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Design of Power System Stabilizer Using Particle Swarm Optimization

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Abstract: A new approach involving Particle Swarm Optimization (PSO) is illustrated for optimal Power System Stabilizers (PSSs) design in a multimachine power system. In PSO, the search directions of tumble behavior for the individual's best location and the global best location of PSO. Simulation results have shown the validity of the proposed PSO in tuning PSS. The proposed model was achieved satisfactory results because with the parameters of the Particle Swarm Optimization algorithm the PSS adds a suitable and fast damping to the oscillation from the case of study, by deleting quickly and maintaining a not so great at the start the magnitude of the oscillation that is compensated.

Key words: Power System Stabilizer · Dynamic Stability · Multiband PSS · Particle Swarm Optimization algorithm

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INTRODUCTION

A power system stabilizer can be most effectively applied if it is tuned with an understanding of the associated power system characteristics and the function to be performed by the stabilizer. The power system stabilizers (PSS) were developed to aid in damping these oscillations by modulation of excitation system and by this supplement stability to the system [1]. Low-frequency oscillations are observed when large power systems are interconnected by weak tie lines. These oscillations may sustain and grow, causing system separation if no adequate damping is available. Moreover, low-frequency oscillations present limitations on the power transfer capability [2]. Power System Stabilizers (PSSs) are now routinely used in the industry to damp out these oscillations. An appropriate selection of PSS parameters results in satisfactory performance during system disturbances [3]. A comprehensive analysis of the effects of the different Conventional Power System Stabilizer (CPSS) parameters on the overall dynamic performance of the power system has been presented in [4]. It is shown that the appropriate selection of CPSS parameters results in satisfactory performance during system upsets. Robust design of CPSSs in multimachine power systems using global optimization technique like Genetic Algorithm (GA) is discussed in [5-8]. However, it needs a very long run time that may be several minutes or even several hours depending on the size of the system under study. Another heuristic technique like Taboo Search (TS) is illustrated in [9] to design a PSS for the multimachine system. Despite this optimization method seems to be effective for the design problem, the efficiency is reduced by the use of highly epistemic objective functions (i.e. where parameters being optimized are highly correlated), and a large number of parameters to be optimized. Furthermore, it is time-consuming method. Simulated Annealing (SA) is developed in [10-11] for optimal tuning of PSS but this technique might fail by getting trapped in one of the local optimal. In addition, it is used only one search agent and has long annealing time. This paper proposes an optimization algorithm known as Particle Swarm Optimization algorithm (PSO) for optimal designing of the PSSs controller in a multimachine power system. The design problem of the proposed controller is formulated as an optimization problem and PSO is employed to search for optimal controller parameters.

Simulation results assure the effectiveness of the proposed controller in providing good damping characteristic to system oscillations over a wide range of loading conditions. Also, these results validate the superiority of the proposed method in tuning controller.

Proposed Power System Topology with Multiband PSS: A two-area four-machine interconnected power system shown in Fig. 1 is used to design PSS. Each generator is represented by a 5th-state transient model [2]. The system

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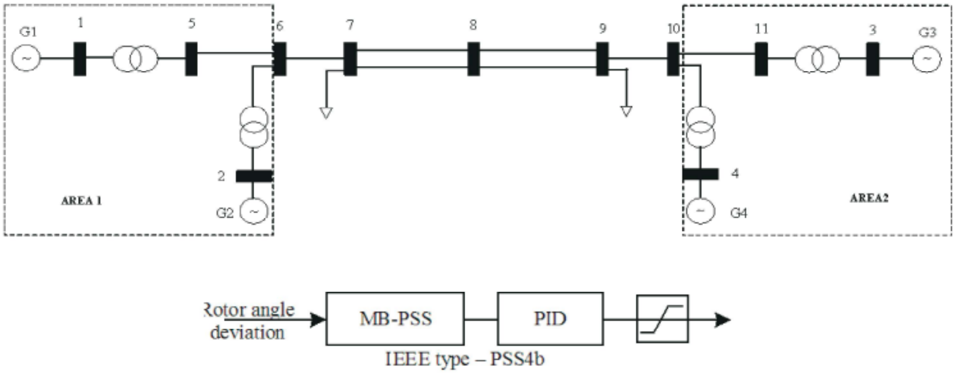

Fig. 1: Two area four machines power system

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 [12].

$$X_d = 1.8 \quad X_q = 1.7 \quad X_l = 0.2 \quad X'_d = 0.3 \quad X'_q = 0.55 \tag{1}$$

$$X''_d = 0.25 \quad X''_q = 0.25 \quad R_a = 0.0025 \quad T'_{d0} = 8.0s \quad T'_{q0} = 0.4s \tag{2}$$

$$T''_{d0} = 0.3s \quad T''_q = 0.05s \quad A_{Sat} = 0.015 \quad B_{Sat} = 9.6 \quad \psi_{T1} = 0.9 \tag{3}$$

$$H = 6.5 \text{ for M1 and M2} \quad H = 6.175 \text{ for M3 and M4} \quad K_D = 0 \tag{4}$$

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,

$$R = 0.0001 pu/km \quad X_l = 0.0001 pu/km \quad b_c = 0.00175 pu/km \tag{5}$$

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

$$\begin{aligned} &\text{M1: P = 700 MW, Q = 185 MVAr,} \quad E_t = 1.03\angle 20.2^\circ \\ &\text{M2: P = 700 MW, Q = 235 MVAr,} \quad E_t = 1.01\angle 10.5^\circ \\ &\text{M3: P = 719 MW, Q=176MVAr,} \quad E_t = 1.03\angle -6.8^\circ \\ &\text{M4: P = 700 MW, Q=202MVAr,} \quad E_t = 1.03\angle -17.0^\circ \end{aligned} \tag{6}$$

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 [13, 2] to study low-frequency electromechanical oscillations to great interconnected power systems. Despite its small size, it mimics the behavior of typical systems in actual operation very closely.

Each area is equipped with two identical round rotor generators rated 20 kV/900 MVA. The synchronous machines have identical parameters [14-15], except for inertias which are H = 6.5s in area 1 and H = 6.175s in area 2 [2]. Thermal plants having identical speed regulators are further assumed at all locations, in addition to fast static exciters with a 200 gain [2, 12]. 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 [2], 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 [2] because the load voltage profile was improved (made closer to unity) by installing 187 MVAr more capacitors in each area. Also, transmission and generation losses may vary depending on the detail level in line and generator representation.

Design of Power System Stabilizar: IEEE Std 421.5 as revised by the IEEE excitation system subcommittee will introduce a new type of power system stabilizer model, the multiband power system stabilizers (PSSs). Although it requires two inputs, like the widely used IEEE PSS2B, an integral of accelerating power PSS introduced at the beginning of the nineties as the first practical implementation of a digital PSS, the underlying principle of the new IEEE PSS4B makes it sharply different. As in case of the previous design method, we

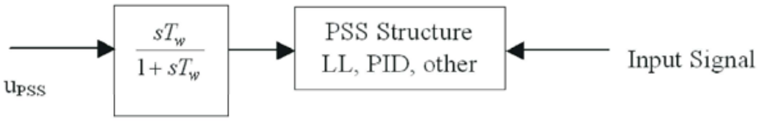

Fig. 1: Structure of PID-PSS

find that the introduction of the voltage regulator eliminates the steady state error and makes the system much faster. But it also introduces low frequency oscillations in the system. Hence we have to design the PSS loop taking input as the perturbation in rotor angular speed (Δω). The block diagram of a single-input PSS is shown in Fig. 1.

Various structures of PSS can be implemented. The common structures are: Lead –Lag Structure of PSS

$$u_{PSS} = K\frac{sT_W}{1+sT_W}\cdot\left(\frac{1+sT_1}{1+sT_2}\right)^P y$$

where y is the input signal PID strucure is

$$u_{PSS} = K\frac{sT_W}{1+sT_W}\cdot\left(K_P+\frac{K_I}{S}+K_DS\right) y$$

The common input signals used are the speed, frequency, electric and accelerating power deviations.

Multiband – PSS: The disturbances occurring in a power system induce electromechanical oscillations of the electrical generators. These oscillations, also called power swings, must be effectively damped to maintain the system's stability. Electromechanical oscillations can be classified in four main categories:

- Local oscillations: between a unit and the rest of the generating station and between the latter and the rest of the power system. Their frequencies typically range from 0.8 to 4.0 Hz.
- Interplant oscillations: between two electrically close generation plants. Frequencies can vary from 1 to 2 Hz.
- Interred oscillations: between two major groups of generation plants. Frequencies are typically in a range of 0.2 to 0.8 Hz.
- Global oscillation: characterized by a common in-phase oscillation of all generators as found on an isolated system. The frequency of such a global mode is typically under 0.2 Hz.

The need for effective damping of such a wide range, almost two decades, of electromechanical oscillations motivated the concept of the multiband power system stabilizer (MB-PSS). As its name reveals, the MB-PSS structure is based on multiple working bands. Three separate bands are used, respectively dedicated to the low-, intermediate-, and high-frequency modes of oscillations: the low band is typically associated with the power system global mode, the intermediate with the interred modes, and the high with the local modes.

Each of the three bands is made of a differential band pass filter, a gain, and a limiter (see the figure called Conceptual Representation). The outputs of the three bands are summed and passed through a final limiter producing the stabilizer output Vstab. This signal then modulates the set point of the generator voltage regulator so as to improve the damping of the electromechanical oscillations. To ensure robust damping, the MB-PSS should include a moderate phase advance at all frequencies of interest to compensate for the inherent lag between the field excitation and the electrical torque induced by the MB-PSS action.

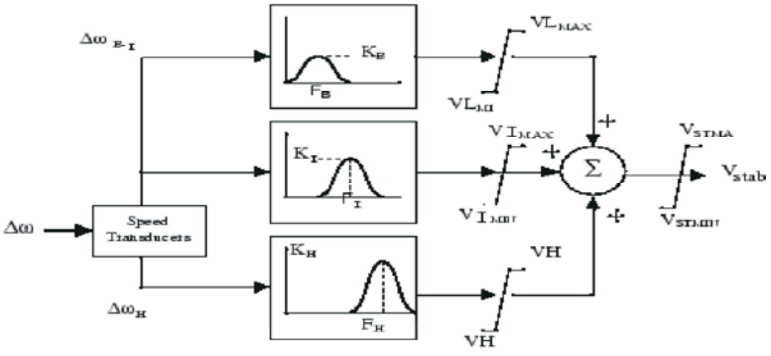

Fig. 2: Multiband PSS structure

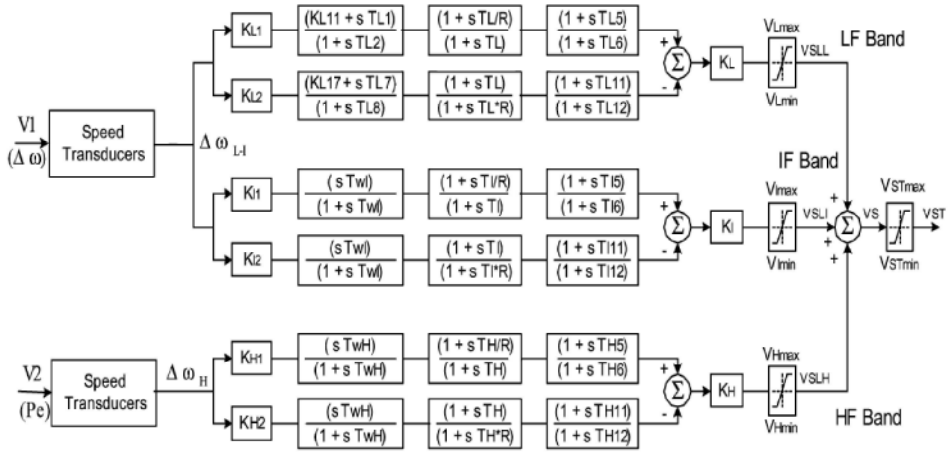

Fig. 3: Internal Specifications of MB-PSS

Generally, only a few of the lead-lag blocks in this figure should be used in a given PSS application. Two different approaches are available to configure the settings in order to facilitate the tuning process:

Simplified Settings: Only the first lead-lag block of each frequency band is used to tune the Multiband Power System Stabilizer block. The differential filters are assumed to be symmetrical band pass filters respectively tuned at the center frequency FL, FI, and FH. The peak magnitude of the frequency responses (see the figure called Conceptual Representation) can be adjusted independently through the three gains KL, KI, and KH. Only six parameters are therefore required for a simplified tuning of the MB-PSS.

Detailed Settings: The designer is free to use all the flexibility built into the MB-PSS structure to achieve nontrivial controller schemes and to tackle even the most constrained problem (for example, multi unit plant including an intermachine mode, in addition to a local mode and multiple interred modes). In this case, all the time constants and gains appearing in the figure called Internal Specifications have to be specified in the dialog box. PSS models in this study refer to the IEEE 421.5 standard, known as Multi-Band Power System Stabilizer (MB-PSS), as shown in Figure 2. In the MB-PSS applied three kinds of filters are low-pass filter, intermediate-pass filter, and high-pass filter, which serves to dampen the local oscillation, the oscillation between networks, and global oscillations [3]. By using this type of PSS, the effect on the stability of the signal due to changes in the turbine power can also be suppressed.

The main parameters for setting the MB-PSS is: gain band: KL = 3, KI = 5.5, KH = 53, the frequency band centers: FL = 0.1076 Hz, FI = 1.1958 Hz, FH = 12 Hz. MB PSS was designed to quell disturbances that occurred in the electric power system. Disturbances caused oscillations in the electromechanical generator in the power system. Electromechanical oscillations can be classified: 1). Local Oscillation. These oscillations are caused by disorders that occur between one generator unit is active and the inactive generator in a power station. The oscillation frequency generally ranges in the range between 0.8 to 4.0 Hz. 2). Oscillation between stations. This oscillation is caused by interference between two adjacent power stations. The oscillation frequency generally ranges in the range between 1 Hz to 2 Hz. 3). Oscillations between areas. This oscillation is caused by a disturbance between two groups of generation stations in a power system. The oscillation frequency generally ranges in the range between 0.2 to 0.8 Hz. 4). Global Oscillation. This oscillation is characterized by oscillations in the same phase in the entire generator. Global oscillation frequency is generally below 0.2 Hz. This oscillation also called power swing, and effectively should be suppressed to maintain the stability of the power system. MB PSS oscillation damping action using the three fields of different frequencies to dampen the entire spectrum frequency oscillations that can occur in the power system is achieved. There are three areas of the frequency used, each of which is used to handle low frequency oscillation mode low, medium, and high. Field of low frequency (low band) is generally associated with global fashion power system. Field intermediate frequency associated with the mode of inter-area power system. Medium field of high frequency is associated with a local mode (in a generating station). Furthermore, IEEE standards-based PSS models applied in Mat lab Semolina software as shown in Fig. 4.

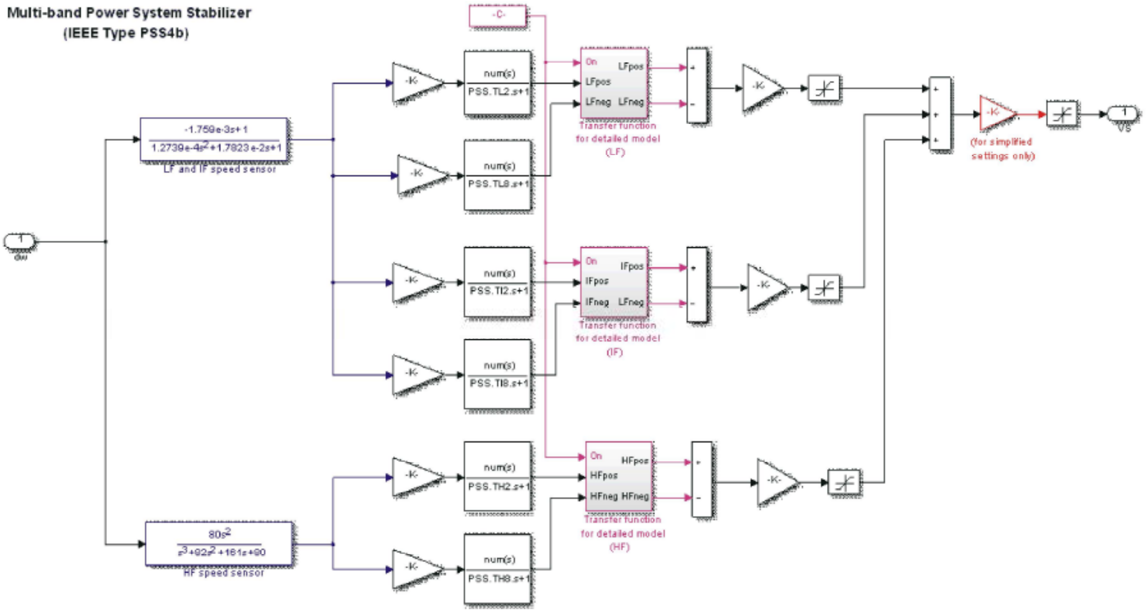

Fig. 4: PSS Model Based on IEEE 421.5

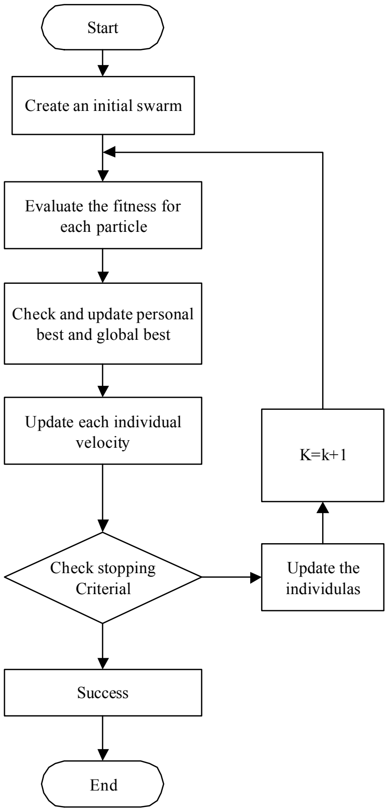

Fig. 5: Flowchart of the PSO procedure

Particle Swarm Optimization: Kennedy and Beernaert developed a particle swarm optimization algorithm based on the behavior of individuals (i.e., particles or agents) of a swarm [16]. Its roots are in zoologists modeling of the movement of individuals (i.e., fish, birds, and insects) within a group. It has been noticed that members of the group seem to share information among them to lead to increased efficiency of the group. The particle swarm optimization algorithm searches in parallel using a group of individuals similar to other AI-based heuristic optimization techniques. Each individual corresponds to a candidate solution to the problem. Individuals in a swarm approach to the optimum through its present velocity, previous experience, and the experience of its neighbors. In a physical n-dimensional search space, the position and velocity of individual i are represented as the velocity vectors. Using this information individual i and its updated velocity can be modified under the following equations in the particle swarm optimization algorithm. The procedure of the particle swarm optimization can be summarized in the flow diagram of Fig. 5.

$$x_i^{k+1} = x_i^{T\,k^{Y}} + v_i^{k+1}$$

$$v_1^{k+1} = v_i^{k} + ai^{U} x_i^{Ibest} - x_U \underset{i}{k}{}_{Z}^{Z} + bi^{T} x_i^{gbest} - x_i^{T\,k^{Y}\,Y}$$

where

$x_i^{(k)}$ is the individual i at iteration k

$v_i^{(k)}$ is the updated velocity of individual i at iteration k

α_i, $n\beta_i$ Are uniformly random numbers between [0, 1]

x_i^{lbest} Is the individual best of individual i

x_i^{bbest} Is the global best of the swarm

RESULTS AND DISCUSSION

Multi-machine electric power system model used is the electric power system consisting of two areas the number generator is 4 units. The nominal voltage is the system used is 230 kV. Each area has two synchronous generators with the same capacity is 900MVA at a voltage of 20 kV. Each generator in both areas (M1, M2, M3, and M4) is connected to the power transformers (T1, T2, T3, and T4). Fourth generators have identical parameters, except inertia (H) is for generators in area 1 of 6.5 seconds and to a generator in area 2 by 6.175 seconds. Each generator is capable of producing active power of 700 MW. Generator load is assumed to be a big burden with constant impedance. Load in area 1 of 967 MW (L1) and in area 2 of 1767 MW (L2).

Fig. 6 shows the frequency response generated by the proposed MB-PSS model. In this condition shows that the area 1 has excess power, while the second area opposite of power shortage, therefore, as shown in Fig. 7 there is a 413 MW power is transferred from one area to area 2. In order to improve the voltage profile in each area then installed two power capacitors (C1 and C2) each with a capacity of 187 MVAr to improve the power factor. Fig. 8 shows that the performance system using Delta Pa PSS very bad. It is seen that the system failed to synchronize. Synchronization failure is due to the Delta Pa PSS using an open loop system is unable to improve response poor results. While using the PSS system design results in this study and also Delta w PSS succeeded in maintaining the stability of the power system multi-machine.

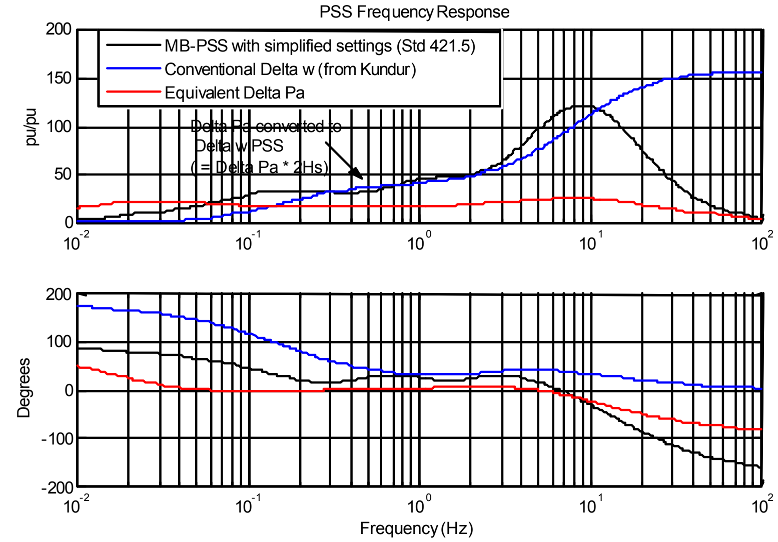

Fig. 6: Frequency response of PSS system

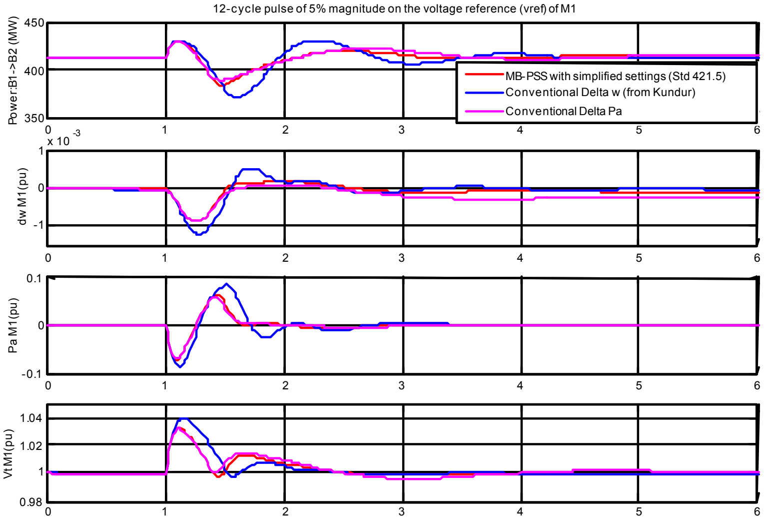

Fig. 7: Performances of Each PSS.

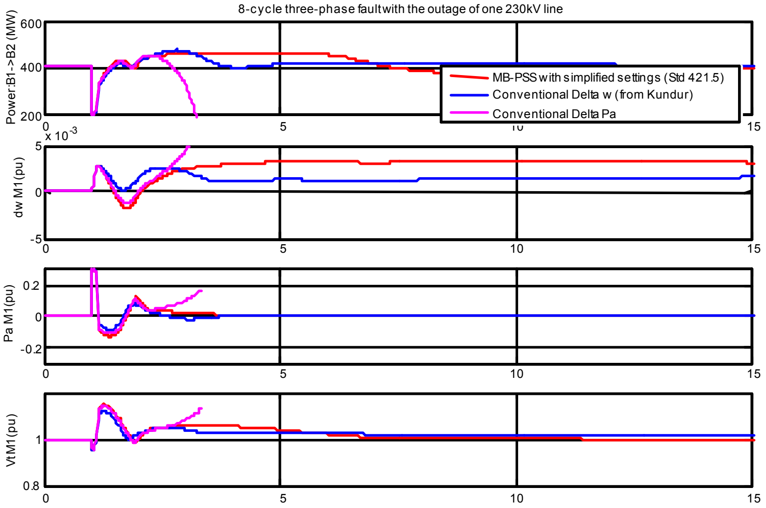

Fig. 8: Performance of PSS in Three-Phase Symmetrical Fault on the Transmission Line

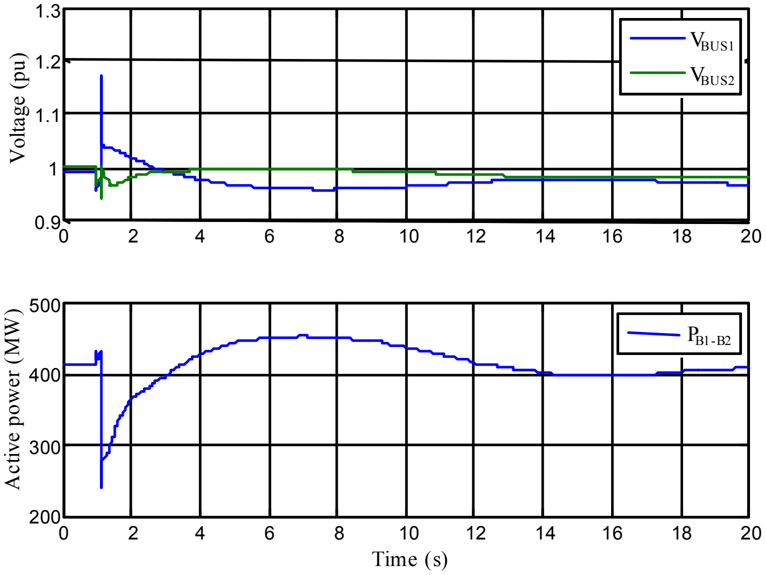

Fig. 9: Voltage response of Bus1 and Bus2 and active power transfer between them at the period of 1 – 1.2 sec.

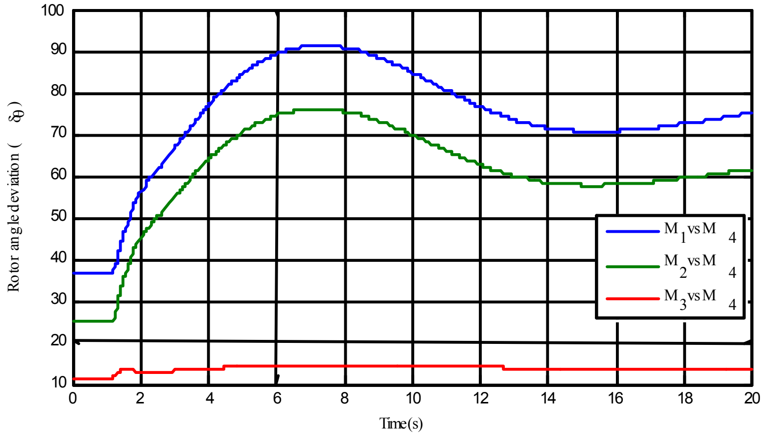

Fig. 10: Rotor angle deviation on generator 4 at the period of 1 – 1.2 sec.

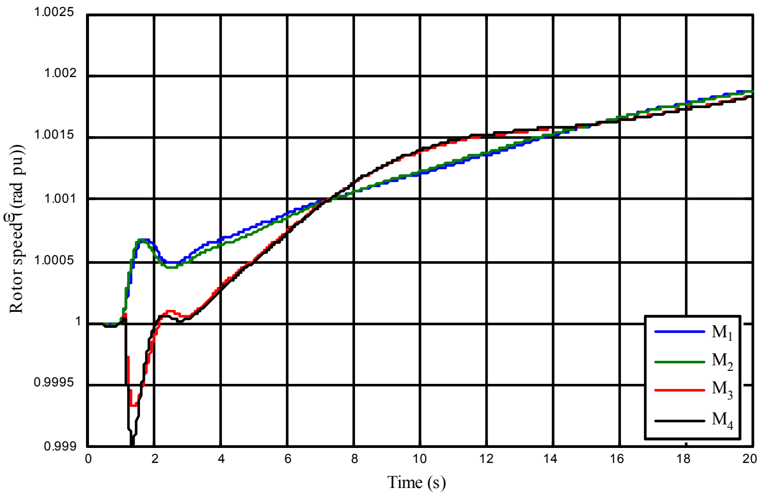

Fig. 11: Rotor speed response of generator 1, 2, 3 & 4 at the period of 1 – 1.2 sec.

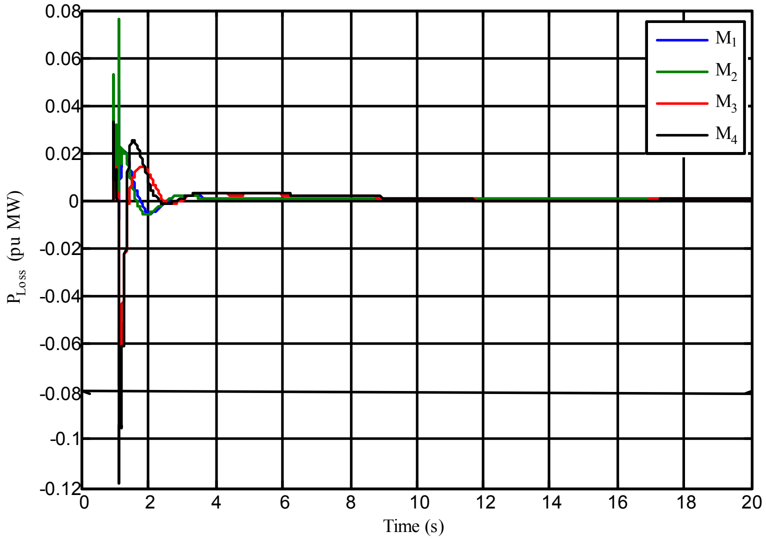

Fig. 12: Power loss at generator 1, 2, 3 & 4 at the period of 1 – 1.2 sec.

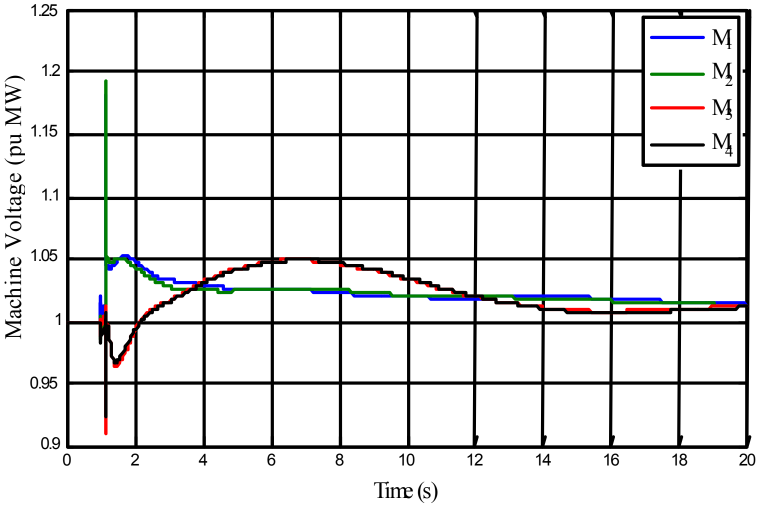

Fig. 13: Machine Voltage of generator 1, 2, 3 & 4 at the period of 1 – 1.2 sec.

Furthermore, the simulation phase to ground disturbance on the transmission line to a state without a state with PSS and PSS. The goal is to find out more about PSS performance against engine characteristics M1, M2, M3, and M4 on the system multi-machine simulated. The results of the three-phase symmetrical interference test to see performance machine shown in Fig. 9. In Figure 9, shows that the PSS result of design using fast sampling method gives very good results, which is marked by the achievement of stability multi-machine system. It appears that the bus voltage bus B1 and B2 practical experience stability in the second-to-4 after previously having state phase transition due to soil disturbance on the transmission line. Almost the same situation also occurred in the graph of the power transfer area 1 to area 2 as shown in Fig. 9. Fig. 10 shows the rotor angle deviation on generator 4 at the period of 1-1.2 sec. Fig. 11 shows the rotor speed response of generator 1, 2, 3 & 4 at the period of 1-1.2 sec. Fig. 12 shows the power loss at generator 1, 2, 3 & 4 at the period of 1-1.2 sec. Fig. 13 shows the machine Voltage of generator 1, 2, 3 & 4 at the period of 1-1.2 sec.

CONCLUSION

Based on the PSS application testing on the machine M1 of the power system multi-machine to short circuit symmetrical three-phase PSS found that that good design results in this study, multiband PSS gives relatively good results in reducing oscillation system variables of which transfer electrical power, changes in angular velocity generator, and the generator terminal voltage. PSS results of the design is able to make the state of the system became stable after four seconds later to various variables of which the voltage on the bus-bus system multi-machine, transfer power from one area to area 2, the speed of the generator rotor angle, change the power generator, and the terminal voltage of the generator achieved by using PSO tuning.

The setting of PSS has been done through optimization PSO Algorithm to obtain the proper adjustment of PSS for damping adequately to the oscillation present in the case of study. With the objective of achieving the setting of PSS, the problem was adapted to PSO Algorithm, optimizing the time constants of the compensator lead-lag and the value of the gain, of the PSS model that was used, because this variable gives us the amount of damping to eliminate the frequency of oscillation of the machine. When testing this setting in the Simulink model were achieved satisfactory results, because with the parameters of the PSO Algorithm the PSS adds a suitable and fast damping to the oscillation from the case of study, by deleting quickly and maintaining a not so great at the start the magnitude of the oscillation that is compensated.

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