POWER SYSTEM STABILIZER DESIGN BASED ON A PARTICLE SWARM OPTIMIZATION MULTIOBJECTIVE FUNCTION IMPLEMENTED UNDER GRAPHICAL INTERFACE

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***Abstract*—Power system stability is considered as a necessary condition for normal functioning of an electrical network. The role of regulation and control systems is to ensure that stability by determining the essential elements that influence it. This paper proposes a Particle Swarm Optimization (PSO) based multiobjective function to tuning optimal parameters of Power System Stabilizer (PSS); it is used for generator excitation system in order to damp electro-mechanicals oscillations of the rotor and consequently improve the power system stability. The computer simulation results obtained by the developed Graphical User Interface (GUI) have proved that the efficiency of PSS optimized by a Particle Swarm Optimization, in comparison with a conventional PSS, showing more stable system responses that also insensitive to large parameter variations. Our present study was performed using a proposed GUI under MATLAB in our work.**
***Keywords:* Power System Stabilizer; Particle Swarm Optimization; Multiobjective Function; Graphical Interface.**

I. INTRODUCTION

Power system stabilizers (PSS) have been used for many years to add damping to electromechanical oscillations. The use of fast acting high gain Automatic Voltage Regulator (AVR) and the evolution of large interconnected power systems with transfer of bulk power across weak transmission links have further aggravated the problem of low-frequency oscillations. The continuous change in the operating condition and network parameters result in corresponding changes in the system dynamics [1, 2]. This constantly changing nature of power systems makes the design of damping controllers a very difficult task. Power system stabilizers (PSS) were developed to extend stability limits by modulating the generator excitation to provide additional damping to the oscillations of synchronous machine rotors. Recent developments in the field of robust control provide methods for designing fixed parameter controllers for systems subject to model uncertainties.

Conventional PSS based on simple design principles such as PI control and eigenvalue assignment techniques have been widely used in power systems. Such PSS ensure optimal performance only at their nominal operating point and do not guarantee good performance over the entire operating range of the power system. This is due to external disturbances such as changes in loading conditions and fluctuations in the mechanical power. In practical power systems networks, a priori information on these external disturbances is always in the form of certain frequency bands in which their energy is concentrated.

PSO appeared as a promising evolutionary technique for handling the optimization problems. PSO has been popular in academia and the industry mainly because of its intuitiveness, ease of implementation, and the ability to effectively solve highly nonlinear, mixed integer optimization problems that are typical of complex engineering systems [3, 4].

As mentioned above, we have developed a global optimization method based on PSO and a multiobjective function using relative and absolute stability parameters that are obtained from the system eigenvalue analysis.

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II. DYNAMIC POWER SYSTEM MODEL

A. Power System Description

The SMIB system used in our study is shown in Fig. 1 including Synchronous Generator, AVR and PSS, and Infinity Bus.

B. The Modeling of Powerful Synchronous Generators

This paper is based on the Park modeling of powerful synchronous generators. The PSG model is defined by Equations (1) to (6) [1, 2]:

$$\frac{d\delta}{dt} = {\omega_B}'(S_m - S_{mo}), \tag{1}$$

$$\frac{d\delta_m}{dt} = \frac{1}{2H}\left[-D(S_m - S_{mo}) + T_m - T_e\right], \tag{2}$$

$$\frac{dE_q^{'}}{dt} = \frac{1}{T_{d0}^{'}}\left[-E_q^{'} + (x_d - x_d^{'})i_d + E_{fd}\right], \tag{3}$$

$$\frac{dE_d^{'}}{dt} = \frac{1}{T_{q0}^{'}}\left[-E_d^{'} + (x_q - x_q^{'})i_q\right], \tag{4}$$

$$\frac{dE_{fd}}{dt} = \frac{1}{T_A}\left[K_A(V_{ref} - V_t)\right] - \frac{1}{T_A}E_{fd}, \tag{5}$$

The first two equations are obtained from the second order swing equation as

$$M\frac{d^2\delta}{dt^2} + D^{'}\frac{d\delta}{dt} = T_m - T_e, \tag{6}$$

with

$$T_e = E_d^{'}i_d + E_q^{'}i_q + (x_d^{'} - x_q^{'})i_d i_q.$$

C. PSS Model

The conventional lead-lag structure is chosen in this study as a Conventional PSS (CPSS). The structure of the CPSS controller model is shown in Fig. 2.

In this paper the PSS signal used, is given by Refs. [1, 2].

$$V_{PSS} = K_{PSS}\frac{pT_\omega}{1 + pT_\omega}\frac{1 + pT_1}{1 + pT_2}\frac{1 + pT_3}{1 + pT_4}\Delta\text{input}. \tag{7}$$

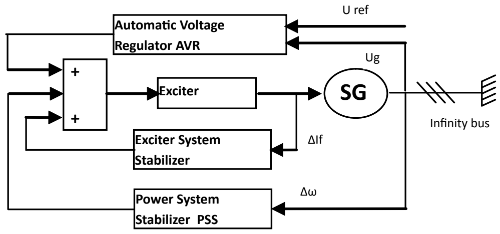

Fig. 1: Standard system IEEE type SMIB with excitation control of powerful synchronous generators.

III. PARTICLE SWARM OPTIMIZATION

A. PSO Theory

PSO is one of the methods among the smart methods for solving the optimization problems that was first introduced as an optimization method by Kennedy and Eberhart [5] and it is inspired by the bird's intelligence. In PSO algorithm, each particle has a value that is called fitness and it is calculated by the fitness function. This fitness is measured by the amount of the closeness to the target. Basically, the beginning of the PSO is in a way that a group of particles is randomly created and in each level, each particle is optimized by the use of two optimum values.

The first value is called the best personal experience or the $pbest$. The other best result which is used is the best position that is gained by a group of particles and it is called the $gbest$. The equation of the velocity update [6] is given as:

$$\begin{aligned} v_l^{k+1} = v_l^k + c_1\text{rand}_1 + \big(pbest_i \\ - s_l^k\big) + c_2\text{rand}_2 + \big(gbest_i - s_l^k\big). \end{aligned} \tag{8}$$

The role of the weight parameter in converging the algorithm is so important because it is used for affecting the velocity at the present moment by the velocity of the previous moment. The equation of the position update is given as:

$$s_l^{k+1} = s_l^k + s_l^{k+1}. \tag{9}$$

The steps PSO are shown in Fig. 3.

B. PSO Numerical Application

We consider the simple case of function with two variables x_1 and x_2 belongin to the natural number set. We intend to minimize:

$$\begin{aligned} F_{\text{obj}}(x_1, x_2) =& (1 - x_1)^2\exp(-x_1^2 - (x_2 + 1)^2)) \\ &- (x_1 - x_1^3 - x_2^5)\exp(-x_1^2 - x_2^2), \end{aligned} \tag{10}$$

Subject to

$$-3 < x_1 \leq 3$$
$$-3 < x_2 \leq 3$$

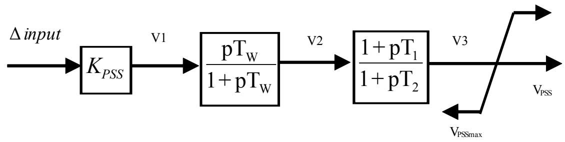

Fig. 2: A functional diagram of the PSS [1].

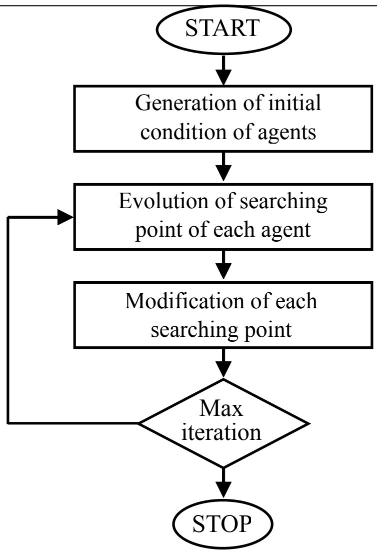

Fig. 3: Particle Swarm Optimization Flowchart.

To calculate and view the various steps of PSO we created and developed a GUI in MATLAB (Figs. 4 and 5).

IV. APPLICATION OF THE PARTICLE SWARM OPTIMIZATION TO PSS

A. Multiobjective Function Choice

The choice of objectives functions generally based on the needs of our controlled system. The purpose of the PSS is to ensure satisfactory oscillations damping and to ensure the overall system stability to different operation points. To meet this goal, we use a function, composed of two multiobjective functions. To understand the concept of this multiobjective function we consider two examples:

Example 1:

We considered system even imaginary part $\omega_{s1} = \omega_{s2}$ and deferring real part σ:

- System 11 : $P_{11,2} = -6 \pm 6\jmath$
- System 12 : $P_{12,2} = -1 \pm 6\jmath$

The poles systems on the imaginary axis and step responses match each system shown in Fig. 6. On learning this result we can see that the decrease real part σ improved dynamic performance and system stability.

Example 2:

We considered two systems with real part $\sigma_{s1} = \sigma_{s2}$ and deferring imaginary part:

- System 21 : $P_{21,2} = -2 \pm \jmath$ with $\zeta = 0.8944$
- System 22 : $P_{22,2} = -2 \pm 8\jmath$ with $\zeta = 0.2425$

The poles systems on the imaginary axis and step responses match each system shown in Fig. 7. The increase in damping coefficient ζ improves system stability.

In view of these results, we proposed an objective function which is composed of two functions. This function aims to maximize stability margin by increasing the damping factors while minimizing the real parts of the eigenvalues of the system, and we the must maximize the set of two objective functions.

$$F_{\text{obj}} = \max(\max(\zeta) - \min(\sigma)). \qquad (11)$$

B. Steps of Multiobjective Function Calculation

The multiobjective function calculating steps are:

1) Formulate the linear system in an open loop (without PSS).
2) Locate the PSS and its parameters initialized by the PSO through an initial population.
3) Calculate the closed loop system eigenvalues and take only the dominant modes.

$$\lambda = \sigma \pm j\omega. \qquad (12)$$

The transfer function of the entire closed loop system (Fig. 8) $F(s)$ becomes:

$$F(s) = \frac{G(s)}{1 - G(s)\text{GPSS}(s)}, \qquad (13)$$

The eigenvalues of the closed loop system are the poles of the transfer function $F(s)$

$$1 - G(s)\text{GPSS}(s) = 0, \qquad (14)$$

with

$$\text{GPSS}(s) = \frac{1}{1 + T_f p}\left[\frac{K_1 p}{1 + T_1 p} + \frac{K_2}{1 + T_2 p}\right], \qquad (15)$$

The optimized parameters of PSS are: K_1, K_2, T_1, T_2 and T_f is constant ($T_f = 0.039$), with $K_1 \in [0.0, 7.0]$, $K_2 \in [0.0, 7.0]$, $T_1 \in [0.0005, 0.1]$, and $T_2 \in [0.0005, 0.1]$.

4) Find the system eigenvalues real parts (σ) and damping factor ζ with:

$$\zeta = \frac{-\sigma}{\sqrt{\sigma^2 + \omega^2}}, \qquad (16)$$

5) Gather both objective functions in a multiobjective function F as follows:

$$F_{\text{obj}} = \max(\max(\zeta) - \min(\sigma)). \qquad (17)$$

6) Returning this multiobjective function value the to the PSO program to restart a new generation.
   - Number of individuals: 120.
   - Generation number: 100.

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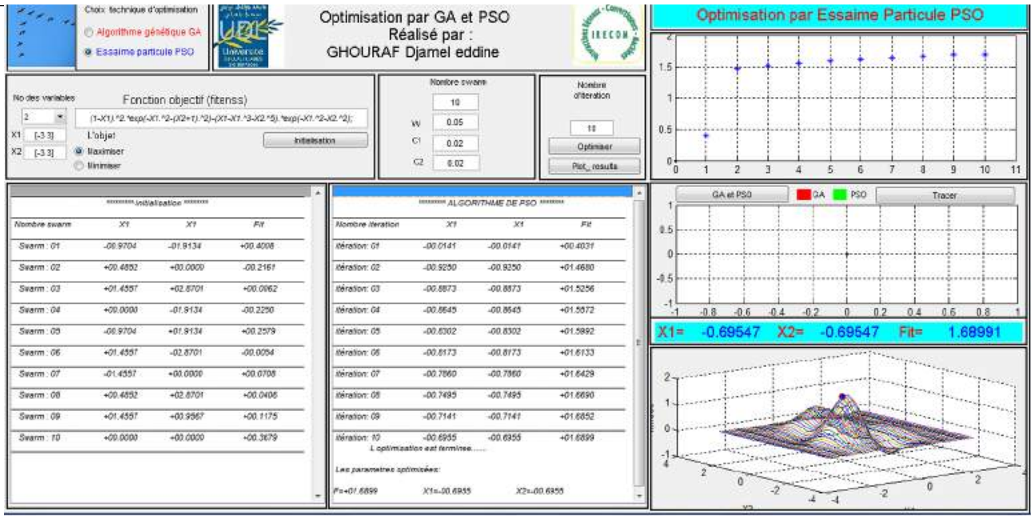

Fig. 4: PSO algorithm developed under GUI/MATLAB.

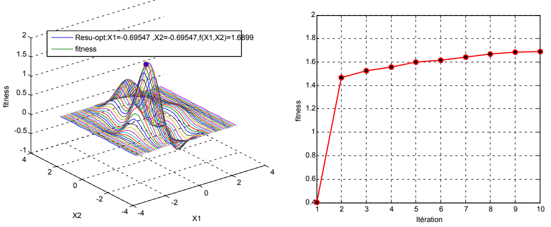

Fig. 5: Optimization results by PSO.

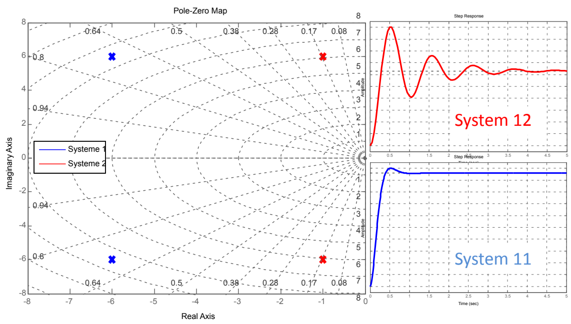

Fig. 6: The σ influence to controlled system.

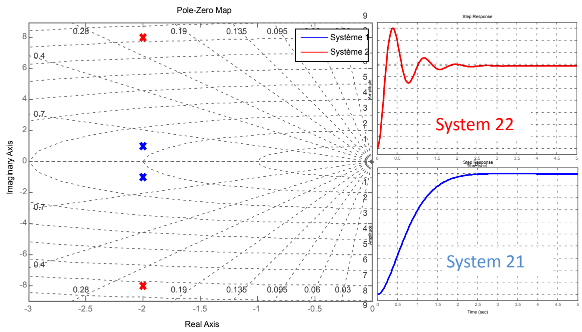

Fig. 7: The ζ influence to controlled system.

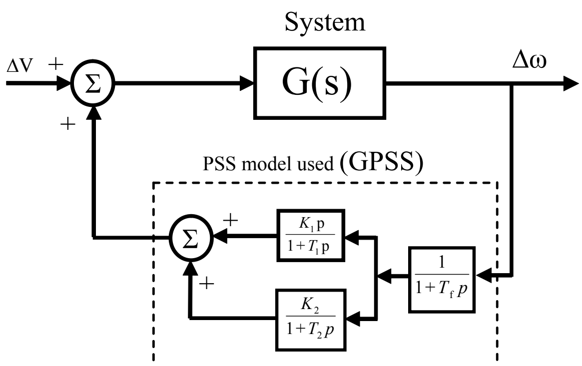

Fig. 8: Closed loop with system-PSS.

V. OPTIMIZATIONS AND SIMULATION RESULTS

A. Implementation of PSS-PSO under the Proposed GUI/ Matlab

To analyzed and visualized the different dynamic behaviors, we have created and developed a GUI under MATLAB, see Fig. 9. This GUI allows us to optimize the controller parameters by PSO, to perform control system from PSS controller, to view the system regulation results and simulation, to calculate the system dynamic parameters, to test the system stability and robustness, and to study the different operating regime (under-excited, nominal and over-excited regime).

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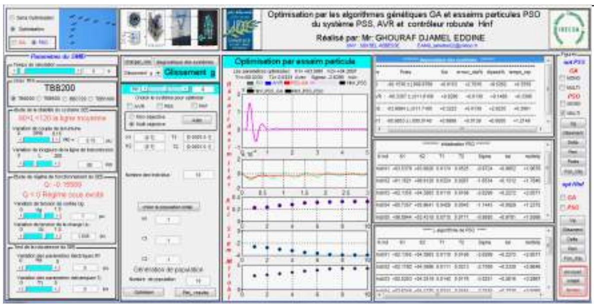

Fig. 9: The GUI / MATLAB.

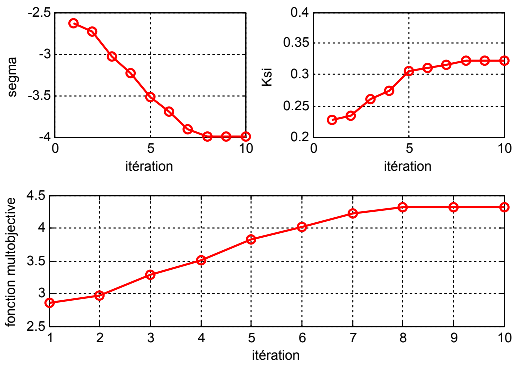

Fig. 10: Optimization results by PSO.

B. Optimizations Results

We present an example for optimization and tuning the parameters of the PSS-PSO using our proposed GUI with these parameters: the number of individuals = 10 and the number of population = 10.

PSO Initialization

$Nind$	K_1	K_2	T_1	T_2	σ	ksi	multiobj
Indi:01	3.5378	3.8920	0.0174	0.0525	-0.9724	0.9952	1.9676
Indi:02	1.1021	6.9120	0.0324	0.0267	-1.6534	0.1312	1.7846
Indi:03	2.1355	4.3883	0.0110	0.0168	-2.6299	0.2272	2.8571
Indi:04	0.7357	5.9641	0.0426	0.0045	-1.1443	0.0929	1.2372
Indi:05	6.0944	3.4318	0.0715	0.0171	-0.9585	0.9781	1.9366
Indi:06	4.7527	0.1397	0.0764	0.0925	-0.9620	0.9639	1.9259
Indi:07	5.7881	1.7068	0.0923	0.0109	-0.9596	0.9691	1.9288
Indi:08	6.6225	3.8505	0.0753	0.0833	-0.9491	0.9745	1.9236
Indi:09	4.4142	0.7110	0.0331	0.0152	-0.9714	0.9731	1.9444
Indi:10	3.5938	3.3202	0.0876	0.0855	-0.9693	0.9908	1.9602

PSO Algorithm

NIter	K_1	K_2	T_1	T_2	σ	ksi	multiobj
Iiter:01	2.1355	4.3883	0.0110	0.0168	-2.6299	0.2272	2.8571
Iiter:02	2.1782	4.3686	0.0111	0.0213	-2.7309	0.2338	2.9646
Iiter:03	2.5253	4.3519	0.0142	0.0176	-3.0251	0.2616	3.2867
Iiter:04	2.6348	4.1270	0.0243	0.0164	-3.2330	0.2738	3.5068
Iiter:05	3.0506	4.2346	0.0174	0.0168	-3.5126	0.3060	3.8186
Iiter:06	2.9993	4.2770	0.0178	0.0268	-3.6991	0.3111	4.0103
Iiter:07	3.0314	4.2291	0.0225	0.0326	-3.9067	0.3160	4.2227
Iiter:08	3.0961	4.2697	0.0230	0.0323	-3.9885	0.3223	4.3108
Iiter:09	3.0961	4.2697	0.0230	0.0323	-3.9885	0.3223	4.3108
Iiter:10	3.0961	4.2697	0.0230	0.0323	-3.9885	0.3223	4.3108

The optimized parameters are: $K_1 = 3.0961$, $K_2 = 4.2697$, $T_1 = 0.0230$, $T_2 = 0.0323$, $\sigma = -3.9885$, $\zeta = 0.322$, and $\text{multiobj} = 4.3108$

The obtained optimization results show that PSO optimization technique is well adapted to the multi-objective function (see Fig. 10):

- Increase damping coefficient ζ.
- Decrease real part of pole σ.
- Increase multiobjective function.

Table I shows the PSS parameters (K_1, K_2, T_1, and T_2) that were optimized by particle swarm optimization under different operating regime (under-excited, nominal and over-excited regime) with different synchronous power generators of type: TBB-200, TBB-500, BBC-720, TBB-1000 (the parameters are shown in Appendix) [7].

TABLE I: Parameters PSS optimized by multiobjective PSO.

regime	K_1	K_2	T_1	T_2	Poles	ζ
TBB 200						
under-excited	4.3562	6.3870	0.0309	0.0416	-6.0989 $\pm j$ 8.8387	0.5679
nominal	7.2520	7.4527	0.0207	0.0331	-3.9057 $\pm j$ 8.4649	0.4190
over-excited	5.2003	6.3812	0.0750	0.0498	-2.3075 $\pm j$ 8.5888	0.2595
TBB 500						
under-excited	2.7870	4.1083	0.0545	0.0409	-3.2214 $\pm j$ 8.1196	0.3688
nominal	5.9281	6.9529	0.0675	0.0093	-2.9649 $\pm j$ 9.2504	0.3052
over-excited	3.2623	4.4385	0.0328	0.0220	-2.9629 $\pm j$ 9.3839	0.3011
TBB 720						
under-excited	6.1599	4.6944	0.0491	0.0205	-4.7821 $\pm j$ 8.4602	0.4921
nominal	6.8091	3.5286	0.0283	0.0502	-3.8781 $\pm j$ 8.2924	0.4236
over-excited	8.1621	1.9421	0.0225	0.0499	-3.4555 $\pm j$ 9.1159	0.3545
TBB 1000						
under-excited	6.6430	2.2218	0.0182	0.0560	-4.8050 $\pm j$ 8.7901	0.4797
nominal	6.1942	2.0608	0.0614	0.0243	-3.8852 $\pm j$ 8.2654	0.4254
over-excited	3.6192	7.1699	0.0148	0.0566	-3.4774 $\pm j$ 9.4535	0.3452

C. Simulation Results

For stability study of SMIB system, we have performed perturbations by abrupt variations of turbine torque ΔT_m of 15% at $t = 1$ second. The following results were obtained by studying the SMIB for the following cases: Opened Loop and Closed Loop System with PSS and PSS-PSO.

We have simulated three operations: the under-excited, the rated and the over-excited. Figures 11 and 12 show simulation results with: a:'s' variable speed, b:'Pe' electromagnetic power system c:'$delta$' the internal angle, d:'Ug' terminal voltage.

From the simulation results, it can be observed that the use of PSS optimized by PSO improves considerably the dynamic performances and granted the stability of the SMIB system studied even in critical situations (especially the under-excited regime).

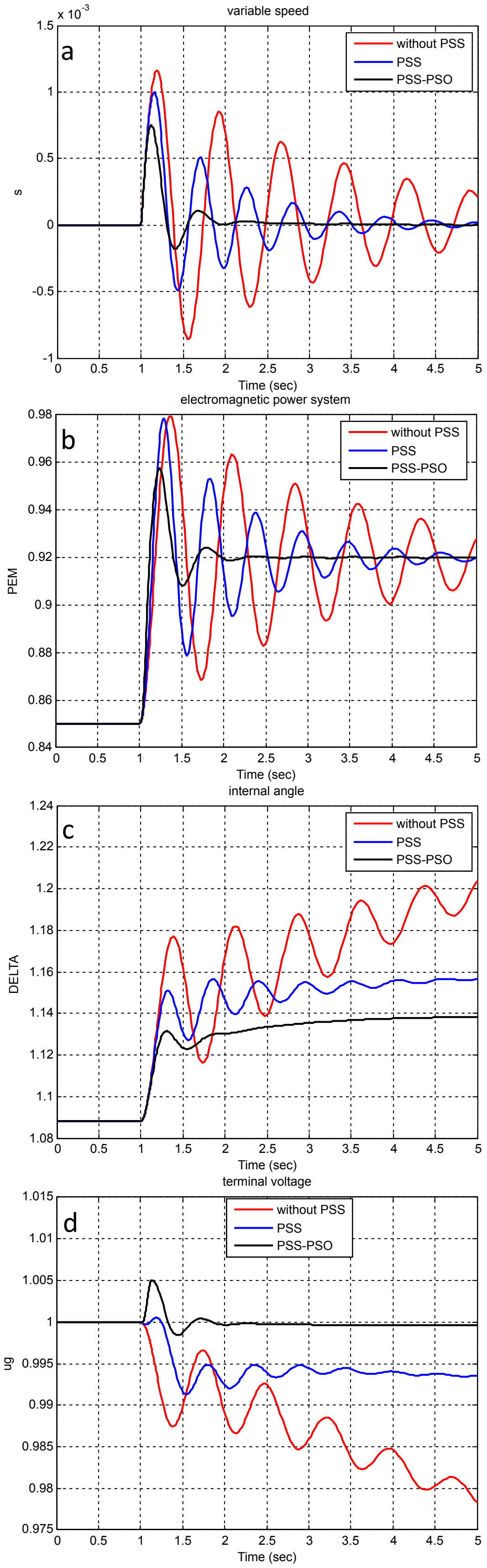

Fig. 11: TBB 200 functioned in the under-excited.

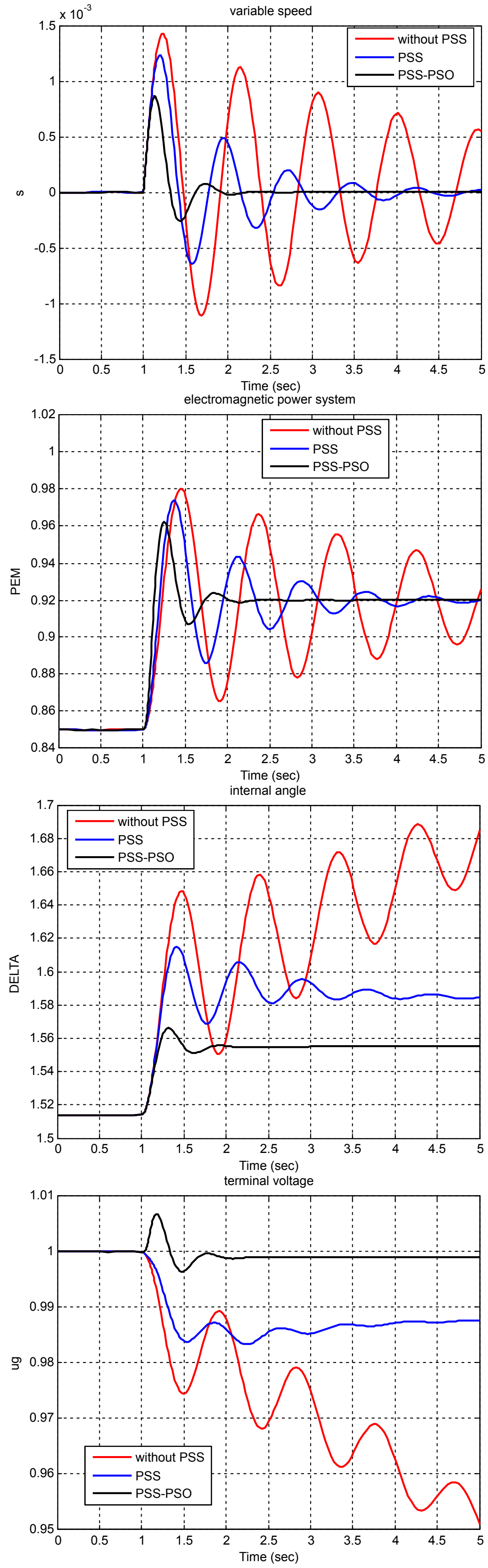

Fig. 12: TBB 500 functioned in the over-excited.

VI. CONCLUSIONS

In this article, we have optimized the PSS parameters by Particle Swarm Optimization; the optimized PSS are used for powerful synchronous generators exciter voltage control in order to improve static and dynamic performances of the power system. This technique (PSO) allows us to obtain a considerable improvement in dynamic performances and robustness stability of the SMIB studied. All results are obtained by using our created GUI/MATLAB.

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APPENDIX

A. *Parameters of the Power System*

Parameters	TBB 200	TBB 500	BBC 720	TBB 1000	Notations
Power nominal	200	500	720	1000	MW
Factor of power nominal	0.850	0.85	0.85	0.9	p.u.
X_d	2.560	1.869	2.670	2.35	Synchronous longitudinal reactance
X_q	2.560	1.500	2.535	2.24	Synchronous reactance transverse
X_s	0.222	0.194	0.220	0.32	Shunt inductive reactance Statoric
X_f	2.458	1.790	2.587	2.17	Inductive reactance of the excitation circuit
X_{sf}	0.12	0.115	0.137	0.14	Shunt inductive reactance of the excitation circuit
X_{sfd}	0.0996	0.063	0.1114	0.148	Shunt inductive reactance of the damping circuit on the direct axis
R_a	0.0055	0.0055	0.0055	0.005	Statoric active resistance
R_f	0.000844	0.00084	0.00176	0.00132	Resistance of the excitation circuit (rotor).