Cumhuriyet Üniversitesi Fen Fakültesi
Fen Bilimleri Dergisi (CFD), Cilt:36, No: 3 Özel Sayı (2015)
ISSN: 1300-1949

Cumhuriyet University Faculty of Science
Science Journal (CSJ), Vol. 36, No: 3 Special Issue (2015)
ISSN: 1300-1949

Performance Evaluation of power system stabilizers Using Teaching Learning Based Optimization of a Multi-Machine System

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Received: 01.02.2015; Accepted: 05.05.2015

Abstract. One of the main problems that lead to instability in a power system is the low frequency oscillation caused by swinging generator rotor. These disturbances cause oscillations at low frequencies that are undesirable since it affects the amount of transferred power through the transmission lines and leads to external stress to the mechanical shaft. In order to compress effectively low-frequency oscillations, a common means is to add a supplementary signal to the synchronous generator excitation system. This is the so-called power system stabilizer, PSS. The parameters of the power system stabilizer have been tuned by the two ways, particle swarm optimization (PSO) and teaching–learning based optimization (TLBO). The robustness of the proposed TLBO-based PSSs (TLBOPSS) is verified on a multi-machine power system under different operating conditions and disturbances. The results of the proposed TLBOPSS are compared with the particle swarm optimization based tuned PSS through eigenvalue analysis, nonlinear time-domain simulation and some performance indices to illustrate its robust performance for a wide range of loading conditions.

Keywords: Power System Stabilizer, Teaching–Learning Based Optimization, Particle Swarm Optimization, Multi-Machine Power System

1. INTRODUCTION

One of the important aspects in electric power system is the stability. Power system stability can be defined as the ability of a power system to remain in a state of equilibrium under optimal operating condition and regain an acceptable state of equilibrium after disturbance. So a power system should maintain frequency and voltage level in the desired level, under different operating condition such as, sudden increase in load, loss of synchronism or switching out of transmission line. Low frequency oscillations in the power systems are in the order of 0.2 to 3 Hz. To enhance system damping, the generators are equipped with PSS that provide stabilizing signals in the excitation system. The most commonly used PSS are conventional PSS, where the gain settings are fixed at certain value, which are determined under particular operating condition [1]. In this paper the TLBO technique is used for optimal tuning of PSS parameter to improve optimization synthesis and the speed of algorithm convergence.

2. TEACHING–LEARNING BASED OPTIMIZATION

The Teaching-Learning-Based Optimization (TLBO) is a novel optimization technique created by Rao et al. This method works on the effect of influence of a teacher on learners. Like other nature-inspired algorithms, TLBO is also a population-based method and uses a population of solutions to proceed to the global solution. The population is considered as a group of learners or a class of learners. The teacher is considered as the most knowledgeable person in the society, so the best learner is mimicked as a teacher. The teacher tries to disseminate knowledge among learners, which will in turn increase the knowledge level of the whole class and help learners to get good marks or grades. So a teacher increases the mean of

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Special Issue: The Second National Conference on Applied Research in Science and Technology

the class according to his or her capability. Teacher will put maximum effort into teaching his or her students, but students will gain knowledge according to the quality of teaching delivered by a teacher and the quality of students present in the class. The quality of the students is judged from the mean value of the population. The process of TLBO is divided into two parts. The first part consists of the 'Teacher Phase' and the second part consists of the 'Learner Phase'. The 'Teacher Phase' means learning from the teacher and the 'Learner Phase' means learning through the interaction between learners [2, 3].

A. Teacher Phase

A good teacher is one who brings his or her learners up to his or her level in terms of knowledge. But in practice this is not possible and a teacher can only move the mean of a class up to some extent depending on the capability of the class. This follows a random process depending on many factors. Let M_i be the mean and T_i be the teacher at any iteration i. T_i will try to move mean M_i towards its own level, so now the new mean will be T_i designated as M_{new}. The solution is updated according to the difference between the existing and the new mean given by

$$Difference_{Meani} = r_i\left(M_{new} - T_F M_i\right) \quad (1)$$

Where T_F is a teaching factor that decides the value of mean to be changed, and r_i is a random number in the range [0, 1]. The value of T_F can be either 1 or 2, which is again a heuristic step and decided randomly with equal probability as

$$T_F = round\left[1 + rand(0,1)\{2-1\}\right] \quad (2)$$

This difference modifies the existing solution according to the following expression

$$X_{new,i} = X_{old,i} + Difference - Mean_i \quad (3)$$

B. Learner Phase

Learners increase their knowledge by two different means: one through input from the teacher and the other through interaction between themselves. A learner interacts randomly with other learners with the help of group discussions, presentations, formal communications, etc. A learner learns something new if the other learner has more knowledge than him or her. Learner modification is expressed as

For i = 1: Pn
Randomly select two learners X_i and X_j, where $X_i \neq X_j$
If $f(X_i) < f(X_j)$
$X_{new,i} = X_{old,i} + r_i(X_i - X_j)$
Else

$X_{new,i} = X_{old,i} + r_i(X_j - X_i)$
End If
End For
Accept X_{new} if it gives a better function value.
The flow chart for the TLBO method is given in Fig 1.

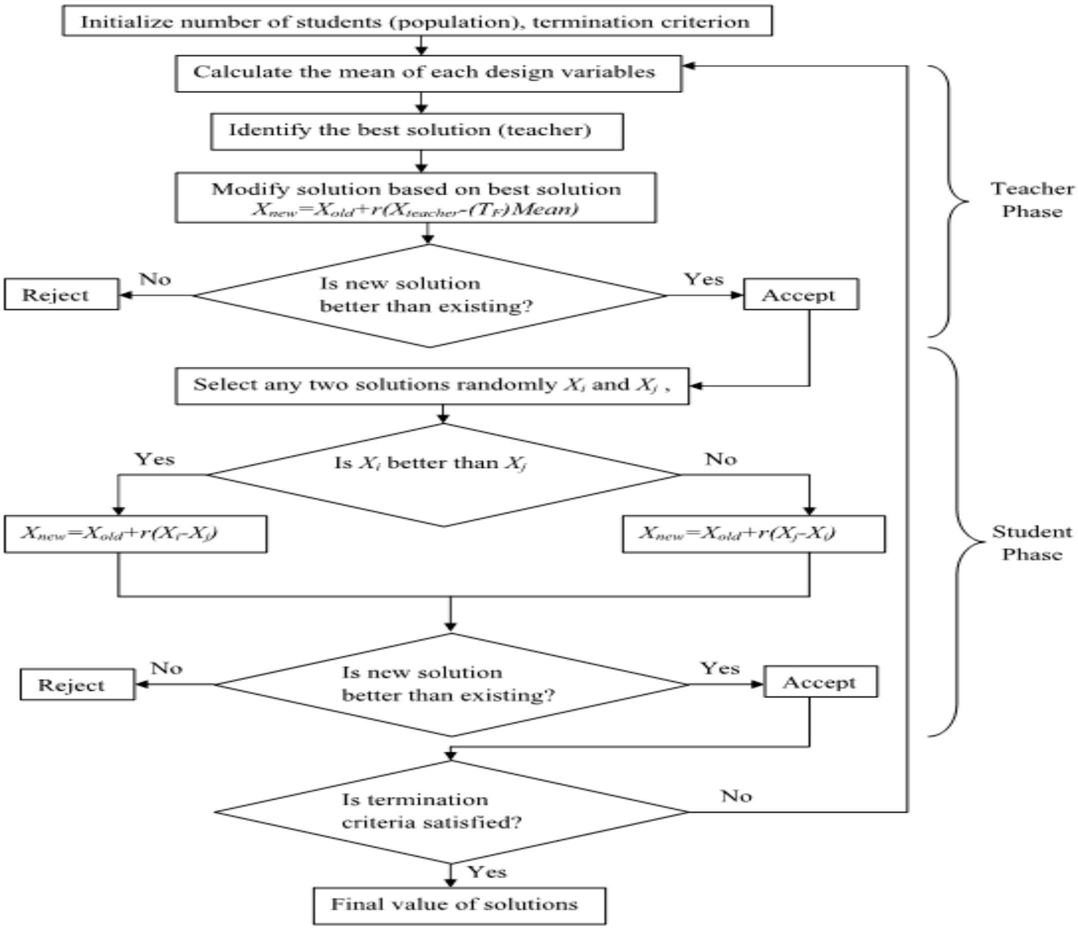

Figure 1. Flow chart showing the working of TLBO algorithm.

3. PROBLEM STATEMENT

3.1. Power system model

The generator in the power system is represented by Heffron–Philips model and the problem is to design the parameters of the power system stabilizers. In this study, the two-axis model [2] given in Appendix is used for time-domain simulations. For a given operating condition, the multi-machine power system is linearized around the operating point. The closed loop eigenvalues of the system are computed and the desired objective functions are formulated using only the unstable or lightly damped electromechanical eigenvalues, keeping the constraints of all the system modes stable under any condition.

3.2. PSS structure

The supplementary stabilizing signal considered is one proportional to speed. The transfer function of
The ith PSS is:

$$U_i = K_i \frac{sT_W}{1+sT_W}\left[\frac{(1+ST_{1i})(1+sT_{3i})}{(1+ST_{2i})(1+sT_{4i})}\right] \omega_i(s) \quad (4)$$

Where $\Delta\omega_i$ is the deviation in speed from the synchronous speed? The value of the time constant T_W is usually not critical and it can range from 0.5 to 20 s. The value of the time constant T_w is usually not critical and it can range from 0.5 to 20 s. In this study, it is fixed to 10 s [5]. The adjustable PSS parameters are the gain of the PSS, K_i, and the time constants, T_{1i}-T_{4i}. The required phase lead can be derived from the lead–lag block even if the denominator portion consisting of T_{2i} i and T_{4i} gives a fixed lag angle. Thus, to reduce the computational burden in this study, the values of T_{2i} and T_{4i} are kept constant at a reasonable value of 0.05 s and tuning of T_{1i} and T_{3i} are undertaken to achieve the net phase lead required by the system.

3.3. PSS design using PSO AND TLBO

In the proposed method, we must tune the PSSs parameters optimally by PSO technique to improve the overall system dynamic stability in a robust way under different operating conditions and disturbances. For our optimization problem, an eigenvalue based multi-objective function reflecting the combination of damping factor and damping ratio is considered as follows:

$$J_3 = J_1 + aJ_2 \tag{5}$$

Where $J_1 = \sum_{j=1}^{NP} \sum_{\sigma i \geq \sigma o} (\sigma_o - \sigma_{ij})^2$, $J_2 = \sum_{j=1}^{NP} \sum_{\zeta_i \leq \zeta_o} (\zeta_o - \zeta_{ij})^2$, σ_{ij} and ζ_{ij} are the real part and the damping ratio of the ith eigenvalue of the jth operating point. The value of a is chosen at α. NP is the total number of operating points for which the optimization is carried out. The value of σ_o determines the relative stability in terms of damping factor margin provided for constraining the placement of eigenvalues during the process of optimization. The closed loop eigenvalues are placed in the region to the left of dashed line as shown in Fig. 2a, if only J_1 were to be taken as the objective function. Similarly, if only J_2 is considered, then it limits the maximum overshoot of the eigenvalues as shown in Fig. 2b. In the case of J_2, ζ_o is the desired minimum damping ratio which is to be achieved. When optimized with J_3, the eigenvalues are restricted within a D-shaped area as shown shaded in Fig. 2c [5].

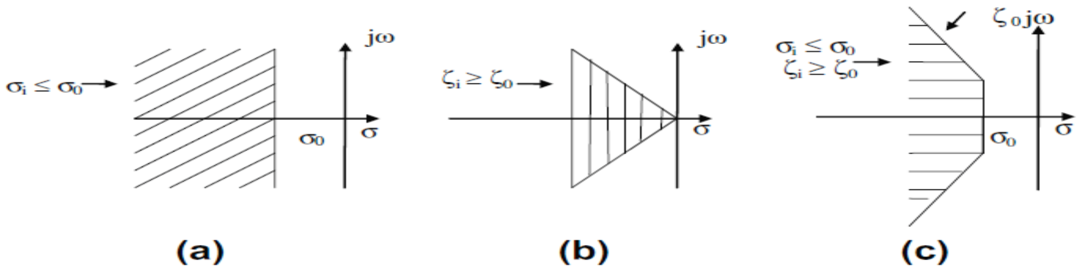

Figure 2. Region of eigenvalue location for objective functions.

The design problem can be formulated as the following constrained optimization problem, where the constraints are the PSS parameter bounds:
Minimize J_3 subject to

$$K_i^{min} \leq K_i \leq K_i^{max}$$
$$T_{1i}^{min} \leq T_{1i} \leq T_{1i}^{max}$$
$$T_{3i}^{min} \leq T_{3i} \leq T_{3i}^{max}$$

The proposed approach employs TLBO technique to solve this optimization problem and search for optimal or near optimal set of PSS parameters (K_i, T_{1i} and T_{3i} for i = 1, 2 ,... ,m), where m is the number of machines.

4. CASE STUDY

In this study, the three-machine nine-bus power system shown in Fig. 3 is considered. Detail of the system data are given in Ref.

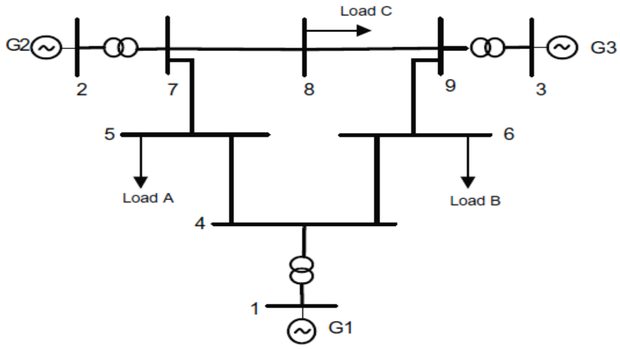

Figure 3. Three-machine nine-bus power system.

To assess the effectiveness and robustness of the proposed method over a wide range of loading conditions, three different cases designated as nominal, light and heavy loading are considered. The generator and system loading levels at these cases are given in Tables 1 and 2.

Table 1- Generator operating conditions (in Pu).

Gen	Nominal	Heavy	Light
	P Q	P Q	P Q
G_1	0.72 0.27	2.21 1.09	0.36 0.16
G_2	1.63 0.07	1.92 0.56	0.80 -0.11
G_3	0.85 - 0.11	1.28 0.36	0.45 - 0.20

Table 2- Loading conditions (in pu).

Gen	Nominal	Heavy	Light
	P Q	P Q	P Q
A	1.25 0.5	2.0 0.80	0.65 0.55
B	0.90 0.30	1.80 0.60	0.45 0.35
C	1.0 0.35	1.50 0.60	0.50 0.25

The each PSS, the optimal setting of three parameters is determined by the PSO and TLBO, i.e. Eighteen parameters to be optimized, namely K_i, T_{1i}, and T_{3i} for i = 1, 2, 3. The optimization of PSS parameters is carried out by evaluating the multi-objective cost function as given in Eq. (5), which considers a multiple of operating conditions. The operating conditions considered are:

(i) Nominal case of the system.
(ii) Heavy loading of the system.
(iii) Light loading of the system.

In this work, the values of σ_{ij} and ζ_{ij} are taken as -1.5 and 0.2, respectively. It should be noted that TLBO algorithm is run several times and then optimal set of PSS parameters is selected. Results of PSSs parameter set values based on the multi-objective function using both the proposed TLBO method and PSO method for more details about the problem solution) are given in Table 3.

Table 3. Optimal PSSs parameters using TLBO and PSO technique**.**

Method	Load Level	Cost %	G_1			G_2			G_3		
			K	T_1	T_3	K	T_1	T_3	K	T_1	T_3
PSO	Nominal	14.633	30.492	0.17016	0.088041	43.676	0.025567	0.11137	13.243	0.17738	0.06469
TLBO		14.522	15.68	0.4054	0.04772	12.307	0.0172	0.1248	10.183	0.063	0.09837
PSO	Heavy	15.009	27.803	0.16205	0.051083	10.085	0.17147	0.45457	10.463	0.019446	0.05027
TLBO		14.85	11.666	0.0781	0.03352	32.689	0.08891	0.1250	10	0.1142	0.1276
PSO	Light	14.595	28.493	0.08378	0.41421	10.005	0. 6723	0.02287	15.37	0.22273	0.09241
TLBO		14.576	25.387	0.1129	0.1191	10	0.3835	0.0659	10	0.1081	0.1027

4.1. Nonlinear time-domain simulation

To evaluate the effectiveness of the PSO based tuned PSSs using the proposed multi-objective function a six-cycle threephase fault disturbance at bus 7 at the end of line 5–7 is considered. The fault is then cleared by line tripping without reclosure. The speed deviations of generators G_1, G_2 and G_3 under the nominal, light and heavy loading conditions are shown in Figs. 4–6.

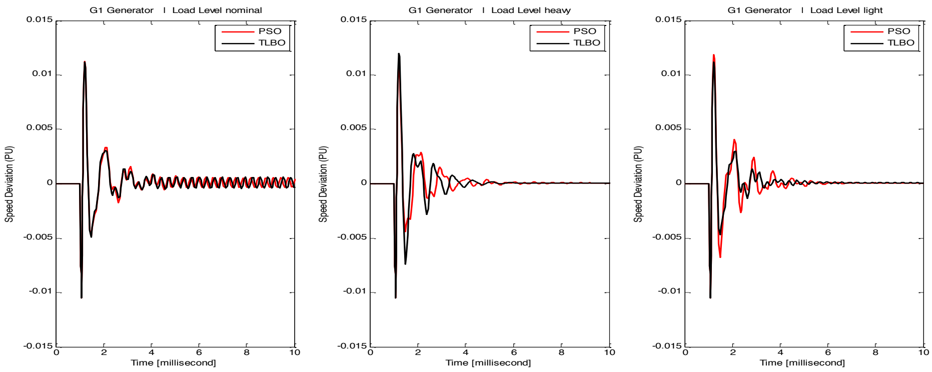

Figure 4. System response under fault disturbance for Generator1.

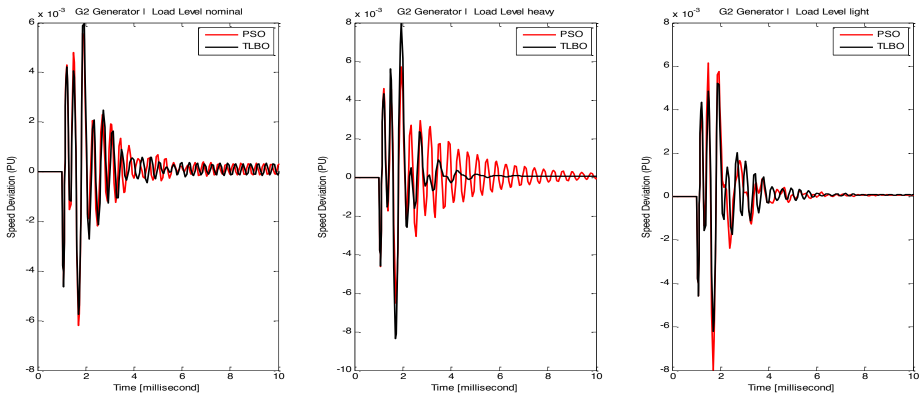

Figure 5. System response under fault disturbance for Generator2.

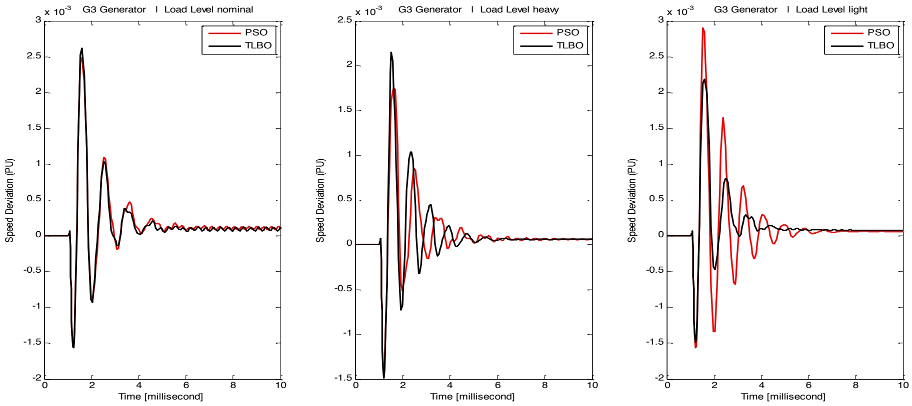

Figure 6. System response under fault disturbance for Generator3.

It can be seen that the TLBO based tuned PSSs using the multi-objective function achieves good robust performance and provides superior damping in comparison with PSO.

5. CONCLUSIONS

In this paper the TLBO technique is used for optimal tuning of PSS parameter to improve optimization synthesis and the speed of algorithm convergence. The proposed TLBO algorithm for tuning PSSs is easy to implement without additional computational complexity. Thereby experiments this algorithm gives quite promising results. The ability to jump out the local optima, the convergence precision and speed are remarkably enhanced and thus the high precision and efficiency are achieved. The effectiveness of the proposed method is tested on a multimachine power system for a wide range of loading conditions and disturbances. The simulation results confirm that the proposed TLBO based tuned PSSs can work effectively over a wide range of loading conditions and is superior to the PSO method.

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