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Enhanced hippopotamus optimization algorithm for power system stabilizers

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ABSTRACT

This article presents techniques for modifying the power system stabilizer's (PSS) parameters. An enhanced version of the hippocampal optimization algorithm (HO) is presented here. HO represents a novel approach in metaheuristic methodology, having been inspired by the observed clinging behavior in hippos. The notion of the HO is defined using a trinary-phase model that includes their position updates in rivers or ponds, defensive techniques against predators, and mathematically described evasive methods. To confirm the efficacy of the recommended approach, this article provides comparison simulations of the PSS objective function and transient response. This study employs validation through a comparison between Original HO and conventional methods. Simulation results demonstrate that, when compared to competing algorithms, the suggested approach yields optimal results and, in some cases, exhibits fast convergence. It is known that, in comparison to the original HO approach, the recommended way can lower the average undershoot of the rotor angel and speed by 12.049% and 26.97%, respectively.

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1. INTRODUCTION

Power system stability is the ability of an electric power system to continue operating stably after experiencing disturbances or changes in operational conditions [1]-[3] Power system stability is very important to maintain the availability of a reliable electricity supply to consumers [4], [5]. Uncontrolled or inadequately addressed disturbances can result in continued disturbances, loss of synchronization between generators, excessive oscillations, or even complete system collapse [6]-[8].

Fluctuating or unpredictable electricity consumption can cause sudden changes in power system load. If not managed properly, these load fluctuations can cause an imbalance between energy production and consumption, which can disrupt the stability of system frequency and voltage [9], [10]. In emergency situations, power system operators may have to remove loads from the grid to prevent a larger system failure. This sudden drop in electricity consumption can affect the frequency and voltage stability of the system if not properly regulated. The use of intelligent demand response technology can help regulate consumer electricity consumption to match power system conditions [11], [12]. By reducing or delaying electricity consumption during peak periods, consumers can help reduce stress on the power system and increase its stability [13], [14].

Power system stabilizer (PSS) is a device used in electric power systems to increase the dynamic stability of the system. Its function is to produce a control signal that is adjusted to regulate the excitation field of the generator, with the aim of compensating for speed and voltage oscillations that arise after a disturbance in the power system [15]. Although conventional power system stabilizers (PSS) have an important role in maintaining the stability of electric power systems, there are several disadvantages that need to be considered, such as conventional PSS parameter settings often must be adjusted manually and require in-depth knowledge of complex power systems. This especially happens if the parameter settings are not optimal or if an unexpected disturbance occurs in the system [16].

The application of metaheuristics to the PSS aims to improve system performance and responsibility in maintaining power system stability. Metaheuristics are optimization techniques used to search for optimal solutions or close to optimal solutions in a complex search space [17]-[19]. Several applications of metaheuristic methods in PSS have been presented, such as the grasshopper optimization algorithm [20], Harris Hawk Optimizer [21], African Vulture Optimization Algorithm [22] and whale optimization algorithm [23]. The application of metaheuristics to PSS allows finding faster and more efficient solutions in optimizing PSS parameters. Even though many metaheuristic approaches to PSS have been presented, there is still a lot of space that can be explored to find the best optimization.

In this paper, a PSS tuning method using an improved Hippopotamus optimization algorithm is presented. Hippos' natural behavior served as the inspiration for the development of the hippopotamus optimization algorithm (HO), a metaheuristic optimization algorithm based on HO behavior [24]. This study makes the following contributions:

- The EHO algorithm, an enhanced version of the Hippopotamus Optimization Algorithm, is introduced.
- EHO implementation in PSS.
- Evaluate whether EHO-based controllers can enhance PSS performance.
- Compare the original HO and the EHO applied to PSS using traditional methods.

Section 2 of the article includes the method, mathematical formulation, justification, and pseudocode for the suggested method approach. There is a simulation and discussion in Section 3. The research conclusions are presented in the last part.

2. METHOD

2.1. Hippopotamus optimization algorithm

A population-based optimization technique called the HO uses hippopotamuses as search agents. Hippos are candidate solutions for the optimization issue in the HO method, which means that each hippos's position update in the search space reflects a value for one of the decision variables. The HO's initialization step entails creating randomized initial solutions, just like traditional optimization techniques. In this stage, the following formula is used to generate the vector of choice variables:

$$X_{ij} = Rand \times \left(UpB_j - LwB_j\right) + LB_j\,;\; i = 1,2, \ldots..N\,;\; j = 1,2, \ldots.dim \tag{1}$$

Where $Rand$ is a disordered amount, LwB_j is the jth lower limit, and UpB_j iss the *j*th upper limit. HO has three concepts, namely updating their position in a river or pond, defense strategies against predators, and avoidance methods.

2.1.1. The position of the hippos in the pond or river is updated (exploration)

Based on the objective function value iteration-the lowest for the minimization problem and the greatest for the maximizing challenge-the dominating hippopotamus is identified. Male dominating hippopotamuses defend the territory and herd against intruders. The male hippopotamuses are surrounded by a number of female counterparts. The location of the male hippos in the herd within the lake or pond is expressed mathematically in (2).

$$X_{ij}{}^{hippo} = Y_{ij} \times \left(Dhippo - X_{ij}I_i\right) + X_{ij}\,;\; i = 1,2, \ldots..N\,;\; j = 1,2, \ldots.dim \tag{2}$$

$$Dhippo = Xbest_{ij} \tag{3}$$

$$h = \begin{cases} I_2 \times \vec{r}_1 + (\sim Q_1) \\ 2 \times \vec{r}_2 - 1 \\ \vec{r}_3 \\ I_2 \times \vec{r}_4 + (\sim Q_2) \\ \vec{r}_5 \end{cases} \tag{4}$$

$$T = exp\left(-\frac{l}{T}\right) \quad (5)$$

$$X_{ij}^{FBhippo} = \begin{cases} r_6 \times h_1(MG - Dhippo) + X_{ij}, T > 0.6 \\ \Xi \; else \end{cases} \quad (6)$$

$$\Xi = \begin{cases} r_6 \times h_2(MG - Dhippo) + X_{ij}, T > 0.5 \\ r_7 \times \left(UpB_j - LwB_j\right) + LB_j, else \end{cases} \quad (7)$$

In (2) X_{ij}^{hippo} represents male hippopotamus position, $Dhippo$ denotes the dominant hippopotamus position (The hippopotamus that has the best cost in the current iteration). r is a random vector between 0 and 1, $\vec{r}_5$ is a random number between 0 and 1 (3), I_1 and I_2 is an integer between 1 and 2 (2) and (3). MG refers to the mean values of some randomly selected hippopotamus with an equal probability of including the current considered hippopotamus (X_{ij}) and Y_{ij} is a random number between 0 and 1 (2). In (4) Q_1 and Q_2 are integer random numbers that can be one or zero. The position of the female or immature hippopotamus ($X_{ij}^{FBhippo}$) in the herd is described by (5) and (6). Although most young hippopotamuses live close to their mothers, occasionally they will wander off from the herd or from their mothers out of curiosity. T indicates that the young hippopotamus has separated from its mother if it is more than 0.6.

2.1.2. Exploration-the hippos' defense mechanism against predators

Hippopotamuses' main defensive maneuver is quickly turning to face the predator and making loud noises to scare it away from getting too close. To effectively ward off the possible threat, hippos may display a behavior during this phase in which they approach the predator and cause it to retreat. The location of the predator in the search space is shown by (8).

$$P_{ij} = r_8 \times \left(UpB_j - LwB_j\right) + LB_j \quad (8)$$

$$D = \left|P_{ij} - X_{ij}\right| \quad (9)$$

$$\overrightarrow{RL} = Levy(\vartheta) \quad (10)$$

$$Levy(\vartheta) = 0.05.\frac{w \times \sigma_w}{|v|^{\frac{1}{v}}} \quad (11)$$

$$X_{ij}^{hippo} = \begin{cases} \overrightarrow{RL} \times P_{ij} + \left(\frac{b}{c - d\cos(2\pi g)}\right)\left(\frac{1}{D}\right) + X_{ij}, fP_{ij} < f_i \\ \overrightarrow{RL} \times P_{ij} + \left(\frac{b}{c - d\cos(2\pi g)}\right)\left(\frac{1}{D.2 + r_9}\right) + X_{ij}, fP_{ij} \geq f_i \end{cases} \quad (12)$$

Where a random vector with a range of zero to one is represented by r_8. In (7) shows how far away the predator is from the ith hippopotamus. A higher value of predator suggests that the predator or other intruding creature is farther away from the hippopotamus's territory in (11). $\overrightarrow{RL}$ is a random vector with a Levy distribution, utilized for sudden changes in the predator’s position during an attack on the hippopotamus. The mathematical model for the random movement of the Lévy movement is calculated as (10). w and v are the random numbers.

2.1.3. Hippopotamus evading the predator (exploitation)

The hippopotamus uses this tactic to find a safe spot close to its current location, and by modeling this behavior in the HO's Phase Tree, it becomes more exploitable in local search. The hippopotamuses' behavior is modeled using in (13) and (14).

$$LwB_j^{lo} = \frac{LwB_j}{t}, UpB_j^{lo} = \frac{UpB_j}{t} \quad (13)$$

$$X_{ij}^{hippoE} = X_{ij} + r_{10} \times ((UpB_j - LwB_j)s + LB_j) \quad (14)$$

The position of the hippotamus that was looked for the closest safe place is represented by ${X_{ij}}^{hippoE}$ in (12). Three scenarios are represented by the random vector or integer s, which is chosen at random using (13). The cases (s) under consideration result in a better local search, or, to put it another way, the suggested algorithm has a greater exploitation quality.

2.2. Power system stabilizers

The basic purpose of PSS is to dampen rotor oscillations by controlling the field excitation of the generator rotor by means of additional stabilizing signals [25]. To ensure sufficient damping, the PSS produces an electrical torque component in response to the rotor speed deviation. In Figure 1, the PSS modeling methodology is displayed.

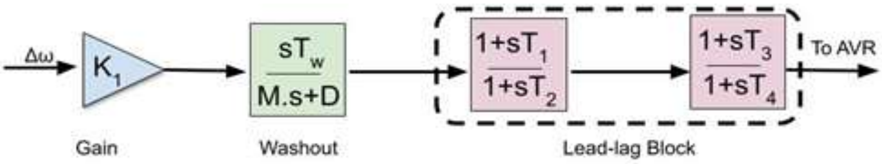


Figure 1. PSS lead-lag type illustration

2.3. Enhanced Hippopotamus optimization algorithm (EHO)

The Elite algorithm is added to the HO approach in this article. As a result, the best options are selected as top predators in order to create an Elite matrix [26]. Based on information about the prey's whereabouts, this matrix array keeps track of the hunt and finding of prey.

$$Elite = \begin{bmatrix} x_{1,j} \cdots x_{1,j} & \cdots & x_{1,d} \\ \vdots \ \ddots \ \vdots & \ddots & \vdots \\ x_{nc,1} \cdots x_{nc,j} & \cdots & x_{nc,d} \\ x_{nc+1,1} \cdots x_{nc+1,j} & \cdots & x_{nc+1,d} \\ \vdots \ \ddots \ \vdots & \ddots & \vdots \\ x_{n,1} \ \cdots \ x_{n,j} & \cdots & x_{n,j} \end{bmatrix}_{nxd} \tag{15}$$

Where the top predator vector, denoted by $x_{1,j}$, is copied n times to create the Elite matrix. The number of dimensions is d, while the number of search agents is n. This article proposes adding (15) to (3) so that it becomes (16). The algorithm of the EHO method can be seen in Algorithm 1.

$$Dhippo = Xbest_{ij}\ x\ Elite \tag{16}$$

Algorithm 1. Enhanced Hippopotamus optimization algorithm (EHO)

```
Input: Population size (N), Maximum number of iteration (T), Number of dimension
procedure EHO
Initialize the parameters based (1).
Calculate of Fitness value
For t : t<T
Phase 1: The position of the hippos in the pond or river is updated (exploration)
For i=1 : N/2
Calculate the new position for i th using (2),(16),(6) (Proposed method)
Update Position of i th population using(8),(9)
End For
Phase 2: Exploration—the hippos' defense mechanism against predators (exploration)
For i=1+ N/2:N
Generate Random Position For Predator using(10)
Calculate the new position for i th using (12)
End For
Phase 3: Hippopotamus Evading the Predator (Exploitation)
Calculate the new bound based on (13)
For i=1:N
Generate Random Position For Population using(14)
End For
Save the best candidate solution found so far
End For
return Best Soluton
End procedure
```

3. RESULTS AND DISCUSSION

3.1. Convergence curve profile

Using the MATLAB/Simulink program on a laptop with 8 GB of RAM and an Intel I5-5200 CPU operating in 64-bit mode at 2.19 GHz, the EHO method code is written. We tested twenty-three benchmark functions to evaluate the performance of the EHO. The benchmark function consists of three categories: multimodal (F8-F13), multimodal with fixed dimensions (F14-F23), and unimodal (F1-F7). The detail of comparison algorithm can be seen in Table 1 (see in APPENDIX). A comparison of unimodal function rankings between algorithms can be seen in Table 2. Rank comparison of multimodal functions between algorithms can be seen in Table 3. Table 4 is a rank comparison of fixed-multimodal functions between algorithms.

Table 2. Rank comparison of unimodal functions between algorithms (F1-F7)

Function	HO	EHO
Sum Rank	12	9
Mean Rank	1.7142857	1.2857143
Total Rank	2	1

Table 3. Rank comparison of multimodal functions between algorithms (F8-F13)

Function	HO	EHO
Sum Rank	8	4
Mean Rank	1.3333333	0.6666667
Total Rank	2	1

Table 4. Rank comparison of fixed-multimodal functions between algorithms (F14-F23)

Function	HO	EHO
Sum Rank	13	11
Mean Rank	1.3	1.1
Total Rank	2	1

3.2. Application EHO for PSS

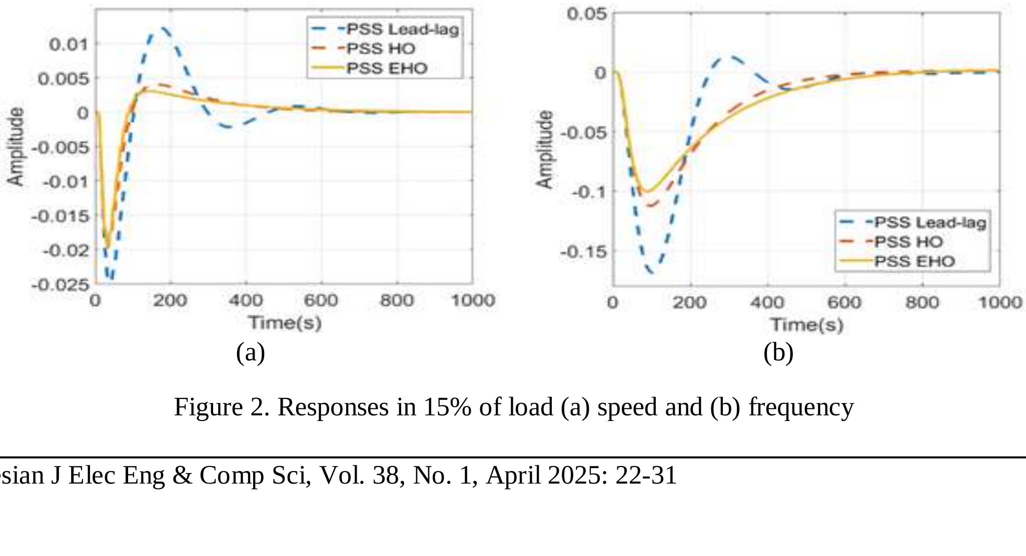
To gauge the effectiveness of the EHO, the PSS parameter was also adjusted. EHO is utilized in order to obtain parameters that satisfy the optimal output specifications. This article evaluates a single machine system owned by Heffron-Philips using several case studies. The case study includes three different system load variations: 15%, 55%, and 85%. In the first stage, the PSS parameter is optimized using the integral of time multiplied absolute error (ITAE). The objective function of the design problem is found to be ITAE. In (17) provides evidence for this.

$$ITAE = \int_0^{Ts} t.|\Delta\omega(t)|.dt \quad (17)$$

The PSS modeling that uses the PSS EHO approach is tested for capability using the loading variation. The first scenario involves loading the system by 15%. Figure 2 shows the response to load changes. Figure 2(a) shows the reaction to rotor speed and Figure 2(b) is an illustration of the rotor angle. Table 5 displays the case 1 outcomes in detail. In Table 5, the proposed method has a speed response value of 0.003074. When compared to alternative methods, the value represents the best performance. The PSS-EHO approach performs 31.0195185% better than the PSS-HO approaches. In the meanwhile, the PSS EHO approach performs best in terms of undershoot rotor angle. It comes to -0.01945. The application of PSS-HO techniques with -0.01973 comes next.

Table 5. Case 1: 15 % of load

Method	Speed response			Rotor angle response	
	Undershoot	Overshoot	Settling time (s)	Undershoot	Settling time (s)
PSS-Lead Lag	-0.0246	0.0132	888	-0.1686	992
PSS-HO	-0.01973	0.004027	822	-0.1124	948
PSS-EHO	-0.01945	0.003074	709	-0.1003	922

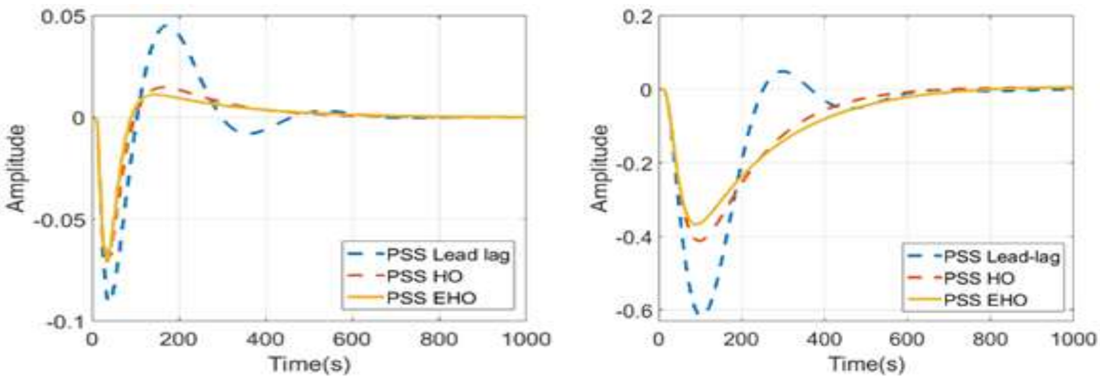


(a) (b)

Figure 2. Responses in 15% of load (a) speed and (b) frequency

In the second experiment, the system will be loaded to 55%. The findings of experiment 2 are shown in Figure 3. Figure 3(a) shows the reaction to rotor speed and Figure 3(b) is an illustration of the rotor angle. Waves obtained using the PSS-EHO approach show it. When contrasted to other approaches, the waves are sloping. Table 6 displays the details of instance 2. As seen in Table 6, the proposed method produces a velocity overshoot value of 0.01139, while the PSS-HO method is in second place with 0.01498. The PSS-HO approach is 31.51887621% less capable than the method suggested in case study 2. The PSS-EHO approach offers the best value for the rotor angle undershoot. This value outperforms the second-best PSS-HO technique by 27.16170691%.

The measurement in case 3, when the system is assigned 85% loading. Figure 4 displays the outcomes of the speed and rotor angle. Figure 4(a) shows the reaction to rotor speed and Figure 4(b) is an illustration of the rotor angle. The case 3 results are displayed in Table 7. The PSS-EHO approach yields the best speed response value, and the PSS-HO method comes in second. The ability of the PSS-EHO method is 31.60886868% higher than that of the PSS-HO approaches. In the meantime, the PSS Lead-lag approach has the worst figure for rotor angle undershoot, coming in at -0.955. The PSS-EHO approach yields the highest score, while the PSS-HO method comes in second. The PSS-EHO approach outperforms the PSS-HO method by 12.06684257%.

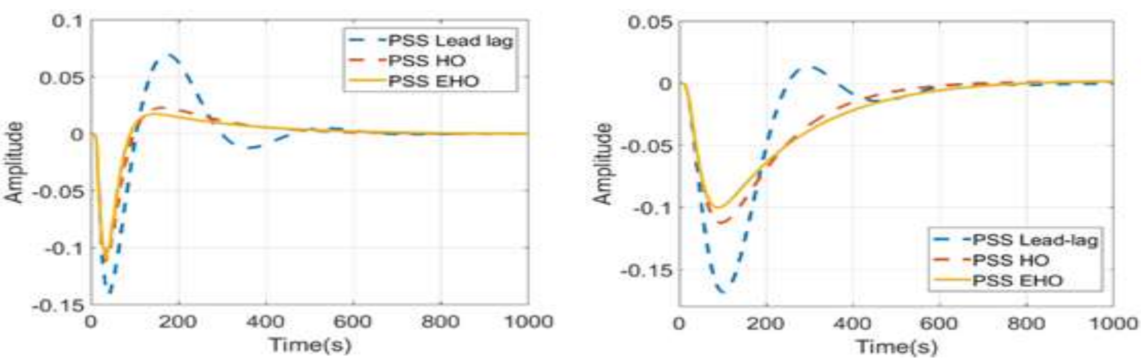


(a) (b)

Figure 3. Responses in 55% of load (a) speed and (b) frequency

Table 6. Case 1: 55 % of load

Method	Speed response			Rotor Angle response	
	Undershoot	Overshoot	Settling time (s)	Undershoot	Settling time (s)
PSS-Lead Lag	-0.09059	0.04524	915	-0.6184	911
PSS-HO	-0.0723	0.01498	872	-0.4121	976
PSS-EHO	-0.07124	0.01139	807	-0.3679	954



(a) (b)

Figure 4. Responses in 85% of load (a) speed and (b) frequency

Table 7. Case 1: 85 % of load

Method	Speed response			Rotor angle response	
	Undershoot	Overshoot	Settling time (s)	Undershoot	Settling time (s)
PSS-Lead Lag	-0.14	0.06992	951	-0.955	999
PSS-HO	-0.11	0.02315	896	-0.6371	947
PSS-EHO	-0.11	0.01759	823	-0.5685	899

4. CONCLUSION

The purpose of this research is to compare the performance of the modified Hippopotamus Optimization Algorithm (HO) and to conduct a thorough literature review. The EHO technique is the suggested approach. The goal is to test on a single machine in order to determine the optimal approach for dampening oscillations in the power system. The suggested approach outperforms the comparative method in load tests at 15%, 55%, and 85%. PSS was subjected to the EHO method in this study. Comparing case studies 1 and 2, it is evident that the undershoot of speed value using EHO has lowered by 26.48%, 27.27%, and approximately 27.162%, respectively, in comparison to the PSS-HO approach. In the meantime, the PSS-EHO's calculation of the undershoot of rotor angle dropped by approximately 12.063% in Case Study 1, 12.014% in Case Study 2, and 12.07% in Case Study 3. Furthermore, the suggested approach is quite flexible in response to variations in load. The experiment's usage of a basic system makes the suggested approach flawed. To ascertain the suggested method's performance further, it must be tested on more intricate systems and non-linear problems.

APPENDIX

Table 1. Comparison of HO and EHO

Function		HO	EHO
F1	Best	1.13E-25	1.58E-26
	Mean	6.01E-17	6.03E-19
	Worst	2.53E-15	2.08E-17
	Std	3.60E-16	2.98E-18
	Rank	2	1
F2	Best	8.73E-13	4.41E-15
	Mean	4.85E-10	7.08E-11
	Worst	4.53E-09	4.96E-10
	Std	8.27E-10	1.12E-10
	Rank	2	1
F3	Best	2.00E-25	6.35E-26
	Mean	2.79E-18	1.41E-18
	Worst	5.59E-17	4.78E-17
	Std	1.02E-17	6.86E-18
	Rank	2	1
F4	Best	4.62E-13	1.15E-13
	Mean	5.49E-10	1.95E-10
	Worst	9.12E-09	3.10E-09
	Std	1.57E-09	4.84E-10
	Rank	2	1
F5	Best	2.82E-03	1.17E-04
	Mean	0.4035	0.63469
	Worst	2.5456	5.6249
	Std	0.53864	1.2763
	Rank	1	2
F6	Best	6.56E-04	8.71E-05
	Mean	0.13194	0.163
	Worst	0.65795	0.59757
	Std	1.22E-01	1.45E-01
	Rank	1	2
F7	Best	7.22E-05	9.05E-05
	Mean	0.0026323	0.0023946
	Worst	0.0080386	0.007547
	Std	0.0017992	0.001724
	Rank	2	1
F8	Best	-31972.6094	-32695.8027
	Mean	-20443.7519	-22396.5212
	Worst	-12569.042	-12567.9501
	Std	4371.9892	5295.5387
	Rank	2	1
F9	Best	0	0
	Mean	0.00E+00	0.00E+00
	Worst	0.00E+00	0.00E+00
	Std	0.00E+00	0.00E+00
	Rank	0	0

Table1. Comparison of HO and EHO *(continued)*

	Function	HO	EHO
F10	Best	8.26E-14	7.99E-15
	Mean	3.48E-10	5.43E-11
	Worst	1.08E-08	8.11E-10
	Std	1.52E-09	1.25E-10
	Rank	2	1
F11	Best	0	0
	Mean	2.22E-18	2.22E-18
	Worst	1.11E-16	1.11E-16
	Std	1.57E-17	1.57E-17
	Rank	0	0
F12	Best	3.68E-06	1.03E-07
	Mean	6.12E-03	3.68E-03
	Worst	1.24E-01	1.40E-02
	Std	1.75E-02	3.72E-03
	Rank	2	1
F13	Best	7.15E-07	2.48E-05
	Mean	6.88E-02	6.25E-02
	Worst	0.23205	0.18629
	Std	5.93E-02	5.19E-02
	Rank	2	1
F14	Best	0.998	0.998
	Mean	0.99822	0.99993
	Worst	1.0087	1.0813
	Std	1.51E-03	1.19E-02
	Rank	1	2
F15	Best	0.00031	0.000308
	Mean	0.000355	0.000357
	Worst	0.000492	0.000553
	Std	4.44E-05	5.09E-05
	Rank	1	2
F16	Best	-1.0316	-1.0316
	Mean	-1.0316	-1.0316
	Worst	-1.0316	-1.0315
	Std	1.31E-06	1.75E-05
	Rank	0	0
F17	Best	0.39789	0.39789
	Mean	0.3979	0.3979
	Worst	0.39819	0.3981
	Std	4.34E-05	3.92E-05
	Rank	0	0
F18	Best	0.39789	0.39789
	Mean	0.3979	0.3979
	Worst	0.39819	0.3981
	Std	4.34E-05	3.92E-05
	Rank	0	0
F19	Best	3	3
	Mean	3	3
	Worst	3.0002	3.0003
	Std	3.95E-05	5.92E-05
	Rank	1	2
F20	Best	-3.8628	-3.8628
	Mean	-3.8626	-3.8627
	Worst	-3.8579	-3.8611
	Std	0.000691	0.000292
	Rank	2	1
F21	Best	-3.3219	-3.3215
	Mean	-3.236	-3.2664
	Worst	-3.0197	-3.0696
	Std	0.090057	0.073546
	Rank	2	1
F22	Best	-10.1532	-10.1532
	Mean	-10.138	-10.14
	Worst	-10.0562	-10.0549
	Std	0.024971	0.023841
	Rank	2	1
F23	Best	-10.4029	-10.4029
	Mean	-10.3818	-10.3953
	Worst	-10.0557	-10.3382
	Std	0.059245	0.015682
	Rank	2	1
	sum rank	33	24
	mean rank	1.434783	1.043478

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