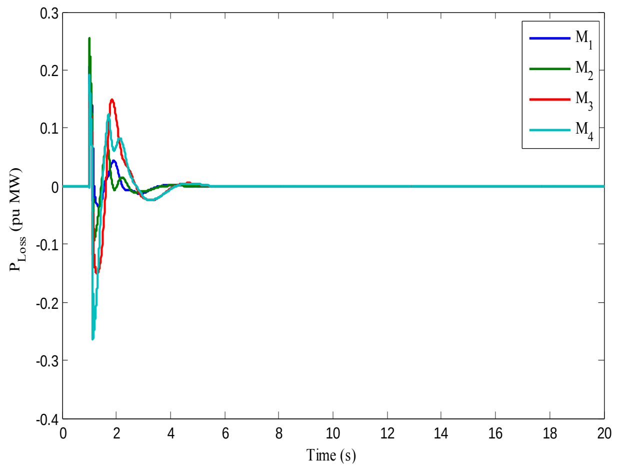

Fig.56 Power loss for two area four machine power system with delta w PSS during LL-G fault

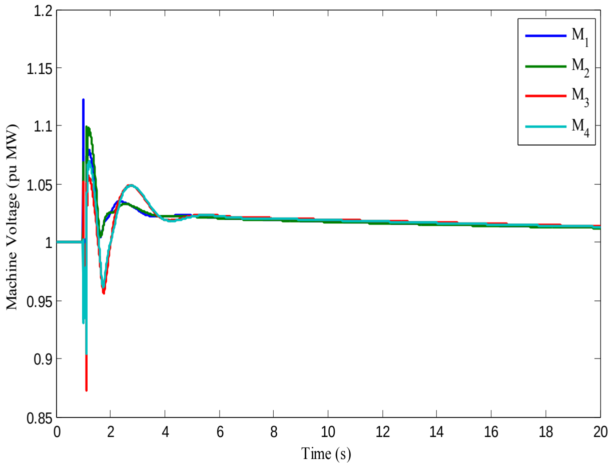

Fig.57 Machine voltage for two area four machine power system with delta w PSS during LL-G fault

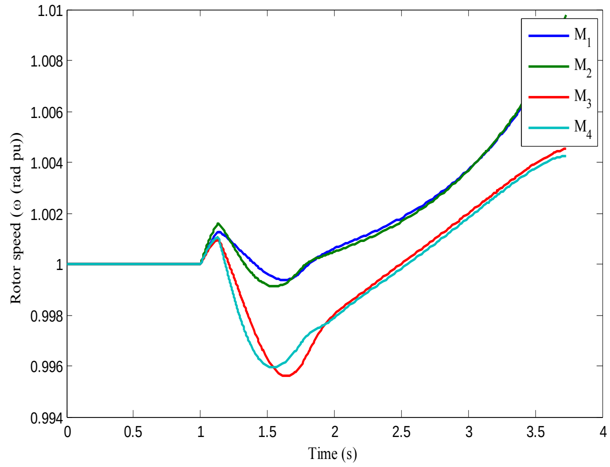

Fig.60 Rotor speed for two area four machine power system with delta Pa PSS during LL-G fault

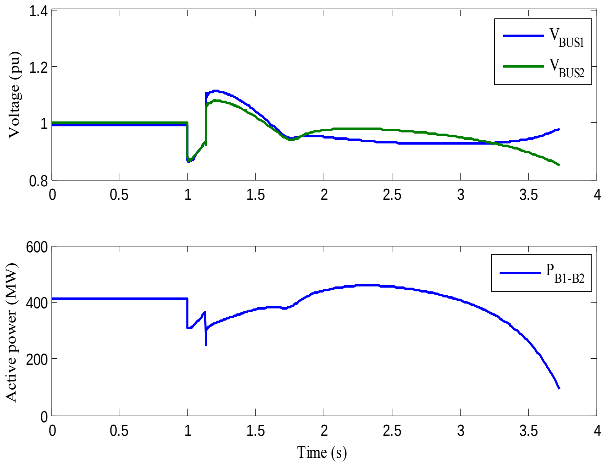

Fig.58 Active power and voltage for bus 1 and 2 with delta Pa PSS during LL-G fault

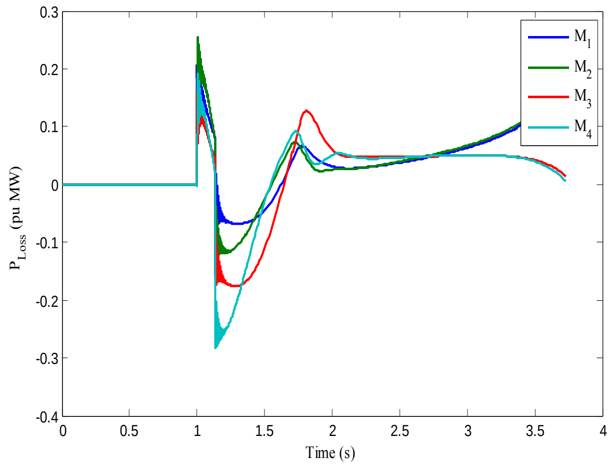

Fig.61 Power loss for two area four machine power system with delta Pa PSS during LL-G fault

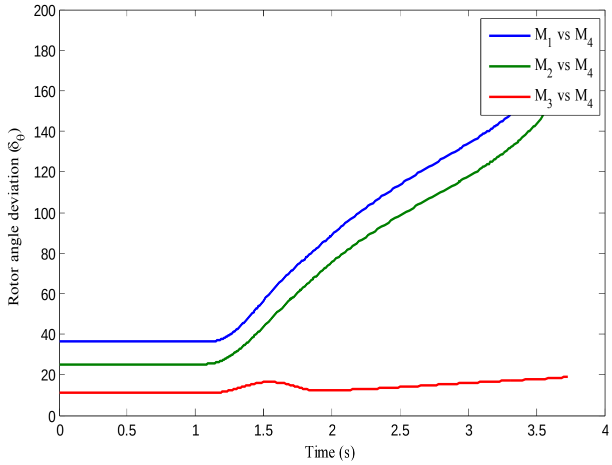

Fig.59 Rotor angle deviation for two area four machine power system delta Pa PSS during LL-G fault

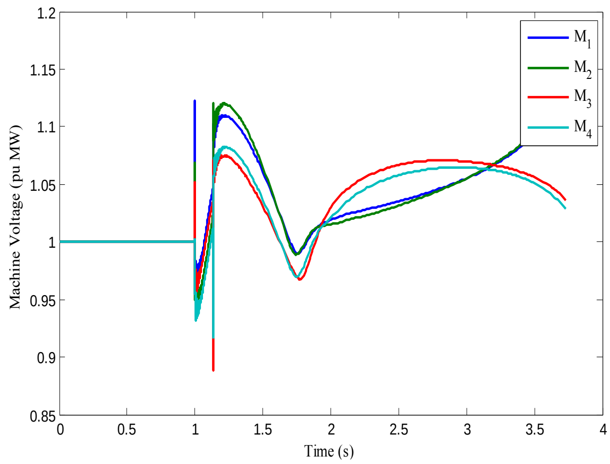

Fig.62 Machine voltage for two area four machine power system with delta Pa PSS during LL-G fault

Conclusion

This paper presented three types of PSSs. The simulated responses of the system power transfer from area 1 to 2, M1 speed, M1 acceleration power and M1 terminal voltage are observed. All PSSs do a good job stabilizing the naturally unstable system. However, it is clear that the multiband PSS (MB-PSS) is superior to the other two PSSs, providing significantly more damping to all modes, especially with respect to the Delta w PSS and Delta Pa PSS. The system lost its synchronism while the MB-PSS and the Delta W PSS succeed in maintaining stability. The latter are both very effective in damping the oscillation of the power transfer. In addition, the power acceleration is more damped with the MB-PSS than any other PSS.

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