Robust Design of PSS for Multimachine Networks using Jellyfish Search Algorithm

Md. Samiul Azam[1], Md. Rashidul Islam[2], Md Shafiullah[3], Mohammad Saiful Islam [4]
[1,2,4]International Islamic University Chittagong, Bangladesh
[3]King Fahd University of Petroleum & Minerals, Saudi Arabia
[1]samiulazam.eee@gmail.com, [2]rashidul05eee@yahoo.com, [3]shafiullah@kfupm.edu.sa, [4]saifulsairat@gmail.com

Abstract—**In interconnected power system networks, low-frequency oscillations (LFOs) have been a significant challenge for engineers for several years, which makes the system unstable by lowering the damping ratio. This article represents a method for designing robust power system stabilizers (PSS) that use the jellyfish search algorithm (JSA) based optimization approach for multimachine networks. The suggested method uses the JSA optimization technique to damp out LFOs by tuning the critical parameters of conventional lead-leg type power system stabilizers (CPSS). In this optimization problem, a damping ratio-based objective function is used to increase the system damping. This method is tested on two separate multimachine networks exposed to a three-phase fault, and compared with two well-known optimization algorithms called particle swarm optimization (PSO) and backtracking search algorithm (BSA). Results show that the JSA optimized technique provides better system damping than PSO and BSA-based techniques, indicating that the suggested technique is robust and reliable.**

I. INTRODUCTION

The interconnected power system is continuously increasing due to the increasing electric power demand in the current decades. In such systems, heavy power is transferred to the load, and the power system operates closer to the limits of transient and dynamic stability. This increased effort to transfer the electric power over massive geographical and electrical distances introduces low-frequency electromechanical oscillation (0.1-3Hz) in the system [1]. These LFOs can grow significantly with time if they are not damped out quickly, resulting in severe system outages [2], [3].

In the 1950s to 1960s, continuously acting automatic voltage regulators (AVR) had widely been used for voltage regulations in many power plants. Although it maintained a constant voltage level to the load, it could not make the “fine adjustments” required to control oscillation in the speed. As a result, the AVR could not dump the low-frequency oscillation for extended periods. Because of AVR’s limitation, the quantity of power transmitted on the system was limited. The Power System Stabilizer (PSS) was integrated into synchronous generators to allow fine-tuning power oscillations, also known as low-frequency oscillations. PSS is used with the excitation mechanism of the synchronous generator to provide an extra control signal to improve the system damping [3]–[6]. Integrating renewable energy sources into the power system can also introduce LFOs [7]. A modified AVR and PSS design are proposed in this article [8] to improve these types of systems’ damping.

Recently, several modern control theory-based PSS models have been designed, including intelligent control, variable structure control, optimal control, and adaptive control [9]–[11]. Regardless of modern control techniques, the conventional lead-leg PSS structure is still most popularly used by power system utilities due to its simplicity [12]–[14]. The parameters of a conventional PSS can significantly impact the power system’s dynamic stability [14]. PSS performance can be improved considerably by choosing the correct parameter values.

PSS can be built in a sequential manner using conventional techniques, with one electromechanical mode being considered at a time [15]. Nevertheless, the stabilizer for one electromechanical mood may cause instability in other moods. That is why sequential techniques are avoided [16]. A gradient-based design is proposed in this paper [17]. However, gradient techniques can become stuck in one of the local optimal, causing them to fail.

On the other hand, these conventional PSSs are designed using a linear model [18]. However, when a system undergoes significant disturbances, the nonlinear effects of the power system become prominent, and the operational point of the system shifts significantly in response. So the liner model can not maintain stability [18], [19]. Therefore, a nonlinear power system stabilizer design was proposed in [20] by Jiang. An excitation controller and nonlinear control for Power System Stabilizer were developed by Fusco et al. [21].

In the last two decades, metaheuristic optimization methods have gained immense popularity. Many algorithms based on these methods have been used extensively in multi-machine PSS design problems, such as the backtracking search algorithm (BSA) [22], particle swarm optimization (PSO) [23], whale optimization algorithm [24], genetic algorithms [25][26][27], cultural algorithms [28], artificial bee colony [29], simulated annealing [19], support vector regression [30], fuzzy gravitational search algorithm [31] and so on.

Artificial jellyfish search algorithm (JSA) [32] is a novel bio-inspired swarm-based metaheuristic optimization method inspired by jellyfish foraging in the sea, which was developed by Jui-Sheng Chou and Dinh-Nhat Truong. JSA has three valuable features: (1) It is simple to apply; (2) It is simple to code; and (3) It only has two internal parameters. The JSA method is validated using 25 large-size (CEC2005) and 50 small-size mathematical benchmarking functions of varying dimensions. The test results demonstrate that JSA can achieve the optimum value in fewer iterations than other optimization methods in its class. The JSA shows comparatively better results in mathematical benchmark testing than the GA, PSO, DE, ABC, GSA, FA, TLBO, SOS, TSA, and WOA algorithms [32].

This novel optimization technique is successfully implemented in different optimization problems such as distribution systems automation [33], optimal power flow [34], PEMFCs' model uncertain parameters [35], parameter estimation of single-phase transformer [36], and so on. But, JSA is not implemented yet to optimize the parameters of PSS in MMPS networks.

In this research, the challenge of developing a robust PSS for MMPS networks is presented as an optimization problem, and the optimal parameter values for PSS are obtained using the JSA technique. The suggested method is tested on two multimachine networks, and the performance of JSA-tuned PSS is compared to that of BSA- and PSO-tuned PSS.

II. Modeling of Power System

A. Synchronous Generator

A fourth-order equation model can represent the n number of synchronous generators in a power system network [3]–[5]. Where any i^{th} generator on that network can be expressed mathematically by these equations:

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

$$\dot{\omega}_l = \frac{1}{M}(P_{mi} - P_{ei} - P_{Di}) \tag{2}$$

$$\dot{e}_q = \frac{1}{T_{do}}[E_{fdi} - e_{qi} - (x_{di} - x'_{di})i_{di}] \tag{3}$$

$$\dot{E}_{f\,\mathrm{dl}} = \frac{1}{T_{Ei}}[K_{Ei}(v_{tri} - v_{ti} + u_{PSSi}) - E_{fdi} \tag{4}$$

The meaning of the symbols used in the given equations is mentioned in the Appendix section. These nonlinear differential equations from (1) to (4) can be linearized with some approximation [5].

B. Conventional PSS:

Fig. 1 illustrates the block diagram of a lead-leg CPSS. The changes in generator angular frequency ($\Delta\omega_i$) are given as input, and the output is taken as the changes in the generator's control signal (U_{pssi}).

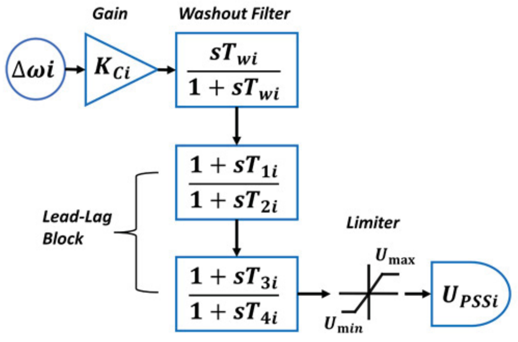

Fig. 1. Conventional lead-leg PSS structure

It consists of a gain or amplifier block (K_{Ci}) that is used to obtain the necessary positive damping. A washout/rest block having time a constant T_w is provided so that PSS remains deactivated when there are no network disturbances. Two lead-leg compensators are used for phase compensation. T_{1i}, T_{2i}, T_{3i} and T_{4i} are the time constants of two lead-leg phase compensators. The control signal's amplitude is limited by the limiter block. When LFO occurs, the phase lead of CPSS compensates for the overall lag of the excitation system.

III. Proposed Optimization Problem

The problem is to optimize the PSS parameters so that it can improve the system damping. The objective function (J) should be maximized:

$$J = \max\{\zeta_i ,\quad i = 1,2,3,\ldots,n\} \tag{5}$$

Here, ζ_i is i^{th} machines minimum damping ratio (MDR), and n is the number of machines.

Optimization parameters:

Maximization of J

$$K_{ci}^{min} \le K_{ci} \le K_{ci}^{max}$$

$$T_{1i}^{min} \le T_{1i} \le T_{1i}^{max}$$

$$T_{3i}^{min} \le T_{3i} \le T_{3i}^{max}$$

IV. Jellyfish Search Algorithm

Jellyfish's food searching behaviour is taken as inspiration for the JSA. It is a relatively new algorithm developed in 2021 by Dinh-Nhat Truong and Jui-Sheng Chou [32]. Fig. 2 shows the flowchart of JSA. Three strategies guide the implementation of the JSA:

- Depending on their "Time control mechanism," Jellyfish may migrate with the sea waves or within the swarm.
- Jellyfish search for areas with a greater supply of food than their present position.
- The position and its objective function affect the amount of food found.

A jellyfish bloom is created by the Jellyfishes' rapid active and passive motions inside the swarm, and Food availability differs in jellyfish-visited areas. Comparing food sizes may help to determine optimal places, i.e., the FF's best value.

The population is first initialized using the Logistic chaotic map described in Eq. (6) [37], and the ocean current is constructed using Eq. (7). As recommended in [32], the value of n is considered 4.0.

$$X_{i+1} = \eta X_i(1 - X_i), \quad 0 \le X_0 \le 1 \tag{6}$$

$$X_i(t+1) = X_i(t) + rand(0,1) \times (X^* - \beta \times rand(0,1) \times \mu) \tag{7}$$

The movements of Jellyfish in a swarm are governed by passive and active motions. Jellyfish move about their locations in passive motion and update their positions according to Eq. (8), and the active motion is defined using the formula shown in Eq. (9).

$$X_i(t+1) = X_i(t) + \gamma \times rand(0,1) \times (U_b - L_b) \quad (8)$$

$$X_i(t+1) = X_i(t) + rand(0,1) \times \overrightarrow{Direction} \quad (9)$$

For active motion, the direction of each Jellyfish is always towards the best foodstuff. The direction is represented by Eq. (10)

$$\overrightarrow{Direction} = \begin{cases} X_j(t) - X_i(t) \;\; if \;\; f(X_i) \geq f(X_j) \\ X_i(t) - X_j(t) \;\; if \;\; f(X_i) < f(X_j) \end{cases} \quad (10)$$

The transition between passive and active motion in ocean currents is governed by the time control variable C(t). It is given by Eq. (11):

$$c(t) = \left| (1 - \frac{t}{Max_{iter}}) \times (2 \times rand(0,1) - 1) \right| \quad (11)$$

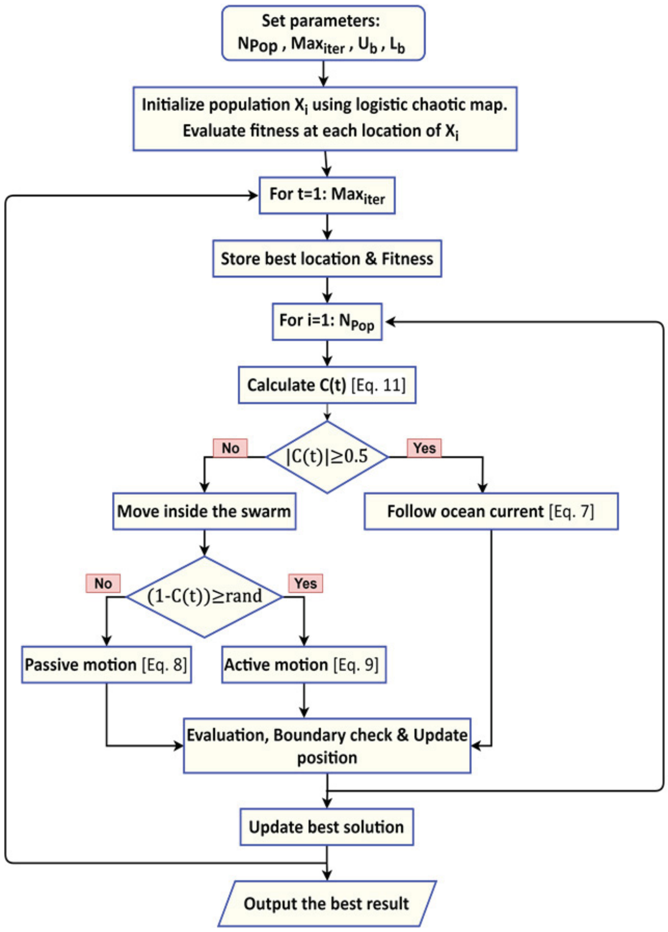

Fig. 2. Flow chart of JSA

V. Simulation Results and Discussion

A MATLAB-based simulation of the linear model of an IEEE-39 bus ten-machine system, and a two-area four-machine system are used to test the efficiency of the JSA in MMPS networks. The JSA optimized PSS simulation results are compared against other PSS based on PSO, BSA, and conventional/without PSS, where all the parameter values remain the same for all algorithms. For each generator, the problem dimension is 5, the size of the population is 100, and the maximum iteration is 1000. T_w is set to 10 seconds in the reset block. K_{ci}, T_{1i}, T_{3i} are optimized using JSA in this paper. K_{ci} limit is set as [0.0 to 50.0], and T_{1i}, T_{2i}, T_{3i} and T_{4i} limits are set as [0.01 to 1.00].

A. Network 1: Two-area four-machine network

The test network-1 is represented in Fig. 3. It is comprised of eleven buses and two areas, which are coupled via a weak link between buses 7 and 9. At buses 7 and 9, the system is subjected to two loads in total. As indicated in Fig. 3, two shunt capacitors are also connected to buses 7 and 9. Reference [3] provides more information about the network data. For a particular base case [3], the JSA technique is used to carry out the optimization process for three parameters K_{ci}, T_{1i} and T_{3i}. T_{2i} and T_{4i} values are set to 0.0500. This MMPS network is tested with different optimization techniques, and the damping ratios are given in [23]. The optimized parameter values are shown in Table-I. Fig. 4 illustrates the objective function variations regarding the iteration numbers for the JSA-tuned PSS. It provides a maximum value of 0.7376 within 1000 iterations, and reaches its optimal value around 600 iterations, indicating that the JSA-based technique has a faster convergence. The MDR for conventional, BSA, PSO, and JSA-tuned PSS are listed in Table II. It shows JSA-tuned PSS provides 4.7 times, 2.3 times and 1.5 times better damping ratio than conventional, PSO and BSA-tuned PSS respectively. Damping ratio analysis demonstrates the overall effectiveness of JSA in optimizing the parameters of PSS in two area four machine network. Bus 7 is subjected to a 3-ϕ fault for 0.1 second which begins at 0.5 second. The whole process is simulated for 5 seconds. Fig. 5 demonstrates angular frequency variations for four machines, where the oscillations are dampened using the conventional PSS. CPSS can not stabilize the system within the simulated time period. Fig. 6 shows the variations in G_3's rotor angle for the same fault using CPSS and JSA-based PSS. It shows JSA-based PSS can stabilize the rotor angle oscillation within 2.7 seconds, which is much faster than conventional PSS. The JSA technique has a substantially shorter settling time than conventional PSS.

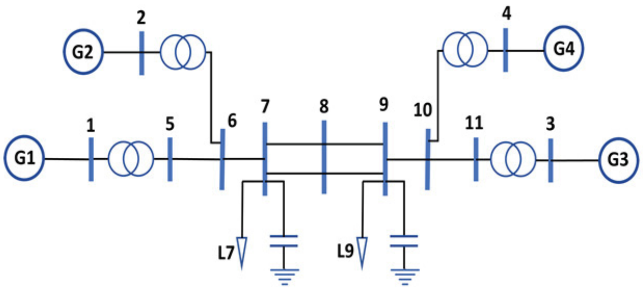

Fig. 3. Two areas four-machine network

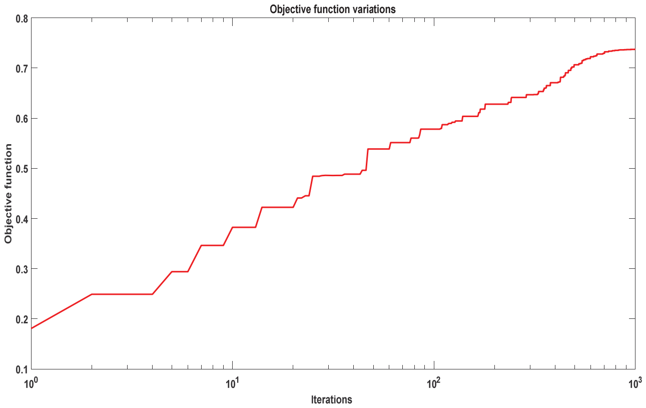

Fig. 4. Changes in the objective function for JSA-tuned PSS.

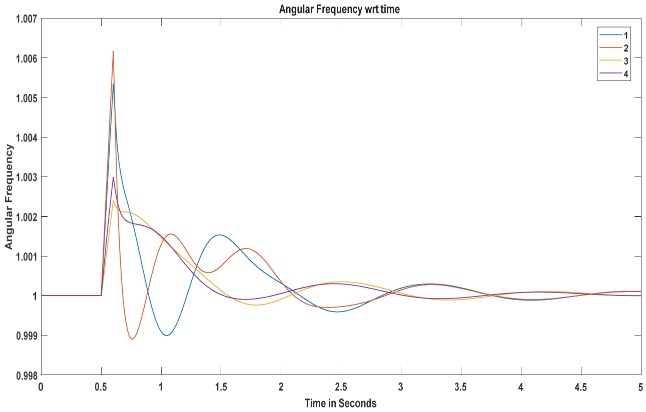

Fig. 5. Angular frequency of four generators.

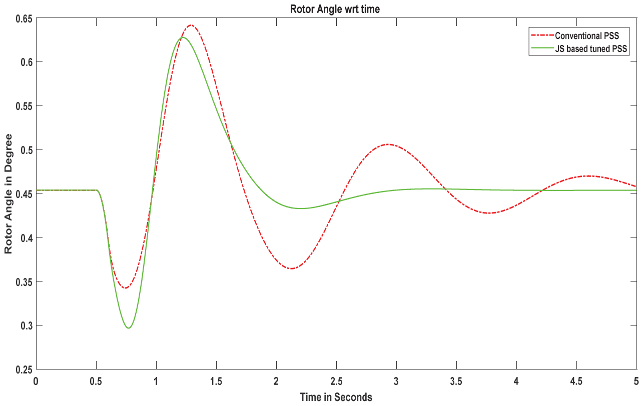

Fig. 6. Rotor angle of G_3.

TABLE I. JSA-TUNED PSS PARAMETERS FOR NETWORK-1

Gen No.	Parameters		
	Kc	T_1	T_3
G1	18.8305	0.0209	0.0250
G2	42.9914	0.0594	0.0796
G3	30.7775	0.0906	0.1241
G4	19.4093	0.0594	0.0860

TABLE II. MDR FOR DIFFERENT OPTIMIZATION TECHNIQUES FOR NETWORK-1

Conventional PSS	PSO-tuned PSS [23]	BSA-tuned PSS [22]	JSA-tuned PSS
0.1558	0.3220	0.5038	0.7376

Fig. 7 shows the control signal of G_3, where percent overshoot is smaller, and settling time is shorter for the control signal for JSA tuned PSS as compared to conventional PSS. Angular frequency of G_3 is illustrated in Fig. 8, which shows JSA-tuned PSS can damp out the oscillation within 3 seconds, but conventional PSS can not stabilize the signal within 5 seconds. Similar response can be observed for other generators. This indicates that the JSA-optimized technique performs better than the CPSS, PSO and BSA-based methods in two area four machine network.

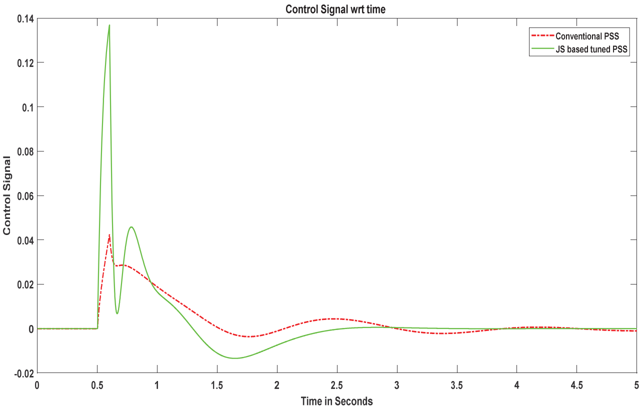

Fig. 7. Control signal of G_3.

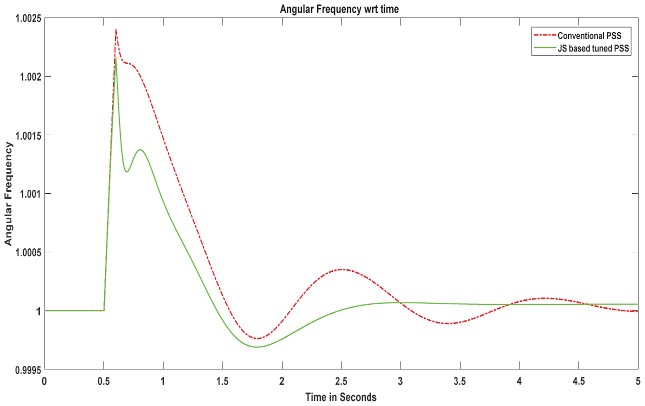

Fig. 8. Angular frequency of G_3.

B. Netwark 2: IEEE-39 Bus netwark

The IEEE-39 bus ten-machine MMPS network is used in this example, as shown in the single line diagram of test network-2 in Fig. 9. 12 tap-changing transformers, 19 loads, 10 generators, 39 buses and 36 transmission lines comprise the system. Generator-1 represents the collection of a number of different generators. Reference [4] contains a detailed description of the system data. For a particular base case [4], the JSA-based technique is used to tune the PSS parameters. Table III illustrates the minimum damping ratio for different methods used with the same configuration of the test network-2 [22]. For the same system configuration, the JSA-based technique provides 7.4 times and 6.3 times better minimum damping ratio compared to PSO and BSA-optimized techniques respectively, which is a significant improvement over two well-known optimization techniques. Table-IV summarizes the JSA-optimized parameters. The objective function variations of JSA-optimized PSS for the IEEE-39 bus system is shown in Fig. 10. It delivers a maximum value of 0.1949 within 1000 iterations, and reaches its optimal value around 700 iterations, which indicates the faster convergence capability of the JSA-based technique. Bus 29 is exposed to a three-phase fault that starts at 0.5 second, and lasts for 0.1 second. The fault is simulated for 5 seconds.

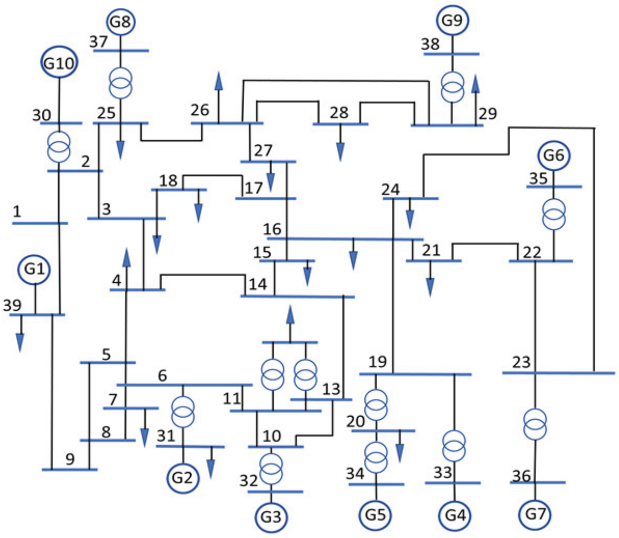

Fig. 9. IEEE 39-Bus Power System network.

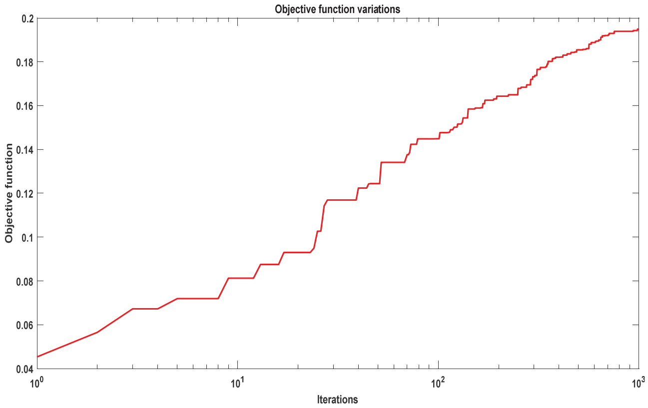

Fig. 10. Changes in the objective function for JSA-tuned PSS

The rotor angle response of G_5 with time is represented in Fig. 11. It indicates that JSA-tuned PSS stabilizes the signal in 4.5 seconds, whereas conventional PSS is unable to achieve stability over the simulated duration, and instead destabilizes the signal. The network exhibits stable behaviour with JSA-based tuned PSS. Fig. 12 illustrates the angular frequency for G_5 with respect to time. The network with CPSS has a varying angular frequency, and it can not stabilize the oscillation. However, the network with JSA-tuned PSS can stabilize the angular frequency within 2 seconds. The control signal's percent overshoot is smaller, and the settling time is faster. Besides, The JSA-based technique stabilizes the control signal in 4 seconds, whereas the CPSS technique destabilizes it. Similar responses can be seen in other generators. This indicates that the JSA-based PSS design is more compatible and robust.

TABLE III. MDR FOR DIFFERENT OPTIMIZATION TECHNIQUES FOR NETWORK-2

Conventional PSS	**PSO-tuned PSS** [22]	**BSA-tuned PSS** [22]	**JSA-tuned PSS**
-0.0334	0.0264	0.0312	0.1949

TABLE IV. JSA-TUNED PSS PARAMETERS FOR NETWORK-2

Gen No.	**Parameters**		
	K_c	T_1	T_3
G_1	0	0	0
G_2	36.2517	0.6845	0.7004
G_3	42.9155	0.6991	0.5929
G_4	44.9636	0.6921	0.9241
G_5	17.5877	0.2540	0.4606
G_6	37.1972	0.7953	0.7464
G_7	14.9012	0.2394	0.1075
G_8	33.1334	0.9423	0.9506
G_9	25.3069	0.5592	0.1156
G_{10}	49.3066	0.9866	0.9524

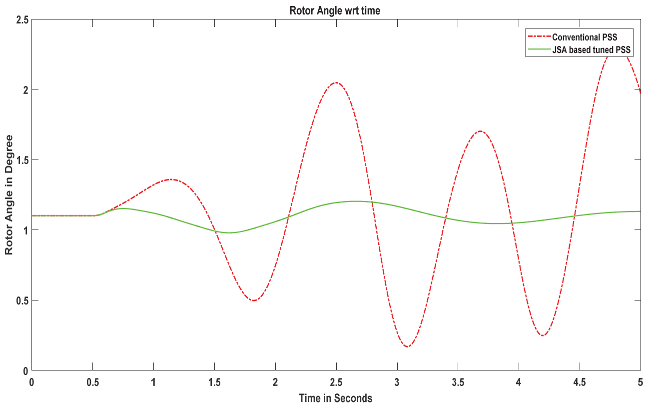

Fig. 11. Rotor angle of G_5.

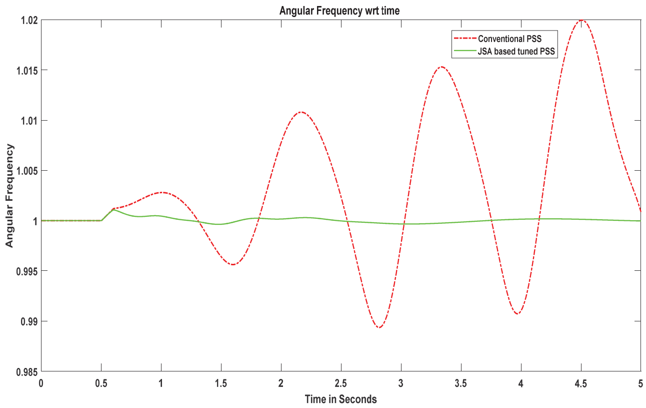

Fig. 12. Angular frequency of G_5.

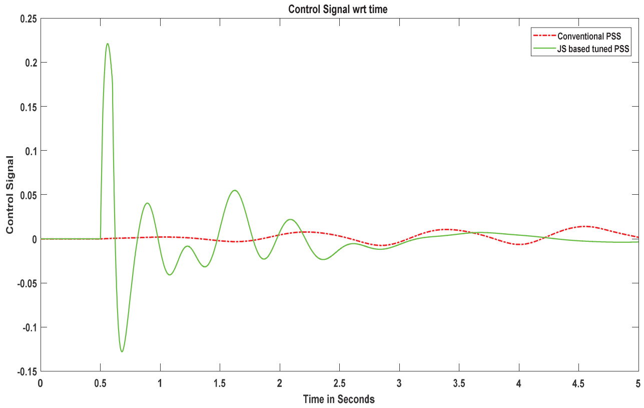

Fig. 13. Control signal of G_5.

VI. CONCLUSION

Various types of disturbances constantly impair the stability of electric power systems by creating LFOs. PSSs are integrated with synchronous generators to enhance the stability of the system. This paper proposes a new PSS design method for the multimachine power system (MMPS) network based on a new optimization algorithm called the artificial jellyfish search algorithm (JSA). The suggested method is tested on two multimachine power systems models with different system configurations. In both cases, the technique's robustness is demonstrated by its convergence independent of the initial guess. Time-domain simulations of angular frequency, rotor angle, and control signal show that JSA-tuned PSS can stabilize the system much faster than conventional PSS. Furthermore, for the identical system design, the damping ratio study of two MMPS networks shows that the JSA-based method provides better damping ratio than the PSO and BSA-optimized techniques. Also, the JSA-based approach requires fewer iterations to achieve convergence. After introducing 3-ϕ faults, the suggested PSS design significantly improves system stability, as shown by time-domain simulations. However, this system can be enhanced in the future by integrating FACTS devices with PSS. Renewable energy sources may also be included in the test network, owing to their widespread use in today's world.

APPENDIX

NOMENCLATURE

T_1, T_2, T_3, T_4 = Time constants for CPSS

K_C = Gain of the CPSS; ∇E_{fd} = Field excitation

$K_1 - K_6$ = Fourth order model constants

T'_{do} = Time constant of the open circuit field

K_E = Excitation system gain

T_E = Excitation system time constant

T_w = Washout block time constant

v_{tr}, v_t = Reference and terminal voltages

v_q, v_d = Voltages of the quadrature and direct axes

i_q, i_d = Currents of the quadrature and direct axes

x'_q, x'_d = Transient reactance of the quadrature and direct axes

x_q, x_d = Reactance of the quadrature and direct axes

ω_0 = Base angular frequency; M = System inertia coefficient

P_D = Damping Coefficient; u_{PSS} = Control input

P_e, P_m = Output electrical power and input mechanical power

e'_q = Internal voltage of the generator

δ, ω = Rotor angle, Angular frequency

REFERENCES

[1] T. Guesmi, A. Farah, H. H. Abdallah, and A. Ouali, "Robust design of multimachine power system stabilizers based on improved non-dominated sorting genetic algorithms," *Electr. Eng.*, vol. 100, no. 3, pp. 1351–1363, 2018, doi: 10.1007/s00202-017-0589-0.

[2] B. Pal and B. Chaudhuri, *Robust control in power systems*. Springer Science & Business Media, 2006.

[3] P. Kundur, *Power System Stability and Control*. Toronto, Ontario: McGraw-Hill, Inc., 1994.

[4] P.W. Sauer and M.A. Pai, *Power system dynamics and stability*. New Jersey: Prentice Hall, 2006.

[5] Y. Yu, *Electric Power System Dynamics*. New York: Academic Press, 1983.

[6] S. Q. Yuan and D. Z. Fang, "Robust PSS parameters design using a trajectory sensitivity approach," *IEEE Trans. Power Syst.*, vol. 24, no. 2, pp. 1011–1018, 2009, doi: 10.1109/TPWRS.2008.2012192.

[7] S. D. Ahmed, F. S. M. Al-Ismail, M. Shafiullah, F. A. Al-Sulaiman, and I. M. El-Amin, "Grid integration challenges of wind energy: A review," *IEEE Access*, vol. 8, pp. 10857–10878, 2020.

[8] P. Sivakumar and C. Birindha, "Stability enhancement of DG sourced power system with modified AVR and PSS," in *Proceedings of International Conference on Computation of Power, Energy, Information and Communication, ICCPEIC 2013*, 2013, pp. 105–109, doi: 10.1109/ICCPEIC.2013.6778508.

[9] D. Xia and G. T. Heydt, "Self-tuning controller for generator excitation control," *IEEE Trans. Power Appar. Syst.*, vol. PAS-102, no. 6, pp. 1877–1885, 1983, doi: 10.1109/TPAS.1983.317797.

[10] Y. Cao, L. Jiang, S. Cheng, O. P. Malik, and G. S. Hope, "A nonlinear variable structure stabilizer for power system stability," *IEEE Trans. Energy Convers.*, vol. 9, no. 3, pp. 489–495, 1994, doi: 10.1109/60.326467.

[11] M. A. Abido and Y. L. Abdel-Magid, "A hybrid neuro-fuzzy power system stabilizer for multimachine power systems," *IEEE Trans. Power Syst.*, vol. 13, no. 4, pp. 1323–1330, 1998, doi: 10.1109/59.736272.

[12] E. V. Larsen and D. A. Swann, "Applying power system stabilizers," *IEEE Trans. Power Appar. Syst.*, vol. PAS-100, no. 6, pp. 3017–3046, 1981.

[13] C. T. Tse and S. K. Tso, "Refinement of conventional pss design in multimachine system by modal analysis," *IEEE Trans. Power Syst.*, vol. 8, no. 2, pp. 598–605, 1993, doi: 10.1109/59.260822.

[14] P. Kundur, M. Klein, G. J. Rogers, and M. S. Zywno, "Application of power system stabilizers for enhancement of overall system stability," *IEEE Trans. Power Syst.*, vol. 4, no. 2, pp. 614–626, 1989, doi: 10.1109/59.193836.

[15] R. J. Fleming, M. A. Mohan, and K. Parvatisam, "Selection of parameters of stabilizers in multimachine power systems," *IEEE Trans. Power Appar. Syst.*, vol. PAS-100, no. 5, pp. 2329–2333, 1981, doi: 10.1109/TPAS.1981.316752.

[16] C. L. Chen and Y. Y. Hsu, "Coordinated Synthesis of Multimachine Power System Stabilizer Using an Efficient Decentralized Modal Control (DMC) Algorithm," *IEEE Trans. Power Syst.*, vol. 2, no. 3, pp. 543–550, 1987, doi: 10.1109/TPWRS.1987.4335165.

[17] V. A. Maslennikov and S. M. Ustinov, "The optimization method for coordinated tuning of power system regulators," in *Proc 12th Power Syst. Computer Conference, PSCC*, 1996, pp. 70–75.

[18] A. Kazemi, M. R. J. Motlagh, and A. H. Naghshbandy, "Application of a new multi-variable feedback linearization method for improvement of power systems transient stability," *Int. J. Electr. Power Energy Syst.*, vol. 29, no. 4, pp. 322–328, May 2007, doi: 10.1016/J.IJEPES.2006.07.011.

[19] M. A. Abido, "Robust design of multimachine power system stabilizers using simulated annealing," *IEEE Trans. Energy Convers.*, vol. 15, no. 3, pp. 297–304, Sep. 2000, doi: 10.1109/60.875496.

[20] Z. Jiang, "Design of a nonlinear power system stabilizer using synergetic control theory," *Electr. Power Syst. Res.*, vol. 79, no. 6, pp. 855–862, Jun. 2009, doi: 10.1016/J.EPSR.2008.11.006.

[21] G. Fusco and M. Russo, "Nonlinear control design for excitation controller and power system stabilizer," *Control Eng. Pract.*, vol. 19, no. 3, pp. 243–251, Mar. 2011, doi: 10.1016/J.CONENGPRAC.2010.11.001.

[22] M. Shafiullah, M. A. Abido, and L. S. Coelho, "Design of robust PSS in multimachine power systems using backtracking search algorithm," *2015 18th Int. Conf. Intell. Syst. Appl. to Power Syst. ISAP 2015*, 2015, doi: 10.1109/ISAP.2015.7325528.

[23] C. Ussawapusitgul and S. Kaitwanidvilai, "Automatic design of robust PSS for multimachine power system using PSO," *IEEE Reg. 10 Annu. Int. Conf. Proceedings/TENCON*, pp. 1065–1069, 2011, doi: 10.1109/TENCON.2011.6129274.

[24] B. Dasu, M. Sivakumar, and R. Srinivasarao, "Interconnected multi-machine power system stabilizer design using whale optimization algorithm," *Prot. Control Mod. Power Syst. 2019 41*, vol. 4, no. 1, pp. 1–11, Feb. 2019, doi: 10.1186/S41601-019-0116-6.

[25] H. Alkhatib and J. Duveau, "Dynamic genetic algorithms for robust design of multimachine power system stabilizers," *Int. J. Electr. Power Energy Syst.*, vol. 45, no. 1, pp. 242–251, Feb. 2013, doi: 10.1016/J.IJEPES.2012.08.080.

[26] M. Shafiullah, M. J. Rana, M. S. Alam, and M. A. Abido, "Online tuning of power system stabilizer employing genetic programming for stability enhancement," *J. Electr. Syst. Inf. Technol.*, vol. 5, no. 3, pp. 287–299, 2018.

[27] M. Shafiullah, M. J. Rana, M. S. Shahriar, and M. H. Zahir, "Low-frequency oscillation damping in the electric network through the optimal design of UPFC coordinated PSS employing MGGP," *Measurement*, vol. 138, pp. 118–131, 2019.

[28] A. Khodabakhshian and R. Hemmati, "Multi-machine power system stabilizer design by using cultural algorithms," *Int. J. Electr. Power Energy Syst.*, vol. 44, no. 1, pp. 571–580, Jan. 2013, doi: 10.1016/J.IJEPES.2012.07.049.

[29] G. Naresh, M. Ramalinga Raju, and M. Sai Krishna, "Design and parameters optimization of multi-machine power system stabilizers using artificial bee colony algorithm," *2012 Int. Conf. Adv. Power Convers. Energy Technol. APCET 2012*, 2012, doi: 10.1109/APCET.2012.6302066.

[30] M. S. Shahriar, M. Shafiullah, and M. J. Rana, "Stability enhancement of PSS-UPFC installed power system by support vector regression," *Electr. Eng.*, vol. 100, no. 3, pp. 1601–1612, 2018.

[31] A. Ghasemi, H. Shayeghi, and H. Alkhatib, "Robust design of multimachine power system stabilizers using fuzzy gravitational search algorithm," *Int. J. Electr. Power Energy Syst.*, vol. 51, pp. 190–200, Oct. 2013, doi: 10.1016/J.IJEPES.2013.02.022.

[32] J. S. Chou and D. N. Truong, "A novel metaheuristic optimizer inspired by behavior of jellyfish in ocean," *Appl. Math. Comput.*, vol. 389, p. 125535, 2021, doi: 10.1016/j.amc.2020.125535.

[33] A. M. Shaheen, A. M. Elsayed, A. R. Ginidi, E. E. Elattar, and R. A. El-Sehiemy, "Effective Automation of Distribution Systems With Joint Integration of DGs/ SVCs Considering Reconfiguration Capability by Jellyfish Search Algorithm," *IEEE Access*, vol. 9, pp. 92053–92069, 2021, doi: 10.1109/ACCESS.2021.3092337.

[34] M. Farhat, S. Kamel, A. M. Atallah, and B. Khan, "Optimal Power Flow Solution Based on Jellyfish Search Optimization Considering Uncertainty of Renewable Energy Sources," *IEEE Access*, vol. 9, pp. 100911–100933, 2021, doi: 10.1109/ACCESS.2021.3097006.

[35] [35] E. A. Gouda, M. F. Kotb, and A. A. El-Fergany, "Jellyfish search algorithm for extracting unknown parameters of PEM fuel cell models: Steady-state performance and analysis," *Energy*, vol. 221, p. 119836, Apr. 2021, doi: 10.1016/J.ENERGY.2021.119836.

[36] H. Youssef, M. H. Hassan, S. Kamel, and S. K. Elsayed, "Parameter Estimation of Single Phase Transformer Using Jellyfish Search Optimizer Algorithm," *2021 IEEE Int. Conf. Autom. Congr. Chil. Assoc. Autom. Control*, pp. 1–4, Mar. 2021, doi: 10.1109/ICAACCA51523.2021.9465279.

[37] Z. Sun, N. Wang, Y. Bi, and D. Srinivasan, "Parameter identification of PEMFC model based on hybrid adaptive differential evolution algorithm," *Energy*, vol. 90, pp. 1334–1341, Oct. 2015, doi: 10.1016/J.ENERGY.2015.06.081.