PSSs Layout using Dandelion Optimization Approach

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Abstract: - This paper develops an optimal Power System Stabilizers (PSSs) design employing the Dandelion Optimization Algorithm (DOA) implemented in a multimachine system. The synthesizing of PSS parameters is shaped as DOA-addressed optimization matter. An objective equation invoked by eigenvalue, incorporating lightly damped electromechanical modes, damping ratio, and factor, is utilized for the PSS layout. The functioning of the suggested DOA-based PSSs (DOAPSS) is evaluated against Differential Evolution-based PSSs (DEPSS) under various running requirements and disturbances. The supremacy of the DOAPSS is validated across time-domain analysis, eigenvalues, and functioning indices, demonstrating its superiority over the DE approach.

Key-Words: - Dandelion Optimization Algorithm, Differential Evolution, Low-Frequency Fluctuations, Power System Stabilizers, D-shaped, Stability Analysis.

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1 Introduction

The stability of the power network remains a critical issue in modern power system analysis, particularly in interconnected systems. Long, heavily loaded transmission lines can lead to various stability challenges, prompting researchers to focus on designing effective Power System Stabilizers (PSS), [1], [2].

Recently, the field of "Heuristics from Nature" has gained traction, leveraging analogies from natural and social systems to solve complex optimization problems. These methods have shown promise in finding optimal solutions for non-differentiable, multimodal, and complex objective functions, [3]. Several heuristic techniques have been applied to PSS design, including Differential Evolution (DE) [4], Particle Swarm Optimization [5], Bacteria Foraging [6], Bacterial Swarm Optimization [7], [8], Harmony Approach [9], Bat Algorithm [10], Approach of Water Cycle [11], Approach of Backtracking Search [12], Approach of Grey Wolf [13], Cuckoo Search Approach [14], [15], Genetic Approach [16], Kidney-Inspired Approach [17], Whale Optimization Approach [18], [19], [20], [21], Farmland Fertility Approach [22], Atom Search Approach [23], and Slime Mould Approach [24]. No matter what, optimization of PSS invariants remains a significant issue regarding power system stability.

This paper introduces the Dandelion Optimization Algorithm (DOA) as a novel method for determining optimal PSS parameters. Inspired by the wind-assisted seed propagation of dandelions, [25], [26], [27], [28], [29], [30], the DOA is tested and compared with the DE method. Time-domain simulations are conducted using MATLAB/Simulink under varying load conditions to assess the effectiveness of the suggested approach.

2 Mathematical Issue Pointing

2.1 Power Network 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. $X = [\delta, \omega, E_q^{'}, E_{fd}, V_f]^T$ while U is the PSS 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 PSS layout.

Consequently, the state framework including m PSSs is created as:

$$\dot{X} = A\,X + B\,U \tag{2}$$

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 $5m \times 1$ status and U vector of $n \times 1$ inner values.

2.2 PSS Frame

Power system benefits still favour the Conventional PSS (CPSS) model owing to its convenience of online synthesizing besides the poor stability guarantee to certain adjustments or variable architecture techniques. In another way, an extensive parsing of various CPSS variable's effects on the aggregate power system dynamic performance is attained in [1] and [2]. It is depicted that the occasion pick of CPSS constants enables acceptable performance through the system turbulence. The i^{th} PSS model is illustrated as:

$$\Delta U_i = K_i \frac{S T_W}{(1+ST_W)} \left[\frac{(1+ST_{1i})}{(1+ST_{2i})} \frac{(1+ST_{3i})}{(1+ST_{4i})} \right] \Delta\omega_i \tag{3}$$

This model is composed of a washout filter, a magnification factor, a limiter and an active compensator as appeared in Figure 1. The resulting sign is inserted as a further entry sign, ΔU_i to the excitation mode regulator. The entry sign $\Delta\omega_i$ is the speed deflection from the contemporary one. The stabilizer factor K_i is employed to find out the damping quantity that shall be injected. While a washout filter fights input sign oscillations to avert terminal voltage steady-state error. In addition, duo lead-lag networks are incorporated to eradicate any lag between the electric torque and the excitation. The limiter is embedded to prevent the PSS product sign from leading the excitation process to heavy fullness, [2]. The PSS and excitation process block diagram is given in Figure 1.

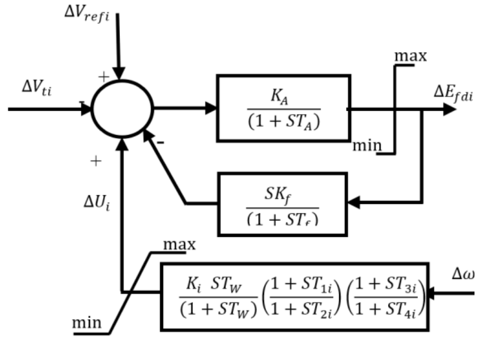

Fig. 1: CPSS and excitation system block diagram.

In this research, the washout time value T_W is considered as 10 seconds, the time constant magnitudes of T_{2i} and T_{4i} have steady reasonable values of 0.05 second. So it is required to maintain the stabilizer time constants T_{1i}, T_{3i} and gain K_i.

2.3 Tested Grid

The tested grid which is composed of nine points and three units as obvious in Fig. 2, is examined here. The system loads and data are pointed out in [2, and 7].

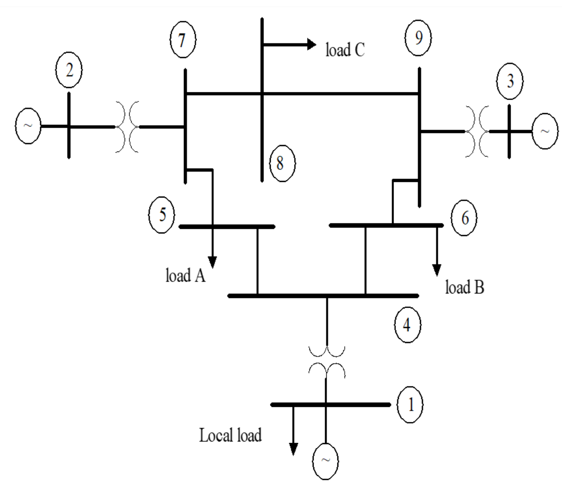

Fig. 2: The tested grid.

3 Dandelion Optimization Algorithm

DOA is an invented technique from the plant seeds motion behaviour. Dandelion plants depend on wind to disseminate seeds. The two crucial elements that influence the dandelion seed dissemination are weather and wind speed. The previous element practically influences the falling distance of seeds. Within, weather influences the capability of saplings to implant near or far. DOA could be mathematically modeled in 3 portions, which are the upward portion, downward portion, and landing portion. DOA is such as any population-based technique assuming that any dandelion seed is a nominated settling, [25].

$$A = \begin{bmatrix} x_1^1 & \cdots & \cdots & x_1^d \\ x_2^1 & \cdots & \cdots & x_2^d \\ \vdots & \vdots & \vdots & \vdots \\ x_p^1 & \cdots & \cdots & x_p^d \end{bmatrix} \tag{4}$$

$$x_i = x_{min} + rand * (x_{max} - x_{min}) \tag{5}$$

$$f_b = min\,(f\,(x_i)) \tag{6}$$

$$x_e = x\left(find\left(fb == f\,(x_i)\right)\right) \tag{7}$$

The size of the population space is designated as p. The size of variables are denominated as d, while $rand$ is a random value of [0,1].

3.1 Upward Part

In the rising phase, a windy and sunny mood lifts dandelion seeds up. On the left side, when it rains there is no wind. Region model seeking appears in this part. Flying dandelion seeds are influenced by wind humidity and speed. Dandelion seeds own the distinction of being capable of flying away considering the rising. In this part, two models depending on weather are namely, [26].

Condition 1: Sunny day circumstances, wind speed lognormal distribution is considered. In this part, DOA provides exploration. The wind helps dandelion seeds to fly wildly to various destinations. The wind speed specifies the seed height. The former part is formulated as:

$$X_{(t+1)} = X_t + \alpha v_x v_y \times ln\ \ Y \times (x_s - x_t) \tag{8}$$

$$x_s = rand(1, \dim) \times rand(x_{\max} - x_{\min}) + x_{\min} \tag{9}$$

$$\ln Y = \begin{cases} \dfrac{1}{y\sqrt{2\pi}} \exp\left(\dfrac{1}{2\sigma^2} \times (\ln y)^2\right) & if\ \ y \geq 0 \\ 0 \quad if\ \ y \prec 0 \end{cases} \tag{10}$$

$$\alpha = rand \times \left(\frac{1}{T^2} t^2 - \frac{2}{T}\, t\ +\ 1\right) \tag{11}$$

$$v_x\ = r\ \times cos(\theta) \tag{12}$$

$$v_y\ = r \times\ sin(\theta) \tag{13}$$

$$r\ = \frac{1}{e^{\theta}} \tag{14}$$

$$\theta = (2 \times rand(\ ) - 1) \times \pi \tag{15}$$

The dandelion seed location through iteration is named as x_t. Wildly nominated locations in the search area via iteration are named as x_s. lnY is a lognormal distribution. α is the adjusted amount that adapt step length of the search. The grade of the dandelion lifting passage because of the separate eddies vigor are symbolized as v_x and v_y.

Condition 2: In rainy day circumstances, there is a dandelion seed growing problem. In these circumstances, regional exploitation is taking place. The arithmetic model of part 2 is:

$$X_{(t+1)} = X_t \times k \tag{16}$$

$$q = \frac{t^2}{T^2 - 2T + 1} - \frac{2t}{T^2 - 2T + 1} + 1 + \frac{1}{T^2 - 2T + 1} \tag{17}$$

$$k = 1 - rand() \times q \tag{18}$$

$$X_{t+1} = \begin{cases} x_t + \alpha v_x v_y nY(x_s - x_t) randn\ if\ \ k \prec 1.5 \\ x_t k\ \ else \end{cases} \tag{19}$$

where k is worked out to provide the local searching range of an agent, $randn$ accounted for the wild values that achieve the fundamental normal distribution, [27].

3.2 Downward Part

In this part, the exploration phase is employed. The dandelion seeds locomotion will be certainly reduced while getting a peak at a specific value. The average data after the upward part is exercised to mirror the settlement of the parental offspring. This is to offer backing for the enhancement of the aggregate population, [28]. The arithmetic formulation of this part is:

$$x_{t+1} = x_t - \alpha\beta_t \times (x_{mean\_t} - \alpha\beta_t x_t) \tag{20}$$

$$x_{mean\_t} = \frac{1}{pop \sum_{i=1}^{pop} x_i} \tag{21}$$

where β_t indicates the action of Points Brownian. It is an irregular rate from the standard normal distribution, [29].

3.3 Landing Part

The exploitation stage takes place in this part. The landing location of the dandelion seeds is picked at stochastic. The dominant location of the most effective dandelion seed is utilized as the optimum selection. Elite data is momently exploited in the region medium to attain inclusive optimum precision. This attitude could be modelled [29] and [30].

$$X_{t+1} = X_{elite} + levy(\lambda) \times \alpha (X_{elite} - X_t \times \delta) \quad (22)$$

$$levy(\lambda) = S \frac{\omega \times \sigma}{|t|^{1/\beta}} \quad (23)$$

$$\sigma = \left(\frac{\Gamma(1+\beta) \times \sin\left(\frac{\pi\beta}{2}\right)}{\Gamma\left(\frac{1+\beta}{2}\right) \times \beta \times 2^{(\beta-1)/2}} \right) \quad (24)$$

$$\delta = \frac{2t}{T} \quad (25)$$

where X_{elite} mirrors the superior location of the operator in each iteration. (λ) represents the task of Levy flight, [30].

4 Objective Function

To assure constancy and achieve further damping at low frequency of fluctuations, the constants of the PSSs can be selected to lessen the next equation:

$$J_t = \sum_{j=1}^{np} \sum_{\sigma_{ij} \geq \sigma_0} (\sigma_0 - \sigma_{ij})^2 + \sum_{j=1}^{np} \sum_{\xi_{ij} \geq \xi_0} (\xi_0 - \xi_{ij})^2 \quad (26)$$

This will locate the eigenvalues of the closed loop system within the D-shape sector distinguished by $\xi_{ij} \rangle \xi_0$ and $\sigma_{ij} \leq \sigma_0$ as indicated in Figure 3.

where ξ and σ are the attenuation rate and real part of the eigenvalue of an operating point, np is the working points numbers considered in the layout process. In this paper, ξ_0 and σ_0 are chosen to be 0.1 and -0.5 in the given order, [14]. Classic limits of the optimized factors are from 1 to 100 for K, and from 0.06 to 1 for T_{1i}, and T_{3i}. Optimization task depends on the equation (26) and it could be written as: reduce J_t according to:

$$K_i^{min} \leq K_i \leq K_i^{max}$$

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

$$T_{3i}^{min} \leq T_{3i} \leq T_{3i}^{max} \quad (27)$$

This research depends on the optimal adjusting of PSS via the DOA approach. The objective of the optimization is to lower the equation (26) to enhance the system attitude in terms of overshoots and settling time for various working events and lastly, lay a small size controller for successful operation.

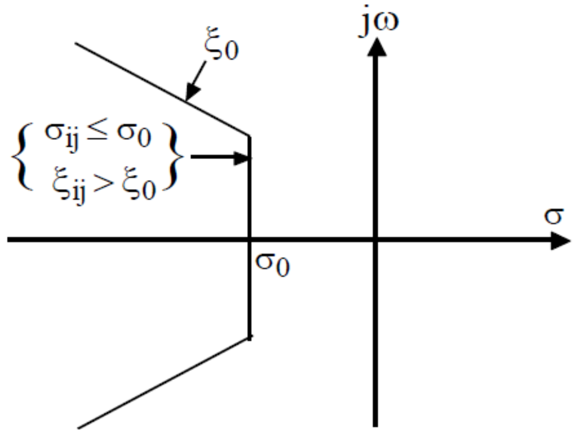

Fig. 3: D-shaped objective function

5 Simulation Outcomes

In this part, the effectiveness of the suggested DOA approach in PSSs layout compared with optimized PSSs with DE is evidenced. Figure 4 demonstrates the variation of equation (26) via two optimization approaches. The final value of equation (26) is lessened via DE and DOA iterations. The final value of equation (26) is zero for every algorithm, demonstrating that whole modes have been moved to the assigned D-sector location in the plane and the suggested target function is attained. Additionally, DOA converges at a superior rate (33 iterations) compared with DE (43 iterations). The attenuation ratios and mechanical modes eigenvalues are specified in Table 1 for three operating events with duo approaches. It is apparent that the DOAPSS attenuation factors have been enhanced to be -1.13, -1.19, and -1.33. Also, the eigenvalues have been moved to the left side in the D-shape. Additionally, the DOAPSS attenuation rates are further than the other controller. Thus, DOAPSS provides superior attenuation behavior with respect to DEPSS. The constants of DE and DOA controllers are reported in Table 2.

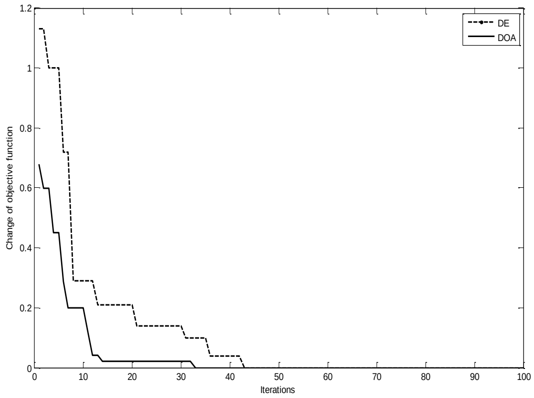

Fig. 4: Objective function variations

Table 1. ζ and modes for three operating events for both approaches

	DEPSS	DOAPSS
Light load	-1.05±0.66j,0.85 -3.73±6.22j,0.51 -3.61±5.93j,0.52	-1.13±0.63j,0.87 -6.31±6.28j, 0.71 -3.43±5.11j,0.56
Normal load	-1.13±0.72j,0.84 -4.27±7.00j, 0.52 -4.18±8.02j, 0.46	-1.19±0.68j,0.87 -6.9±6.78j,0.71 -3.38±5.22j,0.54
Heavy load	-1.16±0.71j, 0.85 -3.5±6.71j,0.46 -3.04±5.2j,0.5	-1.33±0.71j,0.88 -7.98±5.33j,0.83 -4.64±7.26j,0.54

Table 2. Constants of PSSs for both algorithms

	DOA	DE
PSS_1	K=44.732 T_1=0.6364 T_3=0.5281	K=29.6446 T_1=0.5134 T_3=0.7248
PSS_2	K=9.1123 T_1=0.4637 T_3=0.1863	K=7.6338 T_1=0.3721 T_3=0.2344
PSS_3	K=6.4631 T_1=0.4241 T_3=0.1922	K=4.8271 T_1=0.4261 T_3=0.2713

5.1 Response via Normal Loading

The ratification of the grid functioning owing to a 20% raise of generator 1 mechanical torque as a little disturbance is achieved. Figure 5 and Figure 6, illustrates the outcome of $\Delta\omega_{12}$ and $\Delta\omega_{13}$ owing to this disturbance under normal loading event. The system with the suggested DOAPSS is more steadied compared to DEPSS. Also, the average needed steading time to damp grid fluctuations is around 1.1 seconds for DOAPSS, and 1.6 seconds with DEPSS so the nominated controller is eligible for providing sufficient attenuation to the low-frequency fluctuations.

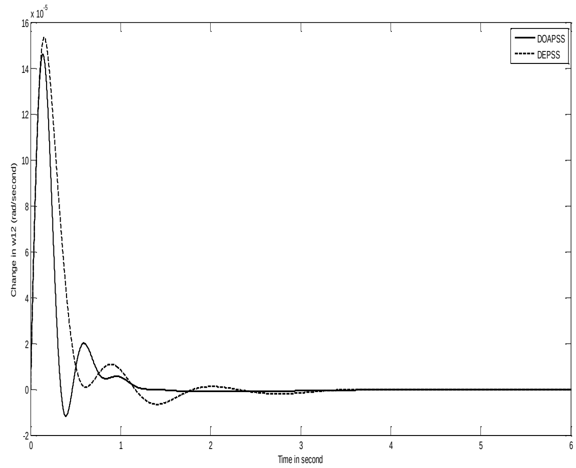

Fig. 5: Variations of $\Delta\omega_{12}$ for normal loading

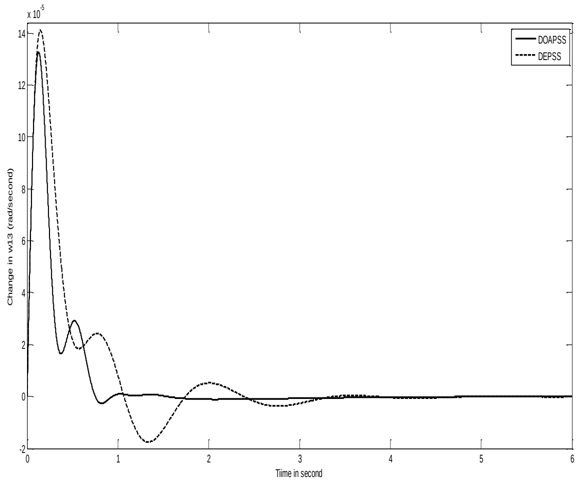

Fig. 6: Output of $\Delta\omega_{13}$ for normal loading

5.2 Response via Light Loading

Figure 7 and Figure 8, illustrates the grid performance via light loading event without changing the controller constants. It is obvious from these outputs, that the suggested DOAPSS has better attenuation behavior on network oscillatory modes, settling down the grid quickly. Also, the average steading time of fluctuations is 2.4 and 1.4 seconds for DEPSS, and DOAPSS consecutively. Hence, the suggested DOAPSS overcomes the DEPSS controller in mitigating oscillations efficiently and diminishing steading time. Therefore, the suggested DOAPSS increases the stability ceiling of the tested grid.

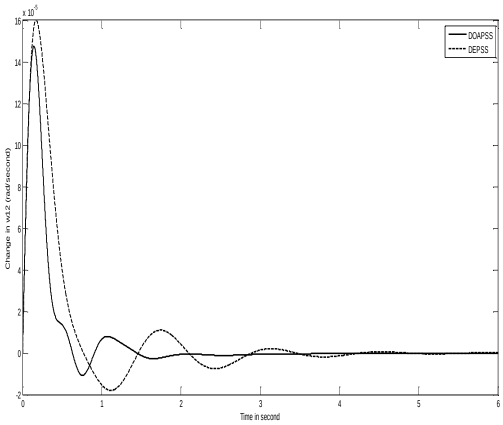

Fig. 7: Variations of $\Delta\omega_{12}$ for light loading

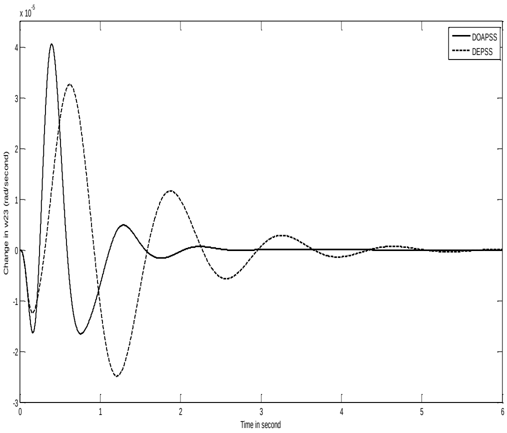

Fig. 8: Variations of $\Delta\omega_{23}$ for light loading

5.3 Response via Heavy Loading

Figure 9 and Figure 10, illustrates the system performance via heavy loading event. These outputs denote the supremacy of the DOAPSS in lessening the steading time and repressing power grid fluctuations. Additionally, the average settlement time of these fluctuations is 1.47 and 1.1 seconds for DEPSS, and DOAPSS consecutively. Thus, the DOAPSS controller highly alleviates the attenuation behavior of the tested grid. Moreover, the settlement time of the suggested PSSs is lower than that in [6] and [8].

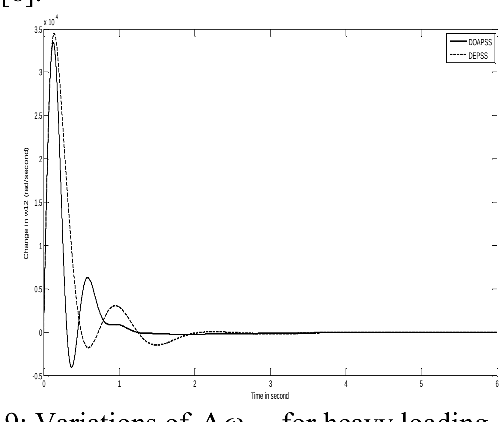

Fig. 9: Variations of $\Delta\omega_{12}$ for heavy loading

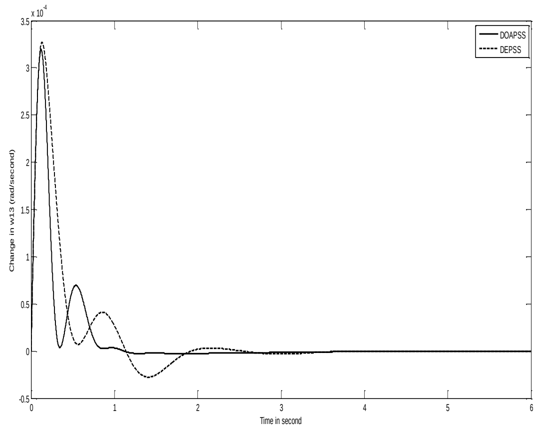

Fig. 10: Variations of $\Delta\omega_{13}$ for heavy loading

5.4 Response for Large Perturbation

Figure 11 and Figure 12, illustrates the performance of $\Delta\omega_{12}$ and $\Delta\omega_{13}$ via serious perturbation. It is emphasized by the fulfillment of a three-phase fault of 6 interval duration at 1.0 seconds near node 7. From these figures, the DOAPSS utilizing the suggested objective function offers convenient damping and gains powerful behavior compared with the other methods.

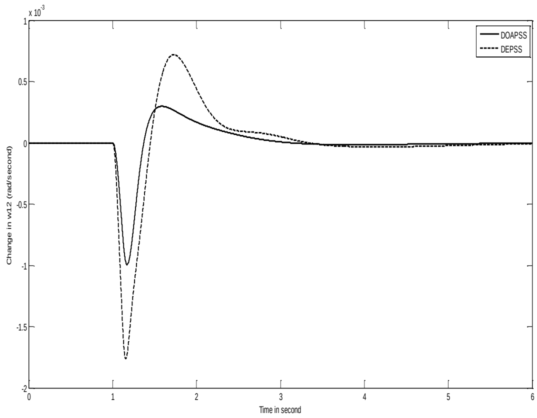

Fig. 11: Variations of $\Delta\omega_{12}$ under severe disturbance

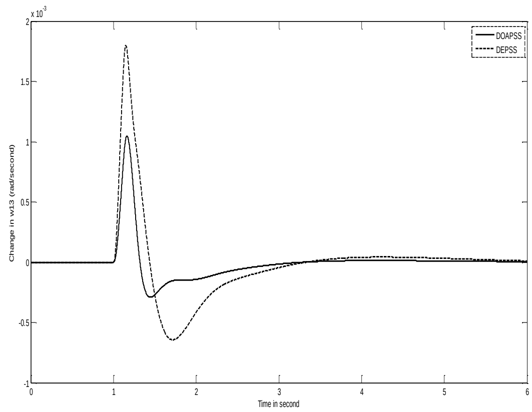

Fig. 12: Variations of $\Delta\omega_{13}$ under severe perturbation

5.5 Durability and Performance Indices

To prove the durability of the suggested controller, certain performance indices: Integral of Time multiplied Absolute amount of the Error (ITAE) and Integral of Absolute amount of the Error (IAE) are being employed:

$$ITAE = \int_0^\infty t\left(\left|\Delta w_{12}\right| + \left|\Delta w_{23}\right| + \left|\Delta w_{13}\right|\right)dt \quad (28)$$

$$IAE = \int_0^\infty \left(\left|\Delta w_{12}\right| + \left|\Delta w_{23}\right| + \left|\Delta w_{13}\right|\right)dt \quad (29)$$

It is trustworthy that the values of these indices are lessened a system better functioning in terms of time domain behavior [8] and [31]. Digital results of robust realization for whole events are tabulated in Table 3. The values of these system indices for DOAPSS are lower compared to DEPSS. This signalizes that the overshoot, steading time, and speed deflections of all units are highly reduced by employing the suggested PSSs via DOA tuning. Also, the values of these pointers are lower than those gained in [10] and [14].

Table 3. Behaviour pointers for both algorithms

loading	IAE $*10^{-4}$		ITAE $*10^{-4}$	
	DEPSS	DOAPSS	DEPSS	DOAPSS
Light	0.1484	0.0442	0.4148	0.2704
Normal	0.2648	0.0648	0.7551	0.5916
Heavy	0.4126	0.1000	0.9406	0.8397

6 Conclusions

A modern optimization approach named as DOA search approach, for optimum modeling of PSS constants is suggested in this research. The PSS constants synthesizing trouble is elaborated as an optimizing one and DOA is utilized to obtain the optimum constants. An objective function basis eigenvalue mirroring the composition of attenuation agents and attenuation ratio which is optimized for different working events. Simulation results assure the validity of the suggested controller to provide better attenuation behavior for grid fluctuations over a large domain of loading events. Also, the network behavior with regard to the 'ITAE' and 'IAE' indices shows that the suggested DOAPSS illustrates its supremacy over DEPSS. Application of such suggested algorithm tuned via new optimization approaches to highly level power systems is the outlook domain of this paper.

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APPENDIX

a) The constants of DOA are given as: Population size = 50; Maximum generation = 100.
b) The constants of DE are given as: Mutation probabilities = 0.5; Crossover probabilities = 0.5; and count of population = 100.

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