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# A novel chaotic teaching–learning-based optimization algorithm for multi-machine power system stabilizers design problem

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ABSTRACT

This paper proposes an efficient optimization algorithm named chaotic teaching–learning algorithm (CTLA), to solve multimachine power system stabilizers design problem. The original teaching learning algorithm as competitive to other optimization algorithms, used two phases to proceed to the global optimal solution: 'teacher phase' and 'learner phase'. However, during the second phase an adequate interaction between the teacher and the learners in entire search space are not guaranteed and the algorithm may be trapped in local optima. Thus, in the proposed CTLA a new phase named "chaotic phase" is added in order to overcome this drawback. The performance of the CTLA is investigated by using a set of benchmark functions. To demonstrate the effectiveness of the proposed algorithm in power systems, the conventional lead-lag power system stabilizers (PSSs) are tuned for: three machines nine bus system (WSCC) and the ten machine thirty-nine bus New England power systems. The performance of the proposed CTLA-based PSS (CTLAPSSs) under different loading conditions and disturbances is investigated through eigen-value analysis, non-linear time domain-simulations and some performance indices.


## Introduction

Low frequency oscillations are observed in large interconnected power system. They can affect both power transfer and its safety, if they are not adequately damped [1,2]. Therefore, low frequency oscillations damping can allow an optimal power system security. To serve this goal, power system stabilizers (PSSs) are commonly used. Many researchers have focused on designing the efficient PSSs [3,5].

The conventional PSSs (CPSS) were tuned based on a linear model for particular operating point [4]. However, due to the non-linearity of the power system and the frequent operating changes, the performance was highly affected. To overcome this problem many different methods have evolved. In [6–8] the authors introduced the use of adaptive control algorithms and robust control methods. Yet, facing the complexity of the power system, a linearized dynamic model is hardly obtained. In addition, it's difficult to apply an online controller because the real electric power systems are time varying, hence a fixed controller is more feasible and suitable. Recently, the Real Time Digital Simulator (RTDS) is employed to study the real-time behavior of power system. Some limitations related to the relatively large computational time due to the hardware architecture of the existing real-time digital simulator has been reported in the literature [9]. The main challenges of the RTDS lie in the limited degree of accuracy simulations caused by the simultaneous simulation of a fast electrical and a long mechanical phenomena. In recent years, the linear model of power system is no longer used and different optimization methods were developed [3,10,11].

Among the well known meta-heuristic optimization techniques we can mention: Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Strength Pareto Evolutionary Algorithm (SPEA). They have been widely used in multi-machine power system design and they proved to have satisfactory results [12–15]. By contrast, when it comes to the fact that; the parameters to be optimized are large and very correlated, the performance of previous methods have degraded. Besides, different parameters are required to guarantee the effectiveness of the above mentioned algorithm, for instance in GA population size, crossover rate and mutation rate are needed, whereas, PSO requires inertia weight, social and cognitive parameters, and Artificial Bee Colony (ABC) needs the number of bees (employed, onlookers and scout), limit, etc.

The original teaching learning algorithm (TLA) method has many advantages such as: less computational effort, independence of initial values of parameters and effectiveness compared with other algorithms [17]. The core of TLA is based on Teacher/Learner relationship; on the one hand, the teacher is seen as a highly skilled expert who tries to share his or her knowledge with students, on the other hand the learners can better learn through interaction between themselves in order to improve their results or grades.

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Our paper will use an algorithm that fits within the chaotic teaching–learning algorithm. The chaotic phase is added to the original TLA in order to improve the quality of solutions and the convergence property. The proposed algorithm is implemented to improve the stability of multi-machine power systems via a design of the power system stabilizer parameters. This technique is applied to two test systems namely three machine nine bus WSCC system and ten machine thirty-nine bus New England system. To evaluate the effectiveness of this new technique, the stability performances are performed and compared to that of other methods based on, original Teaching Learning Algorithm (TLA), Genetic Algorithm (GA) and Fuzzy Gravitational Search Algorithm (FGSA). The results proved that the CTLAPSS can guarantee a good damping characteristics for power system oscillations.

The rest of this paper is organized as follows. In Section "Power system model and damping controller structure", we will describe the power system model and the damping controller structure. The chaotic Teaching Learning algorithm is presented in Section "Chaotic Teaching Learning algorithm". Section "Model validation", investigate the efficiency of the proposed algorithm. In Section "Problem formulation", we will introduce the problem formulation. The application of CTLA method to design PSSs controllers is presented in Section "Practical application". Finally, the conclusion is given in Section "Conclusion".

## Power system model and damping controller structure

### Power system model

The power system can be modeled by a set of nonlinear differential equations as [2]:

$$\dot{\delta}_i = \omega_b(\omega_i - 1) \tag{1}$$

$$\dot{\omega}_i = \frac{1}{M_i}(P_{mi} - P_{ei} - D_i(\omega_i - 1)) \tag{2}$$

$$\dot{E}'_{qi} = \frac{1}{T'_{d0}}(E_{fdi} - (x_{di} - x'_{di})i_{di} - E'_{qi}) \tag{3}$$

$$\dot{E}_{fdi} = \frac{1}{T_{Ai}}(K_{Ai}(v_{refi} - v_i + u_i) - E_{fdi}) \tag{4}$$

where $\delta_i$ and $\omega_i$ are rotor angle and angular speed of the machine-$i$. $\omega_b$ is the base frequency in rad/s. $P_{mi}$ and $P_{ei}$ are the mechanical input and the electrical output powers for the machine $i$, respectively. $D_i$ and $M_i$ are the damping coefficient and inertia constant, respectively. $E_{fdi}$ and $E'_{qi}$ are the field and the internal voltages, respectively. $i_{di}$ and $i_{qi}$ are the $d$-axis and $q$-axis armature current, respectively. $x_{qi}$ and $x'_{di}$ are the $q$-axis transient reactance and the $d$-axis reactance of the generator-$i$, respectively. $T'_{doi}$ is the open circuit field time constant.

$$T_{ei} = E'_{qi}i_{qi} - (x_{qi} - x'_{di})i_{di}i_{qi} \tag{5}$$

### Damping controller structure

The main function of a PSS is to produce auxiliary stabilizing signal through the excitation system in order to damp out the generator rotor oscillations. To achieve this goal, the electrical torque components introduced by PSS must be in phase with rotor speed deviations. The controller gain $K$ fixes the amount of damping produced by the PSS. The lead-lag block, represented by two first-order leadlag transfer functions, provides the desired phase-lead to compensate the phase lag between the excitation voltage and the generator electrical torque. Throughout this study a conventional lead-lag power system stabilizer (PSS) as shown in Fig. 1 is considered. The lead-lag PSS structure was chosen in regards to their simplicity, flexibility, ease of implementation and the facility to on-line tuning. In addition, it is noteworthy that variable or adaptive structures as reported in [3] present a lack of stability. Its transfer function is given below.

$$U_i = K_i \frac{sT_{wi}}{1 + sT_{wi}} \frac{(1 + sT_{1i})(1 + sT_{3i})}{(1 + sT_{2i})(1 + sT_{4i})} \Delta\omega_i \tag{6}$$

where $K_i$ represents a gain, $T_{wi}$ is the time constant of the washout block and $T_{1i} - T_{4i}$ are the time constants of the two lead-lag blocks. Its input signal is the normalized speed deviation $\Delta\omega_i$. While, the output signal is the supplementary stabilizing signal $U_i$.

## Chaotic Teaching Learning algorithm

### Brief overview

This section will briefly explain the Teaching Learning algorithm (TLA). This approach was first introduced by Rao et al. [16,17]. It is basically inspired by the classroom reality where by nature the teacher is seen as reference who influences his or her learners, the students by themselves are positive contributors who interact in order to improve the results and grades. Therefore, the gain knowledge is dependent on both the quality of teacher and students in class.

Like other evolutionary algorithms, TLA try to improve a population of solutions in order to get the global solution. Allegorically, the populations represents a group of learners where each individual consists of the variables to be optimized. The different variables in TLA, are analogous to the different courses offered to learners and the students result is equivalent to the "Fitness" in other optimization algorithms.

### Chaotic Teaching Learning description

How TLA works can be summed up in two phases: the "Teacher phase" and the "Learner phase". The "teacher phase" deals with how learning is obtained from teacher and the "Learner phase" concerns how learning is carried out through the interaction between learners. The algorithm starts by the generation of initial solutions and the evaluation of objective function of each individual. After that the two phases are involved as follows:

*Teacher phase:* In this phase the teacher attempts to improve the mean result of the whole class. In this phase, the learner with the best grade is selected as a teacher of the class. The teacher attempts to improve the mean result of the whole class. For an optimization problem with $d$-dimensional objective function, the

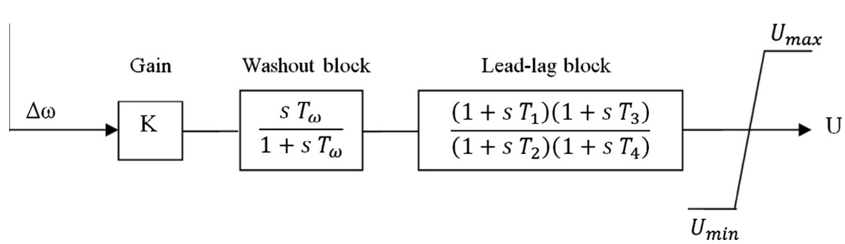


**Fig. 1.** Block diagram for power system stabilizer.