Chaotic Sea-Horse Optimization Approach for TCSC Controller Design

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Abstract: - Using of Thyristor Controlled Series Capacitor (TCSC) as a Flexible AC Transmission System (FACTS) creates various interests for the customer of the network, and each adds to the growth of the power transmission potential of new and existing systems. These interests involve stability enhancement in the system, tunning of voltage, poise of imagine power, load sharing among shunt lines, and decrease in losses of the transmission system. This article introduces a new hybrid approach that evolved from integrating chaotic charts and the sea-horse optimizer. The suggested approach is known as the Chaotic Sea-Horse Optimizer (CSHO). The developed approach accounted for as metaheuristic technique, specifically the Sea-Horse Optimizer (SHO). The SHO is an approach that imitates the sea-horse life in the sea for shifting, seeking to breed and prey. This article illustrates that the CSHO technique is utilized to find TCSC constants in a multimachine network. The developed approach confirms the performance against various operating conditions.

Key-Words: - TCSC; Sea Horse Optimization Algorithm; Chaotic Maps; Cost Function; ITAE; Power System Stability.

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1 Introduction

TCSC is a significant component of FACTS which is adopted widely via new power network companies with extended transmission lines. It has multiple functions to control and operate power grids, including power flow scheduling; loss reduction; yielding voltage support; short circuit current limitation; damping sub-synchronous resonance (SSR); mitigating the power fluctuations; and improvement of transient constancy [1], and [2]. The implementations of TCSC for attenuation of power fluctuations and constancy strengthening is seen in [3] and [4].

In latest former years, distinct scholars have raised approaches for shaping TCSC to promote the attenuation of electromechanical power fluctuations in grids like artificial neural networks [5], [6], and [7], fuzzy methods [7], [8], [9], [10], [11], [12], [13], and [14], robust control [15], [16], [17], [18], and [19], linear quadratic gaussian [20], and [21], discrete control [22], phasor-based [23], frequency response [24], Pole placement [25], [26], [27], [28], and [29], nonlinear control [30], and [31], and hierarchical control [32].

The implementation of metaheuristic techniques in regulating the TCSC has provided promising characteristics. Distinct metaheuristic approaches have been implemented in TCSC recently, like genetic algorithm [33], [34], [35], [36] , [37], [38], and [39], particle swarm optimization [39], [40], [41], and [42], bacteria foraging [43], and [44], bacterial swarm optimization [45], gravitational search algorithm [46], virtual bees algorithm [47], group search optimization [48], and dwarf mongoose [49]. Even though distinct metaheuristic approaches have been approved to tune TCSC, there remains plenty of work for exploration to find the best TCSC parameters. Therefore, this paper illustrates a TCSC parameter adjustment technique with a novel metaheuristic approach called SHO which is enhanced by the presence of a chaotic approach [50], and [51]. This mongrel approach is known as the CSHO approach which is targeted to enhance the characteristics of the SHO approach at the equilibrium center among exploitation and exploration [52]. The developed technique is a combination of SHO and chaotic techniques. The addition of this paper can be reported briefly as follows:

1. A hybrid approach is introduced, namely CSHO that has a novel balance between the exploitation and exploration phases.
2. The developed CSHO is implemented to get the TCSC constants in a multimachine system.

This paper contains various partitions, particularly: partition 2 introduces the modeling of the power grid, and TCSC and describes the test system under study. Partition 3 explains the SHO approach and the CSHO. Partition 4 contains the objective function. The discussion of outcomes is given in part 5. The final section consists of the findings and future works.

2 Problem Formularization

2.1 Power System Pattern

The complicated nonlinear pattern coupled with m generators correlated power grid is constituted by the following group of differential nonlinear equalizations:

$$\dot{X} = f(X, U) \tag{1}$$

X is the state factors values, U is the entry factors values of. $X = [\delta, \omega, E'_q, E_{fd}, V_f]^T$, while U is the TCSC production signs in this research. ω and δ are the rotor speed and angle, consecutively.

V_f, E_{fd} and E'_q are excitation, field, and the inner potential consecutively.

The linearized gradual model about a certain condition is applied commonly to TCSC layout of. Consequently, the state framework including n TCSCs is created as:

$$\dot{X} = AX + BU \tag{2}$$

As $5m \times 5m$ matrix called A that similar to $\partial f / \partial X$, $5m \times n$ matrix called B that similar to $\partial f / \partial U$. All matrices are considered at an appointed working value. X vector of $5m \times 1$ state and U vector of $n \times 1$ inner values.

2.2 Controller TCSC Layout

A classic TCSC composes of a specific series capacitor shunted with a thyristor-dominated reactor (TCR). The TCR is created of a series reactor connected to a duplex directional thyristor exit that is triggered with an angle phase shift α from 90 to 180° regarding to capacitor potential. For power flow and steadiness examination work, a TCSC is shaped like a varying reactance. The TCSC reactance equalization is indicated as below:

$$\Delta \dot{X}_{TCSC} = \frac{1}{T_s}\left(K_s\left(\Delta X_{TCSC}^{ref} + \Delta U_{TCSC}\right) - \Delta X_{TCSC}\right) \tag{3}$$

X_{TCSC}^{ref} is TCSC fixed reactance; K_s and T_s are the TCSC gain and time constant.

Figure 1, shows the suggested TCSC regulator construction. Its variables are designed via different optimization approaches. Distinct suggested inner signs for FACTS to attenuate the swaying of the system. Signs that hold precious data around the mechanical mode are suggested as inner signs. The real power of the transmission line is considered a successful inner sign in [44] for TCSC controller layout. For this point, the real transmission line power is elected here as the inner sign. Moreover, pass 5-7 is treated as the finest position to locate the controller of TCSC in this article as shown in [44], and [45].

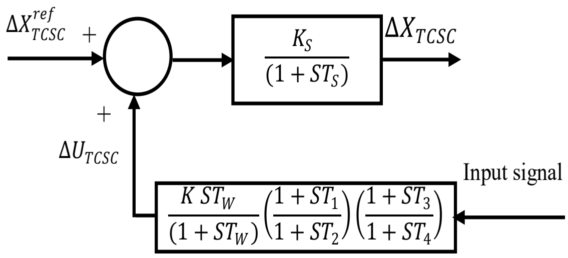

Fig. 1: Block diagram of TCSC

2.3 Investigated System

A test system of nine nodes and three generating units is described in Figure 2. The loading conditions and system data are seen in [2].

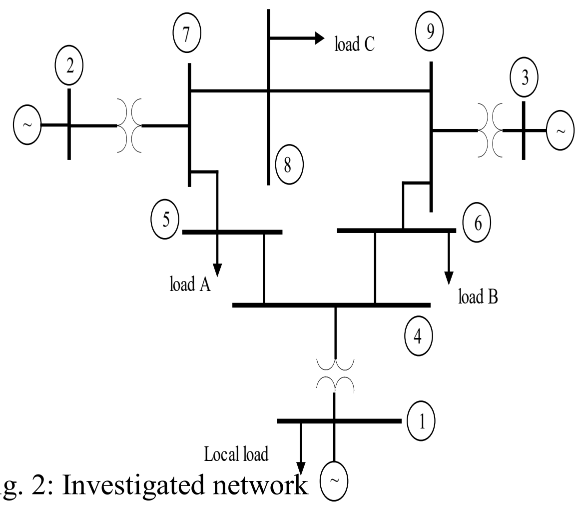

Fig. 2: Investigated network

3 SHO Approach

The SHO is motivated by the seahorse's survival in seeking for the chased victim and reproduction in their environment. The exploitation and exploration notion are set to recognize the deductive technique in the SHO approach to embrace the social attitude of shift and inspection for seahorse chased victims. The final phase of breeding is carried out when the two components have finished. The SHO approach is modeled as follows:

$$sh = \begin{bmatrix} x_{1,i} & \cdots & x_{1,Dim-1} & x_{1,Dim} \\ x_{2,i} & \cdots & \cdots & x_{2,Dim} \\ \vdots & \vdots & \vdots & \vdots \\ x_{N,i} & \cdots & x_{N,Dim-1} & x_{N,Dim} \end{bmatrix} \tag{4}$$

$$sh_{ij} = Rand \times \left(UB_j - LB_j\right) + LB_j \tag{5}$$

$$Sh_{elite} = \arg\min(f(X_i)) \tag{6}$$

where Dim is the variable size and N is the population dimension. The top and bottom limits are named UB and LB that are arbitrary outcomes at every result. Arbitrary rate between 0 and 1 is symbolized by $Rand$. Sh_{elite} is the individuals that possess the least scale of convenience. SHO assumes the motion shape and seeks to chase victim and mate of seahorse's life [50] and [51].

3.1 Seahorse Motion Behaviour

The regular tabulation turns of a reference accounts in the seahorse's motion paradigm. Exploitation and exploration equilibrium using duo studies having a border setting by 0, [50].

Case 1: the operator shifts toward the $Xelite$ in a heliacal motion altering the angle of rotation permanently to broaden the topical answer zone. Case 1 will be expressed as below:

$$X_n(t+1) = X_i(t) + Levy(\lambda)((X_{elite}(t) - X_i(t)) \times x \times y \times z + X_{elite}(t)) \tag{7}$$

$$\theta = rand \times 2\pi \tag{8}$$

$$x = \rho \times \cos(\theta) \tag{9}$$

$$y = \rho \times \sin(\theta) \tag{10}$$

$$z = \rho \times \theta \tag{11}$$

$$\rho = u \times e^{\theta v} \tag{12}$$

$$Levy(\lambda) = s \times \frac{w \times \sigma}{|K|^{\frac{1}{\lambda}}} \tag{13}$$

$$\sigma = \left(\frac{\Gamma(1+\lambda) \times \sin\left(\frac{\pi\lambda}{2}\right)}{\Gamma\left(\frac{1+\lambda}{2}\right) \times \lambda \times 2^{\left(\frac{\lambda-1}{2}\right)}} \right) \tag{14}$$

The rod length identified by the logarithmic helical regular. w and K are arbitrary values [0, 1]. s equals to 0.01, u and v (casual = 0.05 for both) are designated by $\rho.\lambda$ with a casual value [0, 2].

Case 2: In oceans, a seahorse executes a Brownian movement that simulates the movement stretch of another one aiming to obtain a superior navigate as following:

$$X_n(t+1) = X_i(t) + rand \times l\beta_i(X_i(t) - \beta_i X_{elite}(t)) \tag{15}$$

$$\beta_i = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right) \tag{16}$$

$$X_n(t+1) = \begin{cases} X_i(t) + Levy(\lambda)((X_{elite}(t) - X_i(t)) \times xyz + X_{elite}(t)) & if\ r_1 > 0 \\ X_i(t) + rand \times l\beta_i(X_i(t) - \beta_i X_{elite}(t)) & if\ r_1 \le 0 \end{cases} \tag{17}$$

where β_i is the arbitrary step value of the Brownian movement. A fixed amount l (casual = 0.5). r_1 appeared as an arbitrary amount, [50].

3.2 Foraging Attitude of Seahorse

While seahorses' food-searching ride two probable scenarios are found, failure or success. The status is successful if the value of $r_2 > 0.1$ as the seahorse proceeds quicker than the chased victim. Failure status places with varied behavior. The seahorse's failure or success status in food searching is formed as follows:

$$X_n(t+1) = \begin{cases} \alpha((X_{elite}(t) - rand \times X_{new}(t)) + (1-\alpha)X_{elite}(t)) & if\ r_2 > 0 \\ (1-\alpha)X_{new}(t) - rand \times X_{elite}(t)) + \alpha X_{new}(t)) & if\ r_2 \le 0 \end{cases} \tag{18}$$

$$\alpha = \left(1 - \frac{t}{T}\right)^{\frac{2t}{T}} \tag{19}$$

X_{new} is the seahorse's modern location. T is the superior iteration. r_2 is an arbitrary set [0 , 1][51].

3.3 Attitude of Seahorse Breeding

Seahorses are splitted into two sex types at the time of breeding, namely female and male with the same value of composition:

$$Father = X_{sort}\left(1 : \frac{pop}{2}\right) \tag{20}$$

$$MotherX_{sort}\left(\frac{pop}{2} + 1 : pop\right) \tag{21}$$

Sorted X_{sort} amounts deliver the outcome in arising arrangement. $Mother$ and $Father$ are selected by random. In the SHO approach, every pair results in one child.

$$X_i = (1 - r_3)X_{Mother} + r_3 X_{Father} \tag{22}$$

where r_3 is an arbitrary number [0, 1].

3.4 The Chaotic Sea-Horse Optimizer (CSHO)

Various papers have utilized distinct sorts of chaotic charts to help the aim of optimization algorithm. Chaotic charts are efficient in manner and statistics based on randomness [51] and [52]. Relish attitude is altered via parameter variations. As little variations in parameters make several results. In this paper, the logical chaotic representation is utilized to change the $rand$ at equalization (8). So, the logical chaotic representation mathematical equation is as following:

$$y\,log_{(i+1)} = a \times y\,log_i\left(1 - y\,log_{(i)}\right) \tag{23}$$

while a equal 4. The chaotic chart parameters have a domain of [0, 1]. Equalization (8) becomes equalization (24) as follows:

$$\theta = y\log_i \times 2\pi \tag{24}$$

4 Cost Function

A performance indicator can be determined by using the Integration of Time multiplied by the Absolute Error (ITAE) of the deviation in speed of every generating unit. The advantage of this selected performance indicator is that it requires lower dynamic information about the plant. Other indicators, such as the Integration of Square Error (ISE) and Integration of Time multiplied by Squared Error (ITSE), are less suitable due to squaring the error results in unrealistic assessments. Additionally, the Integration of Absolute Error (IAE) is less qualified compared to the ITAE which provides a more factual error evaluation [53], [54], and [55].

Consequently, the cost function J_T is written to be:

$$J_T = \int_0^{t_{sim}} t * \left\{\left|\Delta\omega_{12} + \Delta\omega_{23} + \Delta\omega_{13}\right|\right\} dt \tag{25}$$

Classic limits of the optimized factors are [1-100] for K and [0.06-1] for both T_{1i}, and T_{3i}. Optimization tasks depend on the cost function J_T can be written as: reduce J_T according to:

$$K_i^{min} \le K_i \le K_i^{max}$$
$$T_{1i}^{min} \le T_{1i} \le T_{1i}^{max}$$
$$T_{3i}^{min} \le T_{3i} \le T_{3i}^{max} \tag{26}$$

This research depends on the optimal tuning of TCSC utilizing the CSHO approach. The objective of the optimization is to lower the cost function to enhance the network execution in relation to overshoots and settling time for various working events and finally lay a low-order controller for successful application.

5 Results and Simulations

In this part, the supremacy of the developed CSHO approach in layout TCSC compared to optimized TCSC with SHO is introduced. Table 1 gives the system damping ratio, and eigenvalues of electromechanical modes with various loading events.

Table 1. Modes and ζ for various operating events and algorithms

	SHOTCSC	CSHOTCSC
Light load	$-3.97 \pm 9.26j, 0.39$ $-1.9 \pm 6.22j, 0.29$ $-0.71 \pm 0.66j, 0.73$	$-4.03 \pm 9.03j, 0.41$ $-2.01 \pm 6.18j, 0.31$ $-0.76 \pm 0.64j, 0.76$
Base case	$-3.23 \pm 11.2j, 0.28$ $-1.27 \pm 6.22j, 0.2$ $-0.73 \pm 0.72j, 0.71$	$-3.4 \pm 11.1j, 0.29$ $-1.4 \pm 6.18j, 0.22$ $-0.78 \pm 0.74j, 0.73$
Heavy load	$-3.66 \pm 11.71j, 0.3$ $-0.78 \pm 5.57j, 0.14$ $-0.94 \pm 0.78j, 0.77$	$-3.83 \pm 11.4j, 0.32$ $-0.81 \pm 5.33j, 0.15$ $-0.99 \pm 0.76j, 0.79$

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It is obvious that the damping ratios related to CSHOTCSC are more sizeable than those related to SHOTCSC. Thus, compared with SHOTCSC, CSHOTCSC greatly improves the system stability. Outcomes of TCSC constants corresponding to the developed cost function utilising SHO and CHSO are reported in Table 2.

Table 2. Controller Parameters for CSHO and SHO approaches

	CSHO	SHO
TCSC	K=7.5232	K=5.3625
	T_1=0.5684	T_1=0.6965
	T_3=0.2991	T_3=0.3878

5.1 Outcome for Base Loading

The efficacy of the controller for serious disturbance is verified by the implementation of a three-phase fault of six cycle duration at 1.0 seconds close to node 7. Figure 3 and Figure 4, give the outcome of $\Delta\omega_{12}$ and $\Delta\omega_{13}$ due to this fault under base loading event. It can be shown that the network with the developed CSHOTCSC is steadier than SHOTCSC. Additionally, the average needed settling time to alleviate the oscillations of the system is around 4 seconds with CSHOTCSC, and 4.6 seconds for SHOTCSC so the suggested TCSC is qualified for providing sufficient attenuation to the low fluctuations.

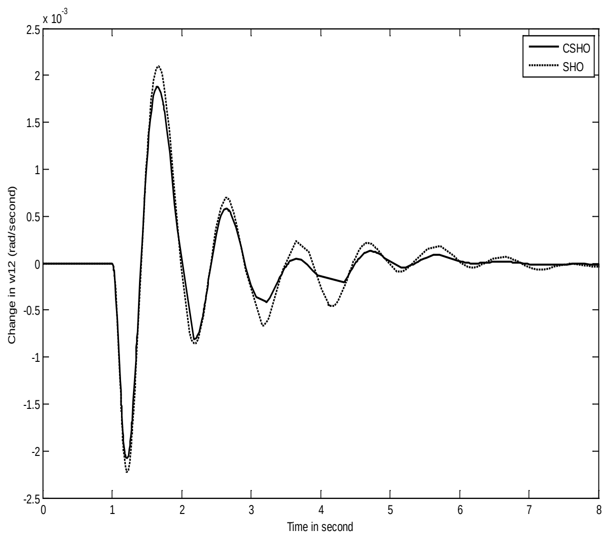

Fig. 3: Outcome of $\Delta\omega_{12}$ for base loading

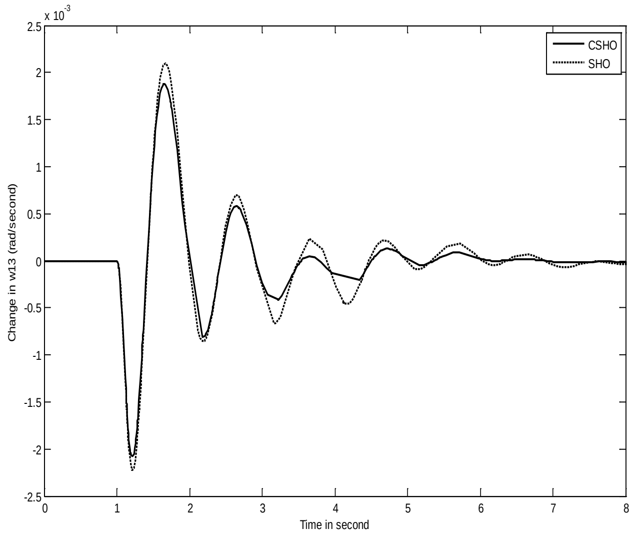

Fig. 4: Outcome of $\Delta\omega_{13}$ for base loading

5.2 Outcome of Light Loading

Figure 5 and Figure 6, give the network outcome for light loading events with the same TCSC factors. It is understandable from Figure 5 and Figure 6, that the developed CSHOTCSC has a good depressing attitude to oscillatory modes of the network and speedily equilibrates it. Moreover, the average stability time of oscillations is T_s =2.10, and 2.60 seconds for CSHOTCSC, and SHOTCSC, subsequently. Thus, the developed CSHOTCSC outlasts the SHOTCSC controller in alleviating fluctuations and diminishing stability time effectively. As a consequence, the developed CSHOTCSC extends the limit of network hardness.

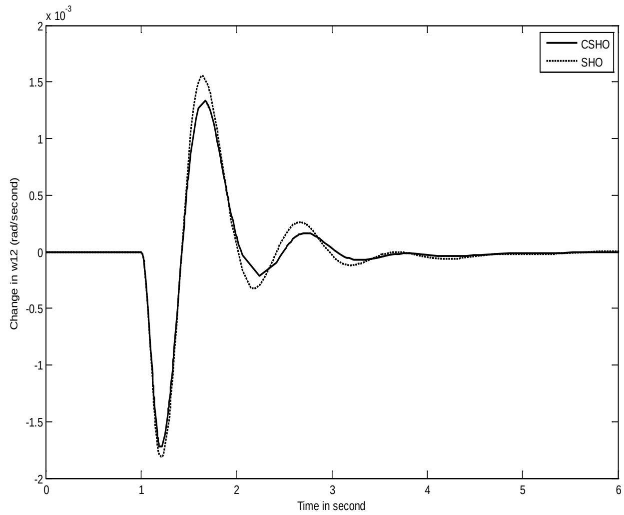

Fig. 5: Outcome of $\Delta\omega_{12}$ for light loading

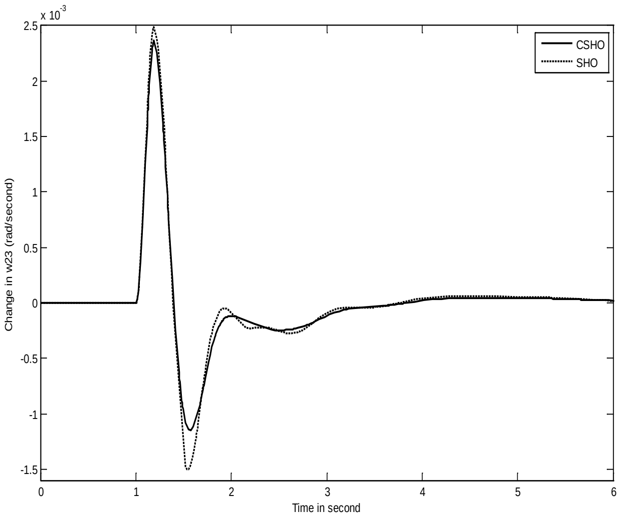

Fig. 6: Outcome of $\Delta\omega_{23}$ for light loading

5.3 Outcome of Heavy Loading

Figure 7 and Figure 8, present the network outcome for heavy loading event. These figures denote the notability of the CSHOTCSC in lessening the stability time and attenuating the oscillations of the test network. Also, the average stability time of these oscillations is T_s =5.10, and 6.0 seconds for CSHOTCSC, and SHOTCSC subsequently. Thus, the CSHOTCSC controller improves markedly the damping attitude of the test network. In addition, the stability time of the developed TCSC is lesser than that in [44].

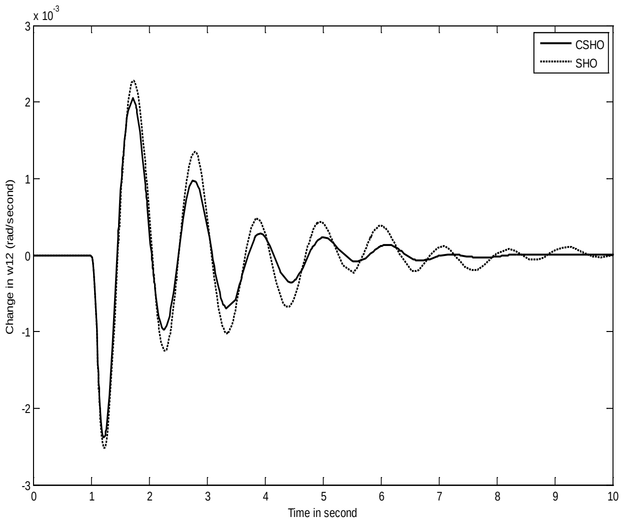

Fig. 7: Outcome of $\Delta\omega_{12}$ for heavy loading

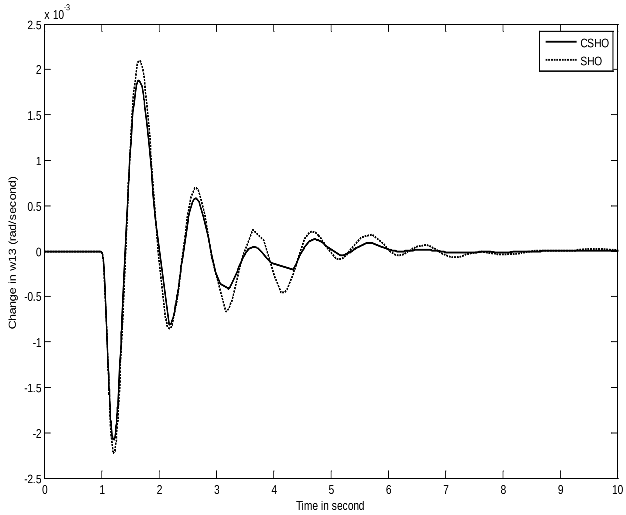

Fig. 8: Outcome of $\Delta\omega_{13}$ for heavy loading

6 Conclusions

A new optimization mechanism known as the CSHO approach, for the optimal layout of TCSC factors, is suggested in this article. The TCSC factors tuning process is organized as an optimization problem and the CSHO approach is exercised to find the best factors. The stability performance of the test system is reinforced to minimize the time-domain cost function. Simulation outcomes emphasize the supremacy of the suggested CSHOTCSC compared with SHOTCSC in granting a good damping attitude to system fluctuations through a broad scope of loading events. Employment of the discussed approach and the latest optimization approaches to more realistic networks and using various FACTs is the outlook domain of this research.

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