Improved Large Scale Power Systems Stabilizer Performance Using Multi-Verse Optimization

Dhanraj Chitara, Prateek K. Singhal, Sanjeev Kumar
Department of Electrical Engineering, Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, INDIA
Email: **dhanraj.chitara@skit.ac.in, prateek.singhal@skit.ac.in, sanjeev.85ee@gmail.com**
Received 24.04.2025 **received in revised form** 30.04.2025, **accepted** 02.05.2025
DOI: 10.47904/IJSKIT.15.1.2025.40-46

Abstract- This paper investigates the improvement of oscillatory stability in large scale power systems by optimizing Power System Stabilizer (PSS) parameters using the Multi-Verse Optimization (MVO) Algorithm. The PSS parameters are designed to utilize a multi-task eigenvalues function for concurrently manages the damping ratio & the real part of eigenvalues, aiming to shift unstable and/or weakly mechanical modes to a designated D-shape area within the s-plane. This algorithm is utilized on the IEEE-68, which consists of 16 machines and 68 buses. The effectiveness of MVO is evaluated through dynamic simulations, eigenvalue analysis, and performance error indicators across several operating scenarios under extreme conditions of critical turbulence, and compared to results derived from the Genetic Algorithm (GA). The solutions illustratie that the virtue of damping and overall dynamic stability of the suggested MVO-PSS is better than GA-PSS in alleviating low-frequency oscillations

Keywords– Low-frequency Oscillations, Multi-Verse Optimization, Genetic Algorithm, Power System Stabilizer.

1. INTRODUCTION

There are two main areas into which stability analysis falls: dynamic stability (resulting from minor disturbances) and transient stability (caused by major signal disturbances). In current times, the issue of rotor swings in large scale power grid presents a significant challenge to power grid experts, and the system is influenced by various contingencies [1]. Power System Stabilizers (PSSs) have been commonly recommended as standard damping controllers to damp out rotor swings in the variety of 0.2-3.0 Hz for many years. Such variations because significant in-phase and ultimately be the cause of failure of the power system. They are incorporated in the control loop of the alternator exciter so that the system will have adequate damping to both types of swing modes. In general, the Conventional PSSs (CPSS) are allocated to die out low frequency oscillation for selected range of operating conditions [2] [3]. A lot of researchers have been contributed in their efforts on design methods of PSS parameters. These methods include conventional control approach [4], digital control [5], modern control approach [6], etc. These approaches necessitate a linearized dynamic model of the power grid, either in transfer function or time-domain format, to adjust the PSS parameters. Nevertheless, it is noted that identifying the linearized mathematical model of extensive interconnected power systems is quite laborious and complicated. Furthermore, the characteristics of actual power systems change over time. Consequently, a static controller is the most practical and appropriate choice.

In order to overcome these disadvantages, numerous techniques including optimization methods that do not required a linearized model of power system, have been extensively used in current years. In the literature, AI approaches including Artificial Neural Networks [7], Fuzzy Logic [8], neuro-fuzzy methods, Genetic Algorithms (GA) [10]-[12], and other meta-heuristic optimization techniques simulated annealing [13], particle swarm optimization [14], tabu search [15], rule-based bacteria foraging [16], harmony search optimization [17], bat algorithms [18], cuckoo search optimization [19]-[22], bee colony optimization [23], ant colony optimization [24], and hybrid optimization methods [25] [26], have been studied to optimize the parameters of the PSS for the single-machine-infinite-bus, multiple-machine-infinite-bus, and the standard well-known IEEE 39-bus systems. In general, through single-objective eigenvalue functions (by changing damping factor or damping ratio) or multi-objective eigenvalue functions (by synchronizing damping ratio and damping factor adjusting), these optimization methods design PSS parameters covering great number of operating conditions under the significant disturbance of power systems.

In this study, the MVO approach is used to concurrently regulate the PSS parameters of the IEEE-68 system [27] [28] under an extensive variety of operating circumstances under critical perturbation scenarios.

A multi-objective eigenvalue-based function is used to regulate the damping ratio and damping factor (real-part of eigenvalue) simultaneously to achieve a definite D-shape section in the stable zone of the s-plane. In comparison to GA, this approach is more optimum and resilient for developing PSS. The advantage of MVO-PSS is demonstrated by analysing its performance using PSAT [29] with performance indices, eigenvalue analysis and time-domain simulations and comparing it to GA-PSS. The findings show that the developed MVO-PSS generated enhanced damping properties and improved small-signal stability across an extensive variety of system conditions.

2. MODELLING OF POWER GRID WITH PSS

A non-linear interconnected power grid can be represented as a collection of fourth-order differential equation that is not linear and it is represented with help of following equation:

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

where X denotes unknown state vector, consists of four variables: field voltage (E_{fd}), internal generator voltage (E_q), rotor speed (w), rotor angle (δ), and (U) represents input variables vector.

In addition, the grid is viewed as a linearized incremental model focused on a specific system condition and is frequently developed in the tuning of PSS [19].

A typical transfer function for PSS is expressed as:

$$\Delta U_j = K_j \left[\frac{sT_w}{1+sT_w}\right] \left[\frac{(1+sT_{1j})(1+sT_{3j})}{(1+sT_{2j})(1+sT_{4j})}\right] \Delta w_j \quad (2)$$

The main aim of PSS is to identify low-frequency oscillations by monitoring the speed variations of the jth machine (as input signal) and producing the output or additional signal (voltage ΔUi) to the excitation system [7]-[12].

The damping controller gain, washout time constant, and two-stage lag-lead compensator comprise PSS's fundamental transfer function. Choosing the right dynamic gain K_j and temporal constants T_w, T_{1j}, T_{2j}, T_{3j}, and T_{4j} is the primary design challenge for PSS. For sake of simplicity, the numerical values of T_w, T_{2j}, and T_{4j} are selected as stable constant value and other parameters K_j and T_{1j} and T_{3j}values are to be determined [16-19].

3. MULTI-VERSE OPTIMIZATION

The MVO is a population-based algorithm suggested by Mirjalili et al. [30], splits the mechanism of searching into two main steps are: exploring versus exploitation. This approach utilizes black and white holes instances to discover the search space via MVO. Alternatively, the wormhole will allow MVO to manipulate the search space. This algorithm believes that each strategy is linked to a world in the approach and each vector in the world, it is an element. In addition, everyone has been given the responsibility of tackling the inflation rate, which relates to the answers associated with the fitness function's values. In a general concept of cosmology in multi-verse concept will use term time over iteration in this approach.

The origin of the planet relies on the principle of big bang theory that explains that it is from enormous eruption. Permitting to this hypothesis, the big bang is the source of everything on this planet, and nothing existed prior to it. A multi verse theory is recently created and widely recognized among physicists. This hypothesis posits that multiple big bangs exist, with each big bang theory leading to the formation of new world. The word multi-verse is opposite the world that applies to the universe. In comparison to the universe, the presence of other universes that all live in the same house. Multiple worlds connect with each other and in multi-verse principle; they might also conflict with one another. It is also implied by the multi-verse hypothesis that there may be in any of the worlds, various physical laws for every universe [30].

The followed principles can be applied through optimization, for the MVO's universe:

- The larger the rate of inflation, the higher will be the risk of white hole to produce.
- The higher inflation rate will create the lower chances to obtaining the black hole.
- Universe with a larger rate of inflation will tend to give entities by white holes.
- More objects will be received by the black hole if the universe has lower inflation rate.

Object in the all universe will be spontaneously pushed through worm holes into the strongest universes independently of the rate of inflation.

It can be understood that the worm holes distort the objects randomly in universe without any concern of their rates of inflation. In sequence to allow for local modifications for each universe and with a strong probability of using worm hole to boost the inflation rate, finally it is concluded wormhole tunnels created between the earth and the universe and the strongest universe that has been found so far.

Implementation of MVO algorithm

1. Initialize the universe with the inflation rate in search region. (Each with desired parameters of PSS K_i, T_{1i} and T_{3i}).
2. Initialize Wep_{min} = 1 and Wep_{max} = 0.2 and for best universe U_{best} = Zeros and inflation rate IR_{best} = Inf.
3. Evaluate fitness for multi-objective eigenvalue based function $f(x) = j$ for every population.
4. The values of travelling distance rate and wormhole existence probability are calculated by equations mentioned in [30] and check the solutions are in the search space or not.
5. Select the population from better to worse dependent on the Area Control Error (ACE) value, i.e. inflation rate measured in step-1.
6. Observe the best elite solution from the population and evaluate the inflation rate.
7. Again modify the position of search agents.
8. For the newly created solutions, evaluate the inflation rate (ACE value) and rank the population from best to worst.
9. Either repeat step-5 till the termination condition is fulfilled and stores the best solution with superior fitness value.

4. CASE STUDY ANALYSIS ON THE EXTENDED POWER SYSTEM OF NEW ENGLAND

The outline of a renowned sixteen-machine, sixty-eight-bus (IEEE-68 system) is taken from [27] [28] and is considered for case study analysis in this work. All generator equations are defined as fourth-order models and are fitted with fast static excitation systems. Table 1 shows six functional settings of IEEE-68 for adjusting the parameters of the PSS.

Table 1: Various functional settings of IEEE-68

Cases	Functional Settings
OS-I	Fundamental Case
OS-II	Disruption of transmission line 1-2
OS-III	Disruption of transmission line 1-27
OS-IV	Disruption of transmission line 8-9
OS-V	Raise the load on bus-17 by 20%
OS-VI	Disruption of transmission line 46-49, raise the load on buses 20 & 21 by 25% and generation raise 20% at G_9

To enable concurrent regulation of damping ratio and damping factor which is real part of eigenvalues, the forty-two parameters of the PSS can be organized to reduce the subsequent multi-objective function [16]-[19] ensuring that eigenvalues of IEEE-68 system with the configured PSS are shifted to a D-shaped area within the stable region of the s-plane.

$$J = \sum_{i}^{n} \sum_{\sigma_{j,i} \geq \sigma_o} (\sigma_o - \sigma_{j,i})^2 + \sum_{i}^{n} \sum_{\zeta_{j,i} \leq \zeta_o} (\zeta_o - \zeta_{j,i})^2 \quad (3)$$

where np, $\xi_{j,i}$ and $\sigma_{j,i}$ are the total of functioning cases to be designated, the damping factor (the real-part of eigenvalues) and damping ratio of the jth eigenvalue mode of the ith functioning setting respectively.
Minimize J subject to:

$$K_j^{\min} \leq K_j \leq K_j^{\max} \quad (4)$$

$$T_{1j}^{\min} \leq T_{1j} \leq T_{1j}^{\max} \quad (5)$$

$$T_{3j}^{\min} \leq T_{3j} \leq T_{3j}^{\max} \quad (6)$$

The major aim of the optimization process is to identify the most advantageous arrangement of PSS parameters that minimizes time domain specifications (e.g., overshoot and settling time). Moreover, the targets are acquiring relatively good damping performance and enhanced small-signal stability performance for widespread selection of functioning setting under acute disturptions.

5. PSS DESIGN AND SIMULATIONS RESULTS

The eigenvalues of IEEE-68 system are computed using PSAT [29] for six functional settings in order to identify the optimal PSS parameter configuration. The eigenvalues with No-damping controller are evaluated only for unstable and/or weakly stable modes of the IEEE-68 system and are depicted in [31]. It is observed that the system displays unstable behavior for six functional settings, and three eigenvalue modes with negative damping ratios are located in the unstable region of the s-plane. Furthermore, the OS-6 is more unstable than other cases. In addition, the system consists of three inter-area modes and eleven local-area modes associated with mechanical aspects, such as rotor speed and rotor angles for six functional scenarios due to significant involvement in their corresponding modes. Consequently, fourteen units out of the sixteen units, excluding Unit-6 and Unit-14, are selected as ideal positions for placing PSSs.
In this case study, an objective function J described in (3) is reduced through GA and MVO by adjusting the fortytwo parameters of PSSs to achieve the target damping factor σ_0 = - 0.5 and desired damping ratio ξ_0 = 0.1 by moving solely the unstable modes and/or weakly damped modes to a definite D-shape area within the stable zone of the s-plane, ensuring stability and confirming relative stability accordingly. Hence, the optimized forty-two PSS parameters K_j, T_{1j} and T_{3j} (for j = 1, 2, ... 16 except 6 and 14) are set as [0-100], [0.01–1] and [0.01–1] respectively [16]-[19]. The time constant value of

washout is specified to 10 sec; T_2 and T_4 are set fixed values of 0.1 sec respectively. The optimized minimum value of J = 0 shows that all unstable and/or marginally stable modes are relocated to a particular *D*-shape region in the stable zone of the *s*-plane using GA and MVO techniques. Table 2 shows the best designed fortytwo parameters for fourteen generators with with MVO-PSS and GA-PSS, respectively, as reported in [31].

Table 2: Best planned parameters of MVO-PSS

Generators Units	With MVO-PSS		
	K_1	T_1 (in Sec.)	T_3 (in Sec.)
Unit-1	58.970	0.921	0.300
Unit-2	33.949	0.563	0.680
Unit-3	41.662	0.234	0.254
Unit-4	50.795	0.170	0.201
Unit-5	37.228	0.627	0.554
Unit-6	19.812	0.734	0.380
Unit-7	25.380	0.732	0.576
Unit-8	68.524	0.172	0.648
Unit-9	62.115	0.906	0.211
Unit-10	32.725	0.439	0.279
Unit-11	90.893	0.354	0.316
Unit-12	51.215	0.266	0.010
Unit-13	46.476	0.873	0.169
Unit-14	1.000	0.646	0.791

Table 3: Eigenvalue Analysis with MVO-based PSSs

Functional Settings	With MVO-PSS
1	$-0.990 \pm i\,7.047$, 13.9%
	$-0.688 \pm i\,3.752$, 18.0%
	$-0.509 \pm i\,3.065$, 15.7%
2	$-1.020 \pm i\,7.046$, 14.3%
	$-0.707 \pm i\,3.736$, 18.4%
	$-0.521 \pm i\,3.080$, 16.6%
3	$-0.997 \pm i\,7.042$, 14.0%
	$-0.691 \pm i\,3.743$, 18.1%
	$-0.526 \pm i\,3.073$, 16.8%
4	$-1.016 \pm i\,7.056$, 14.2%
	$-0.692 \pm i\,3.746$, 18.1%
	$-0.526 \pm i\,3.082$, 16.8%
5	$-0.991 \pm i\,7.047$, 13.9%
	$-0.688 \pm i\,3.753$, 18.0%
	$-0.501 \pm i\,3.070$, 15.7%
6	$-0.987 \pm i\,7.069$, 13.8%
	$-0.693 \pm i\,3.701$, 18.4%
	$-0.526 \pm i\,3.073$, 16.8%

The eigenvalue modes and their corresponding damping ratios for the designed MVO-PSS across six different functional scenarios are presented in Table 3 while for GA-PSS are illustrated in [31]. Table 3 demonstrates that damping ratio with eigenvalues of MVO-PSS is relocated significantly much further from the *D*-shape region in the stable zone of the *s*-plane as compared to GA-PSS [31]. Hence, MVO-PSS provides relatively good dynamic performance and attains improved damping characteristics. Due to the space limitations, the time-domain simulations of the IEEE-68 systesm are completed under severe schemes of various disturbances for six-operating cases and are shown in Table 4.

Table 4: Most severe schemes of disturbances

Schemes	Most Severe Schemes of Disturbances
Scheme-1	At t = 1 second, bus 29 experiences a three-phase, six-cycle short circuit failure without tripping of lines 26–29 of IEEE-68 system.
Scheme-2	At t = 1 second, bus 19 experiences a three-phase, six-cycle short circuit failure without tripping of lines 16–19 of IEEE-68 system.

The drastic speed variations of Δw_6 with GA-PSS and MVO-PSS in OS-6 for schemes 1 & 2 are illustrated in Figure 1 (c) and (d) respectively, while Δw_9 for that same case is presented in Figure 1 (e)-(f) correspondingly. The Figure 1 (a) and (b) depict that the speed responses of all units of IEEE-68 system with No-damping controller are not competent because with the raise of generation, load and tripping of line, all units experience oscillations that are oscillatory in character, grow in size and duration in the same direction, and eventually lose synchronism. Moreover, it also observed that Δw_9 and Δw_6 are most critical speed fluctuations than other generators. Furthermore, the Scheme-2 is most critical perturbation than others. From Figure 1 (c)-(d) and (e)-(f), it is noticed that the most critical speed responses Δw_9 and Δw_6 with MVO-PSSs are quickly damp out the mechanical mode oscillations as compared that of GA-PSS for both schemes of OS-6. This demonstrates the superiority and sufficient capability of the MVO method to achieve the preferred set of PSS parameters for the system in contrast to the GA technique.

As shown in Figure 2 (a)-(b) and Figure 2 (c)-(d) respectively, the performance error indicators IAE (Integral of Absolute Error) and ITAE (Integral of Time Multiplied Absolute Value of Error) are compared with the designed GA-PSS and MVO-PSS for schemes 1 & 2 across six operating cases of IEEE-68 system. The bar-graphs show that both indices with MVO-PSS are lowest for both schemes of six-operating cases as compared to the same obtained by GA-PSS. Hence, it may be concluded that the planned MVO-PSS grant better damping characteristics to die out oscillatory modes with minimum values of time-domain specifications, e.g. settling time and overshoot to that of GA-PSS.

6. CONCLUSIONS

This study examines PSS design employing MVO methods focused on the multi-objective eigenvalue function to increase the dynamic stability of a large-scale interconnected power grid. The effectiveness of the MVO techniques is evaluated using the IEEE-68 system over different operating cases under the critical schemes of disturbances. The suggested optimization approach involves the simultaneous regulation of the both damping factor & damping ratio by minimizing the optimize function to move the unstable and/or weakly mechanical modes into a specified *D*-shaped area within the stable region of the *s*-plane. The simulation results, damping mode analysis, and error indicators demonstrate the success of MVO-PSS, which is then compared to GA-PSS. The comparison illustrates that MVO-PSS outperforms GA-PSS in demonstrating strong damping capability to reduce low frequency oscillations during critical system perturbations.

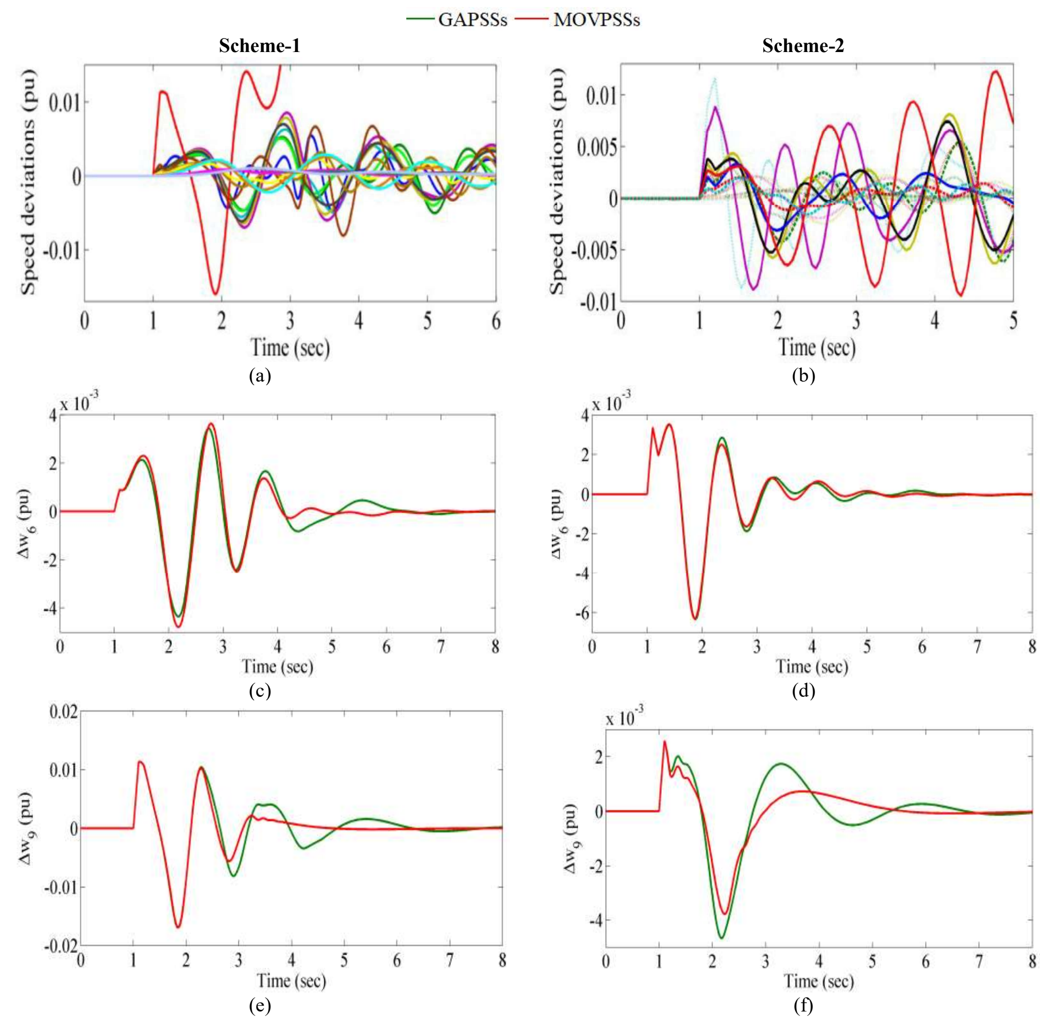

Figure 1: **S**peed fluctuations of Unit with (a)-(b) No-damping controller and (c)-(d) Δw_6 and (e)-(f) Δw_9 with GA-PSS and MVO-PSS for schemes 1 and 2 respectively

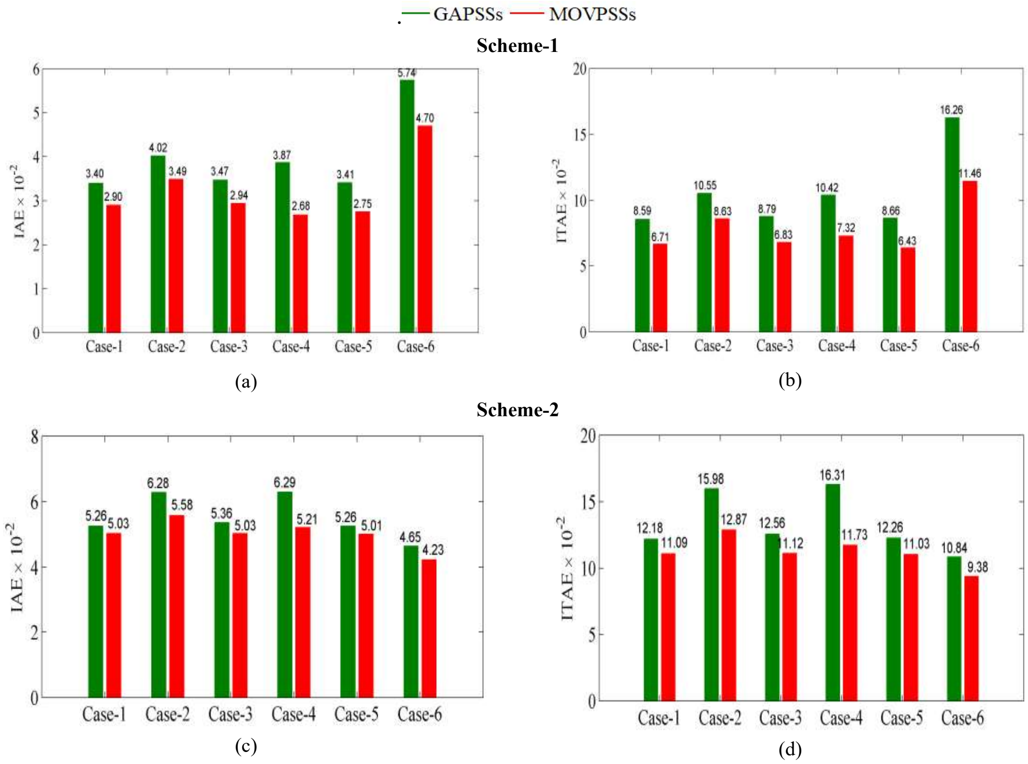

Figure 2: Assessment of Error Indicators with GA-PSS and MVO-PSS for (a)-(b) Schemes-1 (c)-(d) Schemes-2 of six-operating cases of IEEE-68 system

7. REFERENCES

[14] Prabha. Kundur, "Power system stability and control." Edited by Neal J. Balu, and Mark G. Lauby 4.2 (1994).

[15] Prabha Kundur, et al. "Definition and classification of power system stability IEEE/CIGRE joint task force on stability terms and definitions." IEEE transactions on Power Systems 19.3, pp. 1387-1401, (2004).

[16] Francisco P. Demello, and Charles Concordia. "Concepts of synchronous machine stability as affected by excitation control." IEEE Transactions on power apparatus and systems 88.4, pp. 316-329, (1969).

[17] K. Bollinger, et al. "Power stabilizer design using root locus methods." IEEE Transactions on power apparatus and systems 94.5, pp. 1484-1488, (1975).

[18] F. P. DeMello, et al. "A power system stabilizer design using digital control." IEEE Transactions on Power Apparatus and Systems 8, pp. 2860-2868, (1982).

[19] P. Shrikant Rao, and Indraneel Sen. "Robust pole placement stabilizer design using linear matrix inequalities." IEEE Transactions on Power Systems 15.1, pp. 313-319, (2000).

[20] Sukumar Kamalasadan, Gerald D. Swann, and Reza Yousefian. "A novel system-centric intelligent adaptive control architecture for power system stabilizer based on adaptive neural networks." IEEE Systems Journal 8.4, pp. 1074-1085, (2013).

[21] Z. Bouchama, et al. "Reaching phase free adaptive fuzzy synergetic power system stabilizer." International Journal of Electrical Power & Energy Systems 77, pp. 43-49, (2016).

[22] S. M. Radaideh, I. M. Nejdawi, and M. H. Mushtaha. "Design of power system stabilizers using two level fuzzy and adaptive neuro-fuzzy inference systems." International Journal of Electrical Power & Energy Systems 35.1, pp. 47-56, (2012).

[23] Y. L. Abdel-Magid, and M. M. Dawoud. "Tuning of power system stabilizers using genetic algorithms." Electric power systems research 39.2, pp. 137-143, (1996).

[24] Antonio LB Do Bomfim, Glauco N. Taranto, and Djalma M. Falcao. "Simultaneous tuning of power system damping controllers using genetic algorithms." IEEE Transactions on Power Systems 15.1 pp. 163-169, (2000).

[25] Hasan Alkhatib, and Jean Duveau. "Dynamic genetic algorithms for robust design of multi-machine power system stabilizers." International Journal of Electrical Power & Energy Systems 45.1, pp. 242-251, (2013).

[26] M. A. Abido, "Robust design of multi-machine power system stabilizers using simulated annealing." IEEE transactions on Energy conversion 15.3, pp. 297-304, (2000).

[27] M. A. Abido, "Optimal design of power-system stabilizers using particle swarm optimization." IEEE transactions on energy conversion 17.3, pp. 406-413, (2002).

[28] M. A. Abido, "A novel approach to conventional power system stabilizer design using tabu search." International Journal of Electrical Power & Energy Systems 21.6, pp. 443-454, (1999).

[29] S. Mishra, M. Tripathy, and J. Nanda. "Multi-machine power system stabilizer design by rule based bacteria foraging." Electric Power Systems Research 77.12, pp. 1595-1607, (2007).

[30] Kalifullah Abdul Hameed, and Sankaran Palani. "Robust design of power system stabilizer using harmony search algorithm." automatika 55.2, pp. 162-169, (2014).

[31] E. S. Ali, "Optimization of power system stabilizers using BAT search algorithm." International Journal of Electrical Power & Energy Systems 61, pp. 683-690, (2014).

[32] S. M. Abd Elazim, and E. S. Ali. "Optimal power system stabilizers design via cuckoo search algorithm."

International Journal of Electrical Power & Energy Systems75, pp. 99-107, (2016).

[33] Dhanraj Chitara, et al. "Optimal tuning of multi-machine power system stabilizer using cuckoo search algorithm." IFAC-Papers on Line 48.30, pp. 143-148, (2015).

[34] Dhanraj Chitara, et al. "Robust tuning of multi-machine power system Stabilizer via Cuckoo Search Optimization Algorithm." 2016 IEEE 6th International Conference on Power Systems (ICPS). IEEE,pp. 1-6, (2016).

[35] Dhanraj Chitara, et al. "Cuckoo search optimization algorithm for designing of a multi-machine power system stabilizer." IEEE Transactions on Industry Applications 54.4, pp. 3056-3065, (2018).

[36] Ī. Eke, M. C. Taplamacıoğlu, and Kwang Y. Lee. "Robust tuning of power system stabilizer by using orthogonal learning artificial bee colony." IFAC-Papers on Line 48.30, pp. 149-154, (2015).

[37] M. Mary Linda, and N. Kesavan Nair. "Optimal design of multi-machine power system stabilizer using robust ant colony optimization technique." Transactions of the Institute of Measurement and Control 34.7, pp. 829-840, (2012).

[38] Tridib Kumar Das, Ganesh Kumar Venayagamoorthy, and Usman O. Aliyu. "Bio-inspired algorithms for the design of multiple optimal power system stabilizers: SPPSO and BFA." IEEE Transactions on Industry Applications 44.5, pp. 1445-1457, (2008).

[39] S. M. Abd-Elazim, and E. S. Ali. "A hybrid particle swarm optimization and bacterial foraging for optimal power system stabilizers design." International Journal of Electrical Power & Energy Systems 46, pp. 334-341, (2013).

[40] M. A. Pai, Energy function analysis for power system stability. Springer Science & Business Media, (2012).

[41] Rogers, Graham. Power system oscillations. Springer Science & Business Media, (2012).

[42] F. Milano, "Power system analysis toolbox manual-documentation for PSAT version 2.1. 6." Univ Coll. Dublin Dublin Irel. Tech Rep (2010).

[43] Seyedali Mirjalili, Seyed Mohammad Mirjalili, and Abdolreza Hatamlou. "Multi-verse optimizer: a nature-inspired algorithm for global optimization." Neural Computing and Applications 27.2, pp. 495-513, (2016).

[44] Chitara, D., Singhal, P. K., Surana, S. L., Sharma, G., & Bansal, R. C. (2024). "Robust multi-machine power system stabilizer design using bio-inspired optimization techniques and their comparison". International Journal of Electrical Power & Energy Systems, 155, 109615, (2024).