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Comparison of Different Techniques For Tuning of Power System Stabilizer

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Abstract. The power system is subjected to different types of disturbances such as small changes in the load that affects its efficiency and sometimes leads to unstable system. 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 low-frequency oscillations, a common solution is use the power system stabilizer (PSS). In this paper different techniques for Tuning of power system stabilizer is proposed. The parameters of the power system stabilizer has been tuned by the three ways, particle swarm optimization (PSO), genetic algorithm (GA) and teaching–learning based optimization (TLBO). The simulation results indicate the performance of the teaching learning based power system stabilizer is much better than the particle swarm optimization power system stabilizer and genetic algorithm based power system stabilizer.

Keywords: Power System Stabilizer, Teaching–Learning Based Optimization, Particle Swarm Optimization, Genetic Algorithm

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 [1]. The changes in the operating condition of an electric power system usually accompany with spontaneous low-frequency oscillations. Some of the oscillations could fade away and do no harm to power systems; but some of them might stay for a while, grow up gradually, and eventually result in large-scale blackouts [2]. Main cause of electromechanical oscillations is insufficient damping in the power system[3]. Low frequency oscillations in a power system affect the system stability, the operating efficiency of the power system and restrict the operating capability of power transmissions [4]. In order to solve this problem, engineers and researchers have been continually tasked to find simple, effective and economical strategies of stabilizing the power system. Hence, the Power System Stabilizer (PSS), by which a supplementary stabilizing signal is added to the excitation system, emerged as a simple and cost-effective approach [5, 6].

Power System Stabilizers are mainly used to damp low frequency oscillations in the range of 0.2 Hz to 2.5 Hz. The automatic voltage regulator (AVR) regulates the generator terminal voltage by controlling the amount of current supplied to the generator field winding by the exciter. It is mainly used to damp any oscillations accrued to the power system when load is changing. It keeps the terminal voltage of the generator constant so that the voltage on the load side will remains almost constant even the load is vary with time. Next section will present the motivation on this paper. Section three will discuss the system modeling. Then PSS design will be discussed in section four. Finally simulation and PSS implementation will be discussed in section five.

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2. MOTIVATION

This paper will investigate; how to solve the dynamic stability of the single machine connected to infinite bus during small disturbances using PSS. The main objective of this work is to design and implement a power system stabilizer for single machine connected to infinite bus power system to stabilize the system and improve the system response during small disturbances or changes in the system.

3. SYSTEM MODELING

Modeling of the system is an important part of the design. This chapter presents the modeling of the system parts which are; synchronous machine, Automatic Voltage Regulator and the Power System Stabilizer.

3.1. SINGLE MACHINE CONNECTED TO INFINITE BUS LINEAR MODEL

The synchronous generator experience an oscillatory period which can be classified into a transient period and a steady state or dynamic period. The transient period is the first cycles after the disturbance. The consideration on dynamic area reduces the system model to the third order model. Since the interest of this paper is to look after small change in the system, the linearized third order model is sufficient for the analysis. The simplified third order model of synchronous generator connected to infinite bus through a transmission line having resistance Re and reactance Xe has the following assumption over the full order model:

1. Stator winding resistance is neglected.

2. Balancing conditions are assumed and saturation effects are neglected.

3. Damper winding effect is neglected.

From this assumption the linear equation of stator voltage (E'q) that proportional to main winding flux linkage can be found as follow [7, 8]:

$$\Delta E'_q = \frac{K_3}{1+K_3\tau'_{do}s}\Delta E_{FD} - \frac{K_3K_4}{1+K_3\tau'_{do}s}\Delta\delta \tag{1}$$

Where E_{FD} is the rms value of E'q, τ'_{do} direct-axis transient time constant. On the other hand, the incremental electrical torque is computed according to the following:

$$\Delta T_e = K_1\Delta\delta + K_2\Delta E'_q \tag{2}$$

$$E'_q = E + \left(x_d - x'_d\right)I_d \tag{3}$$

Where E is the stator air gap rms voltage. The synchronous generator linearized terminal voltage ΔV_t is given by:

$$\Delta V_t = K_5 \Delta\delta + K_6 \Delta E' \tag{4}$$

Note that the constants K_1,K_2,K_3,K_4,K_5 and K_6 are depended on system parameter and operation conditions. In general K_1,K_2,K_3 and K_6 are positive, whereas K_4 is positive unless Re is high. However, K_5 is positive for low and medium loading and external impedance. But if the loading and the external impedance is high K_5 will be negative. The summary of the simplified linear differential equations of the synchronous machine are as follows:

$$\Delta E'_q = \frac{K_3}{1 + K_3 \tau'_{do} s} \Delta E_{FD} - \frac{K_3 K_4}{1 + K_3 \tau_{do} s} \Delta\delta \tag{5}$$

$$\Delta\omega_m = \frac{1}{2\mathrm{Hs}} \left[\Delta T_m - \Delta T_e - D \Delta\omega_m \right] \tag{6}$$

$$\Delta\delta = \frac{\omega B}{s} \Delta\omega_m = \frac{\omega B}{s} \Delta\varpi \tag{7}$$

Where S is the laplace operator.

3.2. EXCITATION SYSTEM

Excitation system is one of prime importance for the proper operation of synchronous generators. The excitation system can be as simple as a fixed dc power supply connected to the rotor's winding of the synchronous generators. The primary function of a synchronous generator excitation system is to regulate the voltage at the generator output. On other words, using the excitation system in any synchronous machine is to control the field current injected to the rotor. The point of controlling the field current is to regulate the terminal voltage of the machine and maintaining the terminal voltage constant and hence keeping the synchronization of the generator. The excitation system representation is shown in Figure l.

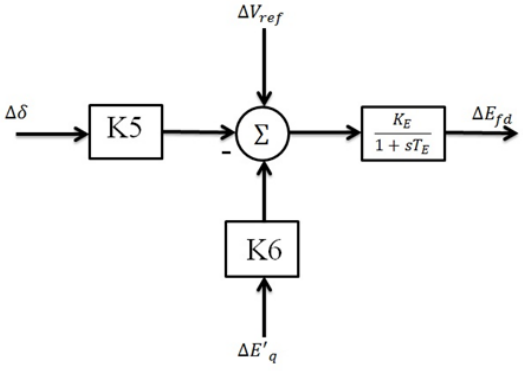

Figure 1. Simple excitation system model

The linearized equation of the excitation system is given by the following equation [7]:

$$\Delta E_{fd} = \frac{K_e}{1+sT_e}\left(\Delta V_{ref} - \Delta V_t\right) \tag{8}$$

3.3. PSS Model

Power System Stabilizer (PSS) is a device which provides additional supplementary control loops to the automatic voltage regulator system and/or the turbine governing system of a generating unit. PSS are often used as an effective and economic means of damping such oscillations. Adding supplementary control loops to the generator AVR is one of the most common ways of enhancing both small-signal (steady state) stability and large-signal (transient) stability [9]. The general equation and the used equation of the PSS is:

$$V_{PSS}(s) = \frac{sK_sT_w(1+sT_1)(1+sT_3)}{(1+sT_w)(1+sT_2)(1+sT_4)} Input(s) \tag{9}$$

This particular controller structure contains a washout block, STW/(1+STW), which is used to reduce the overresponse of the damping during severe events. The constants T_1, T_2 , T_3, and T_4 should be set to provide damping over the range of frequencies at which oscillations are likely to occur.

4. PSS DESIGN USING TEACHING - LEARNING

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 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 [10,11].

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

$$Difference_{Meani} = r_i\left(M_{new} - T_F M_i\right) \tag{10}$$

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

$$T_F = round\left[1 + rand(0,1)\{2-1\}\right] \tag{11}$$

This difference modifies the existing solution according to the following expression

$$X_{newi} = X_{oldi} + Difference - Mean_i \tag{12}$$

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
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Accept X_{new} if it gives a better function value.

The flow chart for the TLBO method is given in Figure 2.

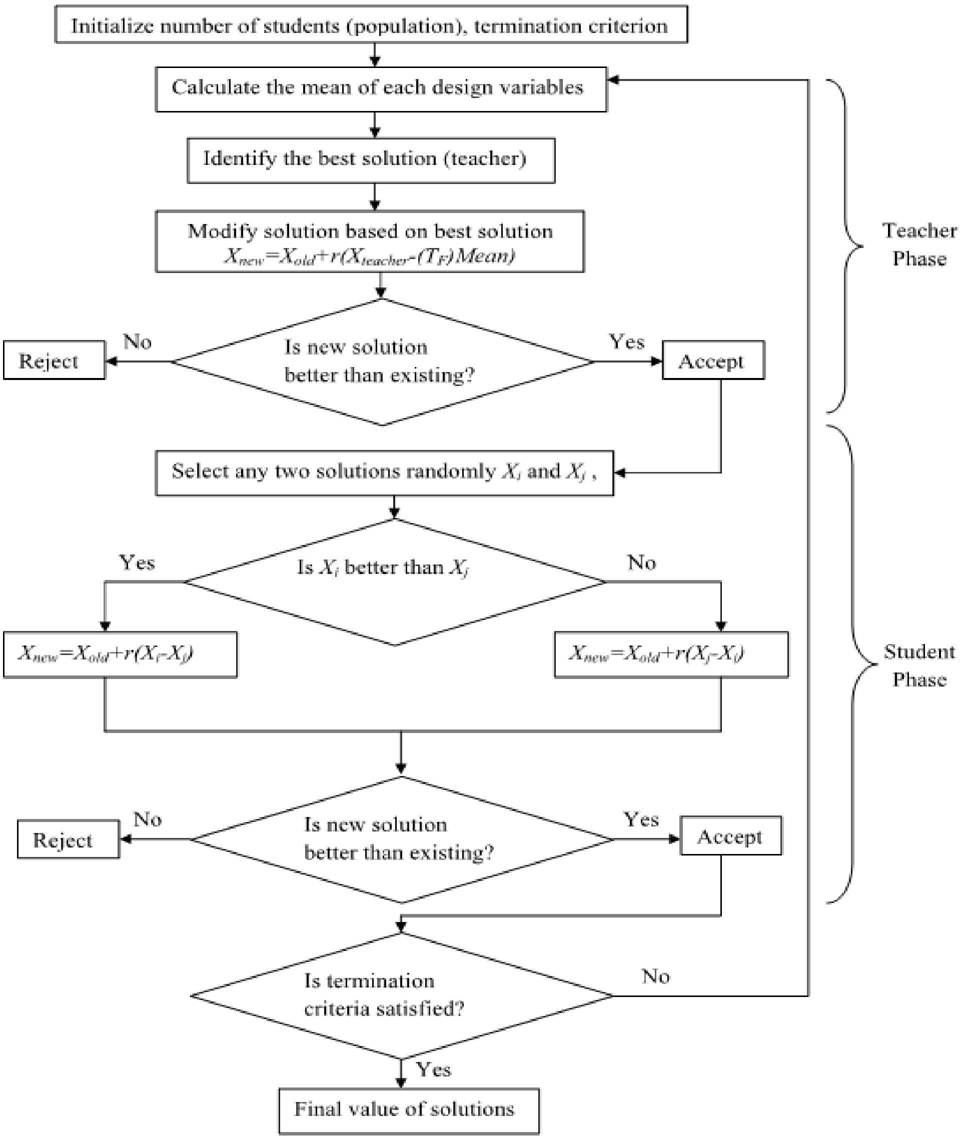

Figure 2. Flow chart showing the working of TLBO algorithm

The PSS parameters are optimized by stimulating a disturbance to the system. Then, PSS parameters with minimum rotor speed deviations are selected via iterative TLBO process as shown in Figure 3.

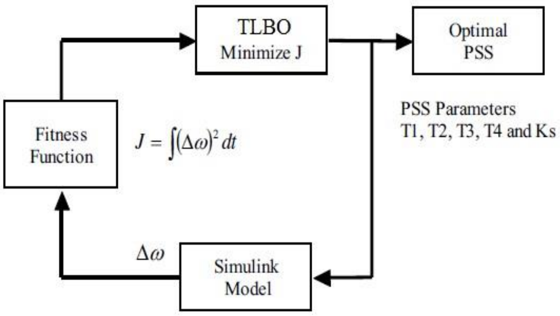

Figure 3. Design procedure with TLBO

In this paper, Eq. (13) is used as a fitness function in TLBO search process.

$$J = \int (\Delta\omega)^2 dt \tag{13}$$

5. SIMULATION RESULTS

5.1. Simulation Model

The system is simulated using MATLAB/Simulink toolbox. The models of the synchronous machine, PSS and the excitation system are linked together to form the Overallsystem representation showing Figure 4.

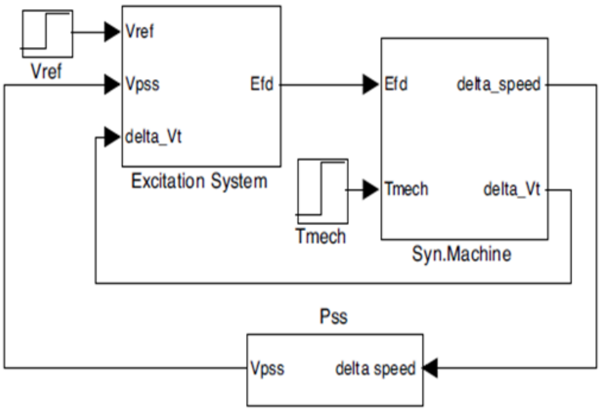

Figure 4. Overall system Simulink Model

5.2. Case Study

The performance of single machine connected to infinite bus power system is tested under a selected operating condition; the dynamic system response is analyzed considering the following variables:

- Rotor angle deviation
- Velocity/Speed deviation

The operating condition is listed below, where $K_5 < 0$ [12]:

$$K_1 = 0.9831, K_2 = 1.0923, K_3 = 0.3864$$
$$K_4 = 1.4746, K_5 = -0.1103, K_6 = 0.4477$$
$$T_{do}' = 5\,sec, T_A = 0.2\,sec, H = 6\,sec$$

Considering the operating condition listed above; the system response without PSS during a step load disturbance oscillates and goes out of stability.

5.3. Simulation Results

PSS parameters designed by Genetic Algorithm and Particle Swarm Optimization are given in Tables 1 and 2 [13]. TLBO is used in this paper to tune PSS parameters as described in the previous section. Table 3 presents the PSS parameters as designed by TLBO.

Table 1. PSS parameters designed by ga [13]

T_1	T_2	T_3	T_4	K_{PSS}
1.4557	0.6143	1.0083	0.1005	2.1783

Table 2. PSS parameters designed by pso [13]

T_1	T_2	T_3	T_4	K_{PSS}
0.3730	0.1096	0.7910	0.0819	7.1144

Table 3. PSS parameters designed by tlbo

T_1	T_2	T_3	T_4	K_{PSS}
0.0785	0.01	1	0.01	100

Figure 5 compare the generator speed deviation with GA designed PSS and with PSO designed PSS and with the proposed TLBO designed PSS during 15% load change. It is clear that the proposed PSS enhance the speed deviation compared to GA designed PSS and PSO designed PSS.

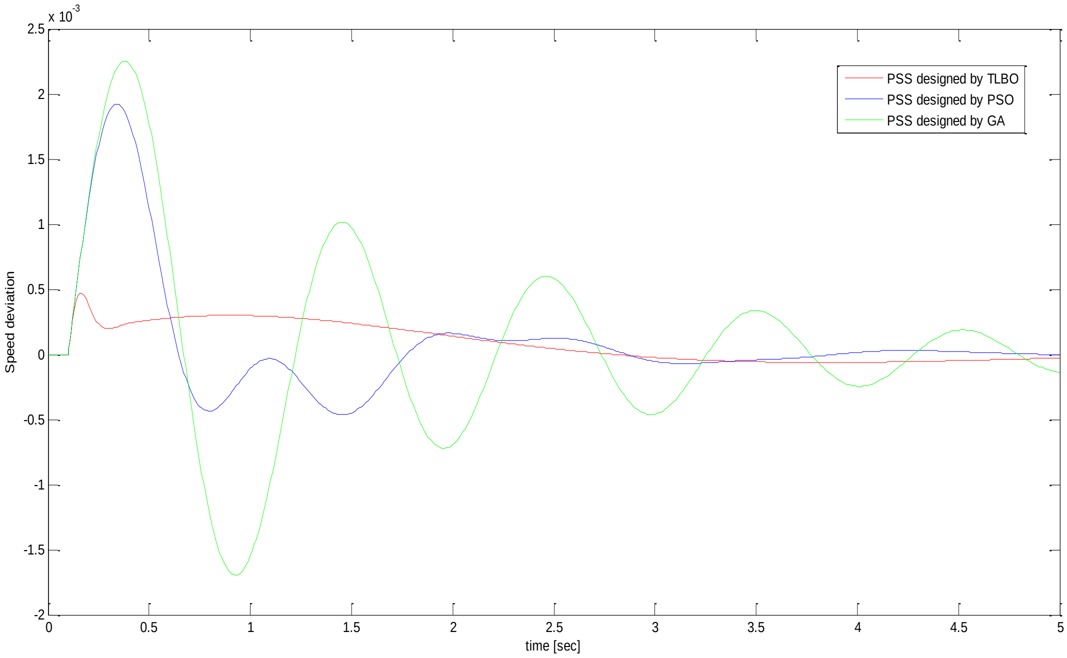

Figure 5. Speed deviation during 15% step load change

Figure 6 compare the generator rotor angle deviation with GA designed PSS and with PSO designed PSS and with the proposed TLBO designed PSS during 15% load change. It is clear that the proposed PSS improve the system transient stability.

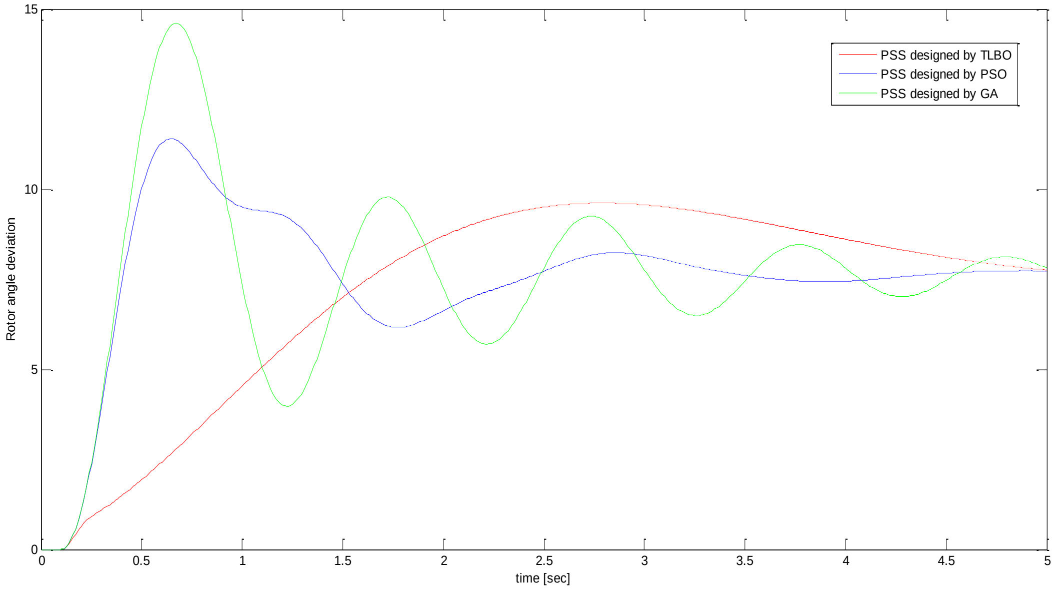

Figure 6. Rotor angle deviation during 15% step load change

6. CONCLUSION

The power system is subjected to different types of disturbances such as small changes in the load that affects its efficiency and sometimes leads to unstable system. 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. To avoid such situation a power system stabilizer is added to the Automatic Voltage Regulator (AVR) to enhance stability in the dynamic range as well as in the first few cycles after a disturbance. The input control signal to the Power system Stabilizer (PSS) is selected to be the deviation in the generator speed. The single machine-infinite bus system is used in this paper as a case study. The effect of the PSS on the system response was studied. Analyzing the results showed that adding PSS gave more damping to the oscillatory system and brings it back to normal operation, stable. The main contribution of this paper is to design an optimal PSS. Teaching learning based optimization (TLBO) is used to design the PSS parameters. The proposed PSS design enhance the system response and provide good damping to the oscillation compared with GA designed PSS and PSO designed PSS.

REFERENCES

[1] Nasar. A, P. J. (2013). Performance Evaluation ofGA and RL based PSS of a Multi-Machine System. International Conference on Circuits, Power and Computing Technologies, 461-466.
[2] Lin, Y.-J. (2013). Proportional plus derivative output feedback based fuzzy logic power system stabiliser. Electrical Power and Energy Systems, 301-307.
[3] Bhati, R. G. (2013). Robust fuzzy logic power system stabilizer based on evolution and learning. Electrical Power and Energy Systems, 357-366.

[4] M. Moghavvemi, H. A. (2012). Damping of low frequency oscillations and improving power system stability via auto-tuned PI stabilizer using Takagi Sugeno fuzzy logic. Electrical Power and Energy Systems, 72–83.

[5] Y.L. Abdel-Magid, M. A. (2010). Parameter optimization of multimachine power system conventional stabilizers using CDCARLA method. Electrical Power and Energy Systems, 498–506.

[6] A.L.S. Pereira, P. A. (2011). Pole placement by coordinated tuning of Power System Stabilizers and FACTS-POD stabilizers. Electrical Power and Energy Systems, 615–622.

[7] Anderson, A. A. (1991). Power System Control and Stability.

[8] Padiyar, K. (1996). Power system Dynamics stability & Control.

[9] Janusz W. Bialek, J. R. (1997). Power System Dynamics Stability and Control.

[10] V.J. Savsani, D. V. (2011). Teaching–learning-based optimization: A novel method for constrained mechanical design optimization problems. Computer-Aided Design, 303–315.

[11] V.J. Savsani, D. V. (2012). Teaching–Learning-Based Optimization: An optimization method for continuous non-linear large scale problems. Information Sciences, 1–15.

[12] S.Al-Omari, A. S.-H. (2007). Design of PID-Swarm Load Frequency Controller of Interconnected Power System. International Conference on Communication, Computer and Power (ICCCP'07), 19-21.

[13] AI-Hadabi, A. A.-O.-H.-L.-L. (2007). Design and Implementation of a Power System Stabilizer for Power System Dynamic Stability Enhancement. Industrial Application of Energy Systems Conference (IAES'2007).