

Optimization of Conventional Stabilizers Parameter of Two Machine Power System Linked by SSSC Using CHSA Technique

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ABSTRACT

This paper presents a method for damping of low frequency oscillations (LFO) in a power system. The power system contains static synchronous series compensators (SSSC) which using a chaotic harmony search algorithm (CHSA), optimizes the lead-lag damping stabilizer. In fact, the main target of this paper is optimization of selected gains with the time domain-based objective function, which is solved by chaotic harmony search algorithm. The performance of the proposed two-machine power system equipped with SSSC is evaluated under various disturbances and operating conditions and compared to power system stabilizer (PSS). The effectiveness of the proposed SSSC controller to damp out of oscillations, over a wide range of operating conditions and variation of system parameters is shown in simulation results and analysis.

KEYWORDS: Power System Stability, SSSC, Chaotic Harmony Search, Conventional Stabilizer, Two Machine System, LFO.

1. INTRODUCTION

Flexible AC Transmission System (FACT) is a novel integrated concept based on power electronic converters and dynamic controllers to enhance the system utilization and power transfer capacity as well as the stability, security, reliability and power quality of AC system interconnections [1]. Today's these devices in many power systems fields have founded. More of FACTS devices have been developed from switch-mode voltage source converter configurations. They are equipped with the energy storage unit, such as DC capacitors [2]. The static synchronous series compensator (SSSC) is

a kind of FACTS devices. SSSC is a member of FACTS family, which is connected in series with a power system. It consists of a voltage source converter, which injected a controllable alternating current voltage at the fundamental frequency and DC capacitor as a storage unit [3]. Although the main function of SSSC is to control the power flow but it can be used for control of dynamic stability of power system [4].

Several application fields for FACTS devices have been introduced. These fields consisting of congestion management, power flow controlling and improves dynamic stability of power systems. In some researches comparative studies between SSSC and other FACTS devices

were carried out [5-7]. Active and reactive power flow control using SSSC and other FACTS devices were investigated [8, 9] respectively. Several controlling methods for FACTS devices have been introduced. Quadratic mathematical programming for the simultaneous coordinated design of a Power System Stabilizer (PSS) and a SSSC-based stabilizer was investigated in [10]. In ref [11] fuzzy logic controller to operate SSSC in the automatic power flow control mode is used. Recently optimization techniques for obtaining parameters of controlling methods were used. These optimization techniques for achieving SSSC's controllers have been published in following literatures. Genetic algorithm (GA) and partial swarm optimization (PSO) in [12-13] were investigated, respectively.

In this paper, a two machine system is considered as a power system. After making a linear system around the operating condition with a disturbance in different loading situation that are converted to optimizing problem. For solving these kinds of problem, several algorithms are recommended above but in this paper chaotic harmony search algorithm (CHSA) is used. By considering available parameter $\Delta\omega$ as an input of lead-lag damping stabilizer this procedure is carried out. In this paper, two SSSC inputs (ϕ , m) and power system stabilizer (PSS) applied independently that connected to the output of the lead - lag controller. Finally, the effectiveness is shown by result evaluation and comparison of performance indices.

2. CHAOTIC HARMONY SEARCH ALGORITHM

This section describes the proposed chaotic harmony search (CHS) algorithm.

First, a brief overview of the IHS is provided, and finally the modification procedures of the proposed CHS algorithm are stated [15-16].

2.1. Improved harmony search algorithm

This method is based on the concept in search of a suitable state in music. In that mean's how a musician with different search modes to reach its desired state. To implement the above concepts in form of algorithm there will be several steps. This process generally in the form of the following five steps will be implemented [15-16].

Step 1. Initializing the problem and algorithm parameters.

Step 2. Initializing the harmony memory

Step 3. Improvising a new harmony.

Step 4. Updating the harmony memory.

Step 5. Checking the stopping criterion.

In the improved harmony search algorithm, two parameters in each iteration are changed. These parameters are pitch adjustment rate (PAR) and bandwidth (bw). The form of the changing these parameters is shown at below equations:

$$PAR = PAR_{min} + \frac{(PAR_{max} - PAR_{min})}{NI} \quad (1)$$

Where,

PAR : pitch adjusting rate for each generation

PAR_{min} : minimum pitch adjusting rate

PAR_{max} : maximum pitch adjusting rate

NI : number of solution vector generations

gn : generation number

Also, we have:

$$bw(gn) = bw_{max} \cdot e^{(gn \cdot \frac{\ln(\frac{bw_{min}}{bw_{max}})}{NI})} \quad (2)$$

Where,
 $bw(gn)$: bandwidth for each generation
 bw_{min} : minimum bandwidth
 bw_{max} : maximum bandwidth

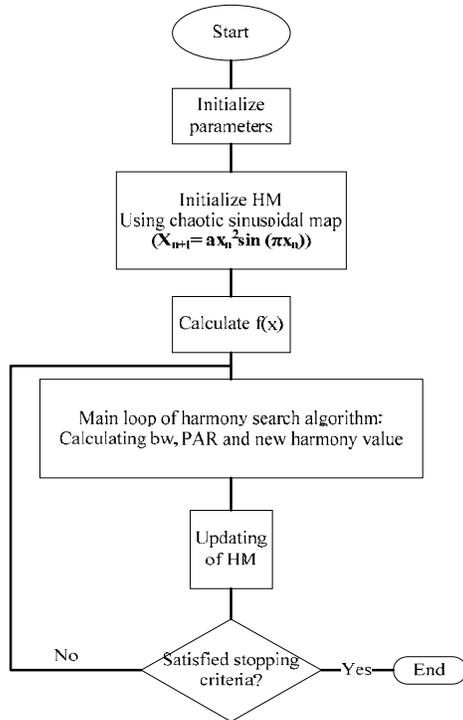


Fig.1. Flowchart of the chaotic harmony search algorithm.

2.2. Proposed method

In numerical analysis, sampling, decision making and especially heuristic optimization needs random sequences with some features. These features consist a long period and good uniformity. The nature of chaos is apparently random and unpredictable. Mathematically, chaos is the randomness of a simple deterministic dynamical system and chaotic system may be considered as sources of randomness [16]. A chaotic map is a discrete-time

dynamical system which modeling in the form of below equation:

$$x_{k+1} = f(x_{k+1}), \quad 0 < x_{k+1} < 1, \quad k=0,1,2,\dots \quad (3)$$

It is represented as:

$$X_{n+1} = ax_n^2 \sin(\pi x_n) \quad (4)$$

When $a = 2.3$ and $x_0 = 0.7$ it has the simplified form represented by:

$$X_{n+1} = \sin(\pi x_n) \quad (5)$$

It generates a chaotic sequence in (0, 1). Initial HM is generated by iterating the selected chaotic maps until reaching to the HMS as shown in below flowchart in Fig.1.

3. MODELING OF THE POWER SYSTEM UNDER STUDY

System under study in this article is a two machine power system that SSSC is installed between terminal voltage of first machine and transmission line. In fact, the generators producing powers through transmission lines and SSSC to the loads delivers. SSSC with two transmission line circuit as shown in Fig.2:

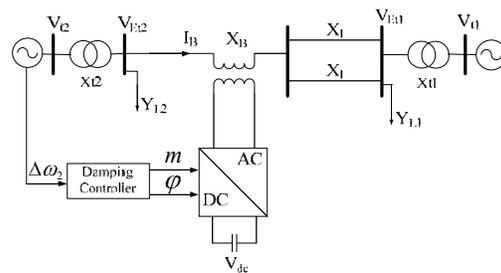


Fig.2. Two machine power system equipped with SSSC

For analysis and enhancing small signal stability of power system through SSSC, dynamic relation of the system is needed. To have these relations through park transformation and ignoring the resistance

of both boosting and exciting transformers can be achieved through following equations [14]:

$$\begin{pmatrix} v_{Bd} \\ v_{Bq} \end{pmatrix} = \begin{pmatrix} 0 & -x_B \\ x_B & 0 \end{pmatrix} \begin{pmatrix} i_{Bd} \\ i_{Bq} \end{pmatrix} + \begin{pmatrix} \frac{m \cdot \cos(\varphi) \cdot v_{dc}}{2} \\ \frac{m \cdot \sin(\varphi) \cdot v_{dc}}{2} \end{pmatrix} \quad (6)$$

$$\dot{v}_{dc} = \frac{k \cdot m}{C_{dc}} (\cos(\varphi) \quad \sin(\varphi)) \quad (7)$$

Where v_B , and i_B are the boosting voltage, and boosting current, respectively. C_{dc} and v_{dc} are the dc link capacitance and voltage [14]. The non linear model of the two machine power system introduced in Fig.3 and is shown in following equations:

$$\begin{aligned} \dot{\delta}_i &= \omega_b(\omega_i - 1) \end{aligned} \quad (8)$$

$$\dot{\omega}_i = \left(\frac{P_{mi} - P_{ei} - D_i \Delta \omega_i}{M_i} \right) \quad (9)$$

$$\dot{E}'_{qi} = \left(\frac{E_{fdi} + (x_{di} - x'_{di})i_{di} - E'_{qi}}{T'_{doi}} \right) \quad (10)$$

$$\dot{E}_{fdi} = \left(\frac{-E_{fdi} + K_{ai}(v_{refi} - v_{ti} + U_{pssi})}{T_{ai}} \right) \quad (11)$$

$$\begin{aligned} T_{ei} &= E'_{qi}i_{qi} \\ &- (x_{qi} - x'_{di})i_{di}i_{qi} \end{aligned} \quad (12)$$

By applying linearization process around the operating point on under study system, state space model of system can be achieved.

4. LEAD-LAG DAMPING STABILIZER

The eigenvalues of the linear system that are called the system modes define the stability of the system when it is affected by a small disturbance. As long as all eigenvalues have negative real parts, the power system is stable when it is subjected to a small disturbance. If one of these modes has a positive real part, the system is unstable. In this case using conventional lead-lag controller, can move the unstable mode to the left-hand side of the complex plane in the area of the negative real parts. The lead-lag damping stabilizer has the following structure:

$$G = K_{PSS} \frac{sT_w}{1 + sT_w} \frac{1 + sT_1}{1 + sT_2} \frac{1 + sT_3}{1 + sT_4} \quad (13)$$

By properly choosing the lead-lag damping stabilizer gains (K_{PSS} , T_1 , T_2 , T_3 , T_4), the eigenvalues of system are moved to the left-hand side of the complex plane and the desired performance of the controller can be achieved. The damping controllers are designed to produce an electrical torque in phase with the speed deviation according to phase compensation method. SSSC's controllers (m , φ) are two parameters that can help them, reach the above goals mentioned. The structure of SSSC based lead-lag damping controller is shown in Fig. 3.

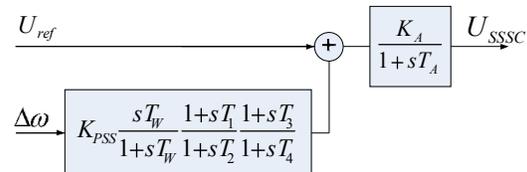


Fig.3 SSSC with lead-lag damping controller

Obtaining precise values of controller parameters (K_{PSS} , T_1 , T_2 , T_3 , T_4) for SSSC

controller based on the optimization algorithm is a problem of optimization. In this study for solving the optimization problem and reach the global optimal value of coefficients T_i , CHS algorithm is used. By applying an impulse disturbance on the power system, parameters, and indicators, it will change. One important parameter is the frequency that speed deviation in form Integral of Time Multiplied Absolute value of the Error (ITAE) as the objective function for the algorithm is selected. The objective function is defined as follows:

$$OF = \int_0^{t_{sim}} t|\omega_1 - \omega_2|dt \quad (14)$$

In the above equations, t_{sim} is the time range of simulation. The design problem can be formulated as the following constrained optimization problem, where the constraints are the controller parameter bounds:

$$K_{PSS}^{\min} \leq K_{PSS} \leq K_{PSS}^{\max} \quad (15)$$

$$T_1^{\min} \leq T_1 \leq T_1^{\max} \quad (16)$$

$$T_2^{\min} \leq T_2 \leq T_2^{\max} \quad (17)$$

$$T_3^{\min} \leq T_3 \leq T_3^{\max} \quad (18)$$

$$T_4^{\min} \leq T_4 \leq T_4^{\max} \quad (19)$$

In order to gain constrains, all oscillation of system under all operating conditions must be damped before machine inertia coefficient ($M_i=2H_i$). Criteria for this damping under condition of settling time with 5% of characteristic should be less than $2H_i$ value. Typical ranges of the optimized parameters are [0.01–100] for K_{PSS} and [0.01– 5] for T_i . It is necessary to note that the in optimizing values of the

controller parameters, algorithm must be repeated several times. Finally, values for lead-lag damping stabilizer gains are selected. Optimal values obtained for the controller parameters in normal load are shown in the Table.1.

Table.1. the optimal gain adjusting of the proposed controllers

controller	K_{PSS}	T_1	T_2	T_3	T_4
ϕ	98.17	0.492	0.259	0.945	0.742
m	83.53	0.098	0.312	0.705	0.687
PSS	99.22	4.01	0.895	0.051	0.901

In this work, in order to acquire better performance, the parameters of CHS algorithm are showed in Table 2.

Table.2. Values of CHS algorithm constant parameters.

parameters	Value
HMS	25
HMCR	0.92
PAR_{\min}	0.35
PAR_{\max}	0.65
bw_{\min}	1e-5
bw_{\max}	1
a	2.3
X_0	0.7

5. TIME DOMAIN SIMULATION

System performance with the values obtained for the optimal conventional lead-lag controller by applying a disturbance in the second generator at $t = 1$ for 6 cycles is evaluated. The speed and terminal voltage deviation of generators at normal load, light load and heavy load with the proposed controller based on the ϕ , m and PSS are shown in Fig (4 –5) respectively.

It is seen that the ϕ -based controller design to achieve good performance is robust, provides premier adjustment and greatly increase the dynamic stability of power systems.

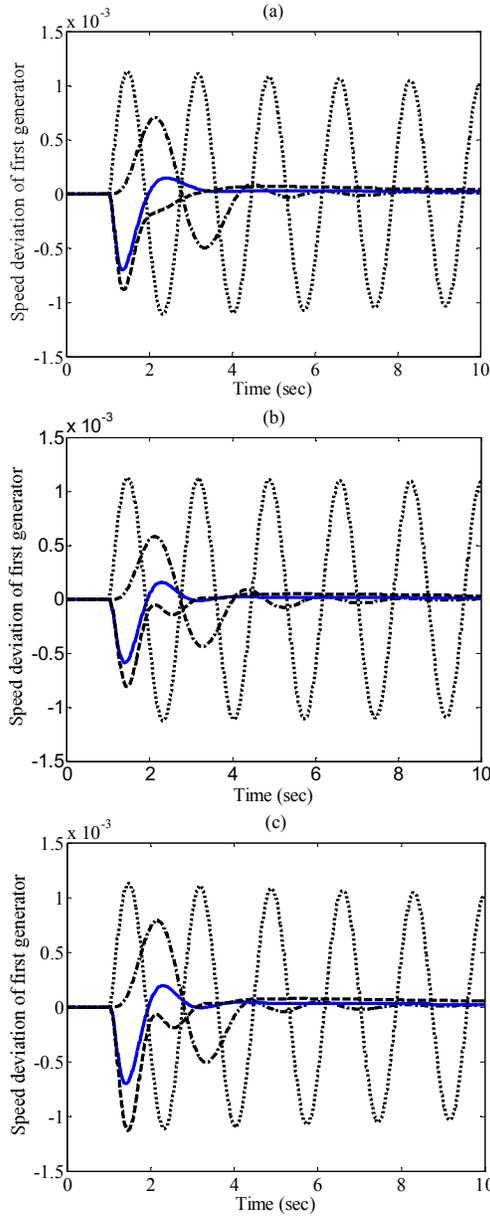


Fig.4. Dynamic responses for speed deviation of first generator with normal (a), heavy (b) and light load (c): solid (ϕ based controller), dotted (m based controller), dot-dashed (PSS controller), dashed (without controller)

To demonstrate performance robustness of the proposed method, from the performance index was used. In this work, an Integral of Time multiplied Absolute value of the Error (ITAE) is taken as the performance index that is defined as:

$$ITAE = 1000 \int_0^{10} t(|\Delta V_{t2}| + 3|\Delta\omega_2|)dt \quad (20)$$

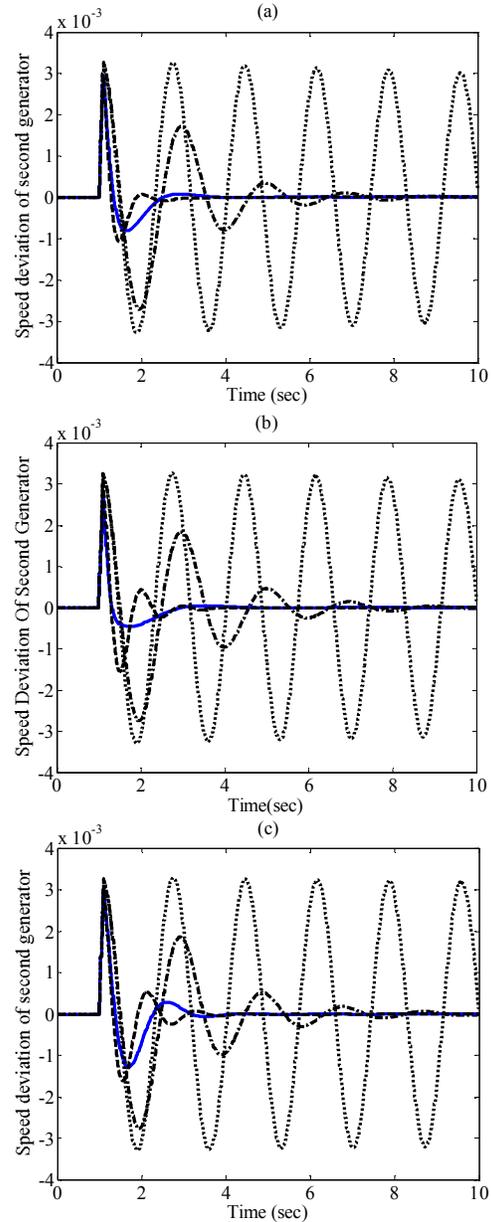


Fig.5. Dynamic responses for speed deviation of second generator with normal (a), heavy (b) and light load (c): solid (ϕ based controller), dotted (m based controller), dot-dashed (PSS controller), dashed (without controller)

Where $\Delta\omega_2$ and ΔV_{t2} are speed deviation and terminal voltage deviation of the second generator, respectively. From the

Table.3, it can be received that the φ based controller is superior to the both m and PSS based controller.

Table.3. Values of performance index ITAE Without controller

Controller	Heavy	Normal	Light
	$P_2 = 1.2$ pu $Q_2 = 0.352$ pu	$P_2 = 0.8$ pu $Q_2 = 0.149$ pu	$P_2 = 0.2$ pu $Q_2 = 0.009$ pu
PSS based controller	46.78	56.7	66.35
m based controller	13.24	18.39	21.75
φ based controller	7.212	8.876	11.83

Table.4. Eigenvalues of system in normal load φ based controller

$P = 0.8$ (pu)
$Q_2 = 0.149$ (pu)
-19.1341
-18.6636
$-0.0110 \pm 3.6796i$
-1.5116
-1.3829

Table.5. Eigenvalues of system in different operating conditions PSS based controller

Heavy	Normal	Light
$P_2 = 1.2$ pu $Q_2 = 0.352$ pu	$P_2 = 0.8$ pu $Q_2 = 0.149$ pu	$P_2 = 0.2$ pu $Q_2 = 0.009$ pu
-18.3512	-18.6639	-18.2041
-18.9767	-19.1879	-18.8747
$-4.3435 \pm 8.0762i$	$-3.9223 \pm 2.3453i$	$-4.3839 \pm 8.0619i$
-1.8169	-1.7481	-1.9641
-1.6141	-1.5134	-1.6949

5. CONCLUSIONS

The chaotic harmony search algorithm was successfully used for the modeling of SSSC based conventional lead-lag damping stabilizer. In fact the design of the problem and obtain controller coefficients is converted into an optimization problem

which is solved by a CHS algorithm with the time domain objective function. In this design for each of the control signals from available state variable $\Delta\omega_2$ is used. The efficiencies of the proposed SSSC controller for improving dynamic stability performance of a power system are illustrated by applying disturbances under different operating points. Results from time domain simulation shows that the oscillations of synchronous machines can be easily damped for power systems with the proposed method. To analyze performance of SSSC's controller one index was used. This index in term of ITAE is introduced that this index demonstrates that lead-lag with φ based damping controller is superior to both m and PSS based damping controllers.

Table 6. Eigenvalues of system in different operating conditions m based controller

Heavy	Normal	Light
$P_2 = 1.2$ pu $Q_2 = 0.352$ pu	$P_2 = 0.8$ pu $Q_2 = 0.149$ pu	$P_2 = 0.2$ pu $Q_2 = 0.009$ pu
-18.3586	-18.1809	-18.2101
-18.9902	-18.6729	-18.9034
$-1.0132 \pm 1.8934i$	$-0.8874 \pm 1.8089i$	$-1.0753 \pm 1.9249i$
-1.7604	-1.4375	-1.9187
-0.5781	-0.5581	-0.586

Table 7. Eigenvalues of system in different operating conditions

Heavy	Normal	Light
$P_2 = 1.2$ pu $Q_2 = 0.352$ pu	$P_2 = 0.8$ pu $Q_2 = 0.149$ pu	$P_2 = 0.2$ pu $Q_2 = 0.009$ pu
-18.6455	-18.5105	-18.2835
-18.4112	-18.5105	-18.6498
$-2.0520 \pm 6.3363i$	$-2.0425 \pm 6.3358i$	$-2.0671 \pm 6.3373i$
-1.8319	-1.9708	-1.5447
-1.6388	-1.7626	-1.3575

APPENDIX

Table.8. system parameters

First generator	$M = 6.4 MJ/MVA, T'_{do} = 6 s$ $X_d = 0.8958 pu, X_q = 0.8645 pu,$ $X'_d = 0.1198 pu$
Second generator	$M = 3.01 MJ/MVA, T'_{do} = 5.89 s$ $X_d = 1.3125 pu, X_q = 1.2578 pu,$ $X'_d = 0.1813 pu$
Excitation system	$K_{A1} = K_{A2} = 10, T_{A1} = T_{A1} = 0.05 s$
Transformers	$X_T = X_E = X_B = 0.1 pu$
Transmission line	$X_L = 0.5 pu$
Operating condition	$P = 0.8 pu, V_b = 1 pu$
DC link parameter	$V_{DC} = 2 pu, C_{DC} = 1 pu$
SSSC parameter	$\varphi = -78.21^\circ, T_s = 0.05$ $m = 0.08, K_s = 1$

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