Cooperation search algorithm for tuning automatic voltage regulator system

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ABSTRACT

The cooperation search algorithm (CSA) duplicates teamwork in every part of the company. This paper presents an approach to setting automatic voltage regulator (AVR) with proportional-integral-derivative (PID) control based on CSA. To get the performance of the proposed method, this paper uses the maximum overshoot, rise time, settling time, and error. This paper uses the whale optimization algorithm (WOA), grasshopper optimization algorithm (GOA), particle swarm optimization (PSO), and sine-cosine algorithm (SCA) methods as a comparison in measuring the performance of the CSA method which is used as the optimization of PID parameters on the AVR. From the simulation, the application of the CSA method to get the optimal PID parameter value has an average result that can reduce the maximum overshoot by 10.97% compared to the GOA, PSO and SCA methods.

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1. INTRODUCTION

In the electric power system, there are 3 kinds of stability controllers to obtain an optimal system condition, namely control on the generation side, control on the network side, and control on the distribution side (load) [1]. Control on the generation side is to maintain the stability of a generator in supplying power [2]. Meanwhile, control on the network side is the ability of the transmission network to be able to reach loads with various disturbance conditions [3] and control on the distribution or load side is mainly regarding the stability of the power used [4].

An alternating current (AC) generator is equipment that functions to convert mechanical energy (motion) into electrical energy (electricity) by means of magnetic field induction. This energy change occurs due to a change in the magnetic field in the armature coil (where the voltage is generated in the generator) [5], [6]. It is called a synchronous generator because the number of rotations of the rotor is equal to the number of turns of the magnetic field in the stator. Generator speed regulation has two methods, namely by governor and excitation current regulation. Setting the excitation current is to regulate the excitation current that enters the generator. The excitation current enters the exciter to produce a voltage according to the excitation.

The working of the automatic voltage regulator (AVR) is to regulate the amplification current in the exciter. If the generator output voltage is below the nominal voltage of the generator voltage, the AVR increases the amplification current in the exciter. On the other hand, if the generator output voltage exceeds the nominal voltage of the generator, the AVR will reduce the excitation current in the exciter. Thus, if there is a change in the generator output voltage, the AVR can be stabilized automatically because it is equipped with equipment such as tools used to limit the minimum or maximum amplifier that works automatically.

An automatic voltage regulator (AVR) has an important role in the power system. This encourages efforts to improve AVR performance and maintain an efficient and stable response to transient changes in terminal voltage. The control technique that is popular and widely used by researchers to improve the AVR's ability to maintain a better response is the classic proportional-integral-derivative (PID). This control has a simple design and has the ability to handle changing system variations.

The PID method still has weaknesses in overcoming the problems of nonlinear loads, time delays and established operating values. Optimization techniques are widely used and popular in overcoming this problem by optimizing control parameters. Artificial intelligence methods are gaining popularity as optimization techniques for tuning control parameters. One of the popular artificial intelligence techniques used for optimization is the metaheuristic method. This method uses adaptive control theory which is easy to implement and suitable for complex analysis. several metaheuristic methods used to tune the parameters controlling on the AVR system are methods grasshopper optimization algorithm [7]–[9]. Whale optimization algorithm [10]–[12], sine–cosine-algorithm [13]–[15], Harris Hawks optimization [16]–[18] and black widow algorithm [19], [20] .

This paper discusses the application of the cooperation search algorithm (CSA) method to tune the PID parameters on the AVR. The CSA method can avoid being trapped in local minimum conditions by searching extensively throughout the space and having reflective learning so as to strike a good balance between global exploitation and local exploration. This results in the best solution. The CSA method also has an internal competition operator so that it can update the position of the solution in the vicinity of the destination point environment and then guarantee a better continuity of the solution. The performance and effectiveness of CSA are measured by making comparisons with other methods. In addition, variations of loading are used to determine the performance. The structure of the remaining paper is as follows: section 2 describes the CSA and AVR system design models. The results and analysis of the performance criteria are discussed in section 3. The results are summarized in section 4.

2. METHOD

2.1. Cooperation search algorithm (CSA)

The CSA method is an optimization that duplicates the work of a team within an enterprise [20]. The solution to this problem is assumed to be an employee. While a set of employees form a group in the company. The performance of each employee is assumed to be based on the value of the problem being handled. The popular solution is assumed by the supervisory board. A collection of external files is grouped as a board of directors. The chairman of the board of directors is chosen at random [21]. The concept of the CSA method is divided into 4 parts and can be detailed as:

2.1.1. The squad structuring part

Each employee in the team is a random variable as in (1). The leader's solution is selected from the initial value in an attempt to obtain an external elite set. This is done after evaluating all solutions.

$$x_{i,j}^{k} = \emptyset\left(\underline{x}_j, \overline{x_j}\right), i \in [1, l], i \in [1, j]\, , k = 1 \tag{1}$$

The number of solutions in the current swarm is i . $x_{i,j}^{k}$ is the jth value of the ith solution in the k-th cycle. Function to generate random numbers that are evenly distributed in the range $[i, j]$ is $\emptyset\left(\underline{x}_j, \overline{x_j}\right)$.

2.1.2. Squad communication organizer

It is applied to information pathways from leaders, boards of directors and supervisors to employees. Employees will always update the latest information. This can be modeled mathematically in (2). The information path is divided into 3 parts, namely information from the chairman (A), information from the board of directors (B) and information from supervisor (C). The chairman is chosen at random from the board of directors to simulate the rotation mechanism. The board of directors and supervisors have the same position.

$$u_{i,j}^{k+1} = x_{i,j}^{k} + A_{i,j}^{k} + B_{i,j}^{k} + C_{i,j}^{k}\, , i \in [1, l], i \in [1, j]\, , k \in [1, K] \tag{2}$$

$$A_{i,j}^{k} = \log\left(\frac{1}{\emptyset(0,1)}\right) . \left(gbest_{ind,j}^{k} - x_{i,j}^{k}\right) \tag{3}$$

$$B_{i,j}^{k} = \alpha \, . \, \emptyset(0,1)[\tfrac{1}{M}\sum_{m=1}^{M} gbest_{m,j}^{k} - x_{i,j}^{k}] \quad (4)$$

$$C_{i,j}^{k} = \beta \, . \, \emptyset(0,1)[\tfrac{1}{l}\sum_{i=1}^{l} pbest_{i,j}^{k} - x_{i,j}^{k}] \quad (5)$$

Where $u_{i,j}^{k+1}$ is the jth value of the i th group solution at $k+1$. The j-th value of the i-th personal best-known solution in the k-th cycle is $pbest_{i,j}^{k}$. $gbest_{m,j}^{k}$ is the j th value of the inth global most famous solution from start to k th cycle. ind is a randomly selected index from the set {1,2,. . . , M}. α and β are learning coefficients to adjust the degree of influence of $B_{i,j}^{k}$ and $C_{i,j}^{k}$.

2.1.3. Reflective knowledge organizer

These sessions are used to encourage the employee's overall effort by retaining the memory of previous information. this is to improve the ability of each employee. in this session can be modeled as (6).

$$x_{i,j}^{k+1} = \begin{cases} u_{i,j}^{k+1} \; if \; (F(u_i^{k+1} \le F\left(v_i^{k+1}\right)) \\ v_{i,j}^{k+1} \; if \; (F(u_i^{k+1} < F\left(v_i^{k+1}\right)) \end{cases} , \, , i \in [1,l], i \in [1,j]\,, k \in [1,K] \quad (6)$$

Where the fitness value of the solution x is $F(x)$. Each x variable is converted into a feasible zone with in (7). The fitness value $F(x)$is to enter the value constraint that deviates into the objective value $f(x)$ in (8). A feasible solution is obtained when all constraints are met properly so that the fitness value is the same as the original goal value. On the other hand, the solution is not feasible when the value of the constraint violation becomes positive. This makes the objective value smaller than the fitness value. With this method, swarms are encouraged to avoid viable search areas:

$$x_j = \max\left\{\min\{\overline{x_j}, x_j\}, \underline{x_j}\right\} \quad (7)$$

$$F(x) = f(x) + \sum_{e=1}^{e} c_e^1 \, . \max(g_e(x), 0\} + \sum_{f=1}^{f} c_f^2 \, . \, |h_f(x)\} \quad (8)$$

where the j th value in solution $x$to evaluate is x_j. c_e^1 penalty parameter for the dissimilarity limitation e- th. c_f^2 is penalty coefficient for the f-th dissimilarity limitation.

2.2. AVR system schematic

AVR is formed from four parts, namely: amplifier, exciter, generator, and sensor. V_t Is the synchronous generator terminal voltage [22], [23]. The AVR modeling can be seen in Figure 1. This voltage is identified by the sensor to be compared with a reference voltage (V_{ref}) through a comparator [24], [25]. The difference between the reference voltage (V_{ref}) and the sensor voltage (V_s) forms the error voltage (V_e) [26]. The error voltage (V_e) is the output of the comparator. The excitation current functions to manage the rotor field current in a synchronous generator.

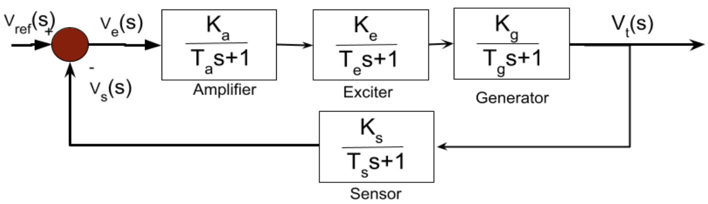

Figure 1. The AVR system [27], [28]

2.3. PID controller

Proportional-integral-derivative (PID) has a simple design and easy to implement so this makes PID more popular. PID has 3 important parts, namely proportional (k_p), integral (k_i)and derivative (k_d). The PID block diagram can be modeled as:

$$PID = k_p + \frac{k_i}{s} + sk_d \quad (9)$$

2.4. The proposed CSA controller in AVR system

The proportional integral derivate (PID) controller is the most widely applied feedback for several years. PID is a strong and easy to understand controller. In addition, PID provides excellent control performance despite having dynamic characteristics. The proposed CSA as PID control is used to get a better AVR system response. CSA -based controller design requires three important parameters, namely proportional (k_p), integral (k_i)and derivative (k_d). Figure 2 is a block diagram of the AVR with the proposed control.

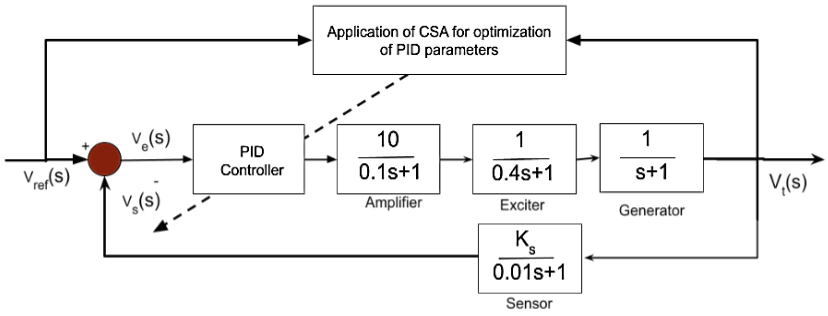

Figure 2. The AVR with PID-CSA

3. RESULTS AND DISCUSSION

CSA program code is written using Matlab/Simulink with an Intel i5 (2.2 GHz) processor and 8 GB Ram. CSA performance validation was compared with the WOA, GOA, PSO, and SCA methods. To determine the performance of the CSA method, the optimal function is used. Figure 3 is the convergence curve of the method used. The Figures 3 (a), (b), (c), (d), (e), (f) and (g) (see Appendix) is unimodal function. The Figure 3 (h), (i), (j), (k), (l), and (m) (see Appendix) is multi-modal function. The Figures 3 (n), (o), (p), (q), (r), and (s) (see Appendix) is composite function. PID control designs often use one of the following methods: integrated absolute error (IAE), the integral of squared-error (ISE), and integrated of time-weighted-squared-error (ITSE). The three methods can perform analytical evaluation well. All three methods have advantages and disadvantages. ISE and IAE have long turnaround times but can produce small overshoots. This is influenced by ISE and IAE calculating each error against time. On the other hand, ITSE can overcome the weaknesses of ISE and IAE. IAE, ISE and ITSE equations are as:

$$IAE = \int_0^\infty e(t).dt \tag{10}$$

$$ISE = \int_0^\infty e^2(t).dt \tag{11}$$

$$ITSE = \int_0^\infty t.e^2(t).dt \tag{12}$$

Initially, the AVR system was designed and set up. Simulations are run to obtain optimal parameter values using each method. The obtained PID parameters are shown in Table 1. The comparison of the simulation results obtained on the AVR system with different controls is shown in Figure 4. Table 2 is the result of the transient response of each method. in Table 2, the maximum overshoot value of the PID-CSA method has a better value of 4.85% than the PID-GOA method, 1.4% compared to PID-PSO, 7.7% compared to PID- SCA. On the other hand, the maximum overshoot value of PID-CSA is below the PID-WOA value of 16.46%.

Tabel 1 PID optimization value

Method	P	I	D
PID - WOA [10]	0.7847	0.9961	0.3601
PID - GOA [9]	1.3825	1.4608	0.5462
PID - PSO [29]	1.7774	0.3827	0.3184
PID - SCA [30]	0.9826	0.8337	0.4982
PID - CSA	0.9265	0.645	0.2875

Tabel 2 Transient Response of the AVR System

Method	Rise Time	Maximum Overshoot	Settling Time	Peak Time
PID - WOA [9]	0.26	1.07	0.55	0.432
PID - GOA [8]	0.13	1.2	0.97	0.286
PID - PSO [29]	0.161	1.27	1	0.383
PID - SCA [30]	0.138	1.168	0.724	0.304
PID - CSA	0.198	1.12	0.9	0.345

CSA method as PID control was tested with variations in loading changes, namely increasing + 50% and decreasing 50%. The parameters changed were the time constants of the exciter (T_e), and generator (T_g). In testing the load variation by increasing the time constant of the exciter (T_e) by + 50% which can be seen in Table 3. The maximal overshoot value of the proposed method is 17.7% better than the PID-GOA method, 7.9% compared to the PID-PSO and 9.44% compared to the PID-SCA method. Meanwhile, by reducing the time constant of the exciter (T_e) by -50%, the PID-CSA method was 19.2% better than the PID-GOA method, 19.7% compared to the PID-PSO method and 11% compared to the PID-SCA method. Table 4 is the detail of the test by reducing the time constant of the exciter (T_e) by -50%.

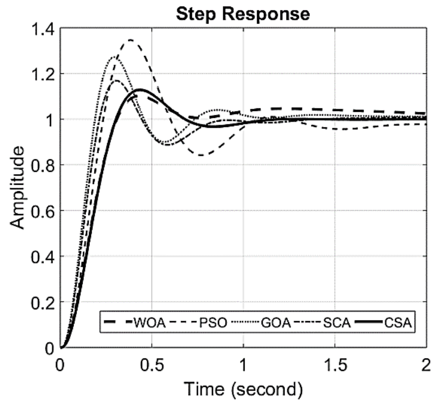

Figure 4. Terminal voltage output graph of the AVR system for several algorithms

Tabel 4. Transient response from AVR with T_e -50%

Method	Rise Time	Maximum Overshoot	Settling Time
PID - WOA	0.13	1.11	2.19
PID - GOA	0.103	1.348	1.5
PID - PSO	0.08	1.353	0.862
PID - SCA	0.089	1.255	1.284
PID - CSA	0.13	1.13	1.58

Tabel 3. Transient response from AVR with T_e +50%

Method	Rise Time	Maximum Overshoot	Settling Time
PID - WOA	0.262	1.128	2.09
PID - GOA	0.188	1.346	2.12
PID - PSO	0.158	1.235	1.453
PID - SCA	0.183	1.252	0.899
PID - CSA	0.257	1.144	1.08

Tabel 5. Transient response from AVR with T_g +50%

Method	Rise Time	Maximum Overshoot	Settling Time
PID - WOA	0.284	1.089	2.42
PID - GOA	0.197	1.2855	1.3
PID - PSO	0.165	1.182	2.02
PID - SCA	0.194	1.074	2.685
PID - CSA	0.277	1.09	1.16

Tabel 6. Transient response from AVR with T_g -50%

Method	Rise Time	Maximum Overshoot	Settling Time
PID - WOA	0.118	1.21	0.693
PID - GOA	0.097	1.46	1.66
PID - PSO	0.076	1.4595	1.22
PID - SCA	0.084	1.3586	1.35
PID - CSA	0.119	1.24	1.3

Testing by increasing the time constant of the generator (Tg) by + 50%. Table 5 shows the details of the test. The maximal overshoot value of the proposed method is 8.9% better than the PID-GOA method, and 0.5% compared to the PID-PSO method. On the other hand, the PID-SCA method is 1.46% better than the PID-CSA method and the PID-WOA method is 0.09% better than the PID-CSA method. Testing by reducing the time constant of the generator (Tg) by -50%. Table 6 shows in detail the test by reducing the time constant of the generator (Tg) by -50%. The maximal overshoot value of the proposed method is 17.74% better than the PID-GOA method, 17.7% compared to the PID-PSO method and 9.56% from the PID-SCA method. On the other hand, the PID-WOA method is 2.41% better than the PID-CSA method.

4. CONCLUSION

The AVR functions to maintain the synchronous generator voltage in the nominal position when there is a change in load. The AVR control functions to increase stability and get a high response. The optimization method is used to reduce and minimize errors or deviations in the control parameter settings in the AVR. The latest parameter setting method is presented based on CSA to obtain optimal PID parameters. The CSA method is repeated based on maximum iterations to get the PID parameter value based on the integral of time multiplied squared error (ITSE). By using 3 experiments, namely normal conditions, changes in the time constant of the exciter and changes in the time constant of the generator, the average maximum overshoot value obtained from the PID-CSA method is 13.68% better than the PID-GOA method, 9.44% from the PID-PSO method and 9.84 % of the PID-SCA method.

APPENDIX

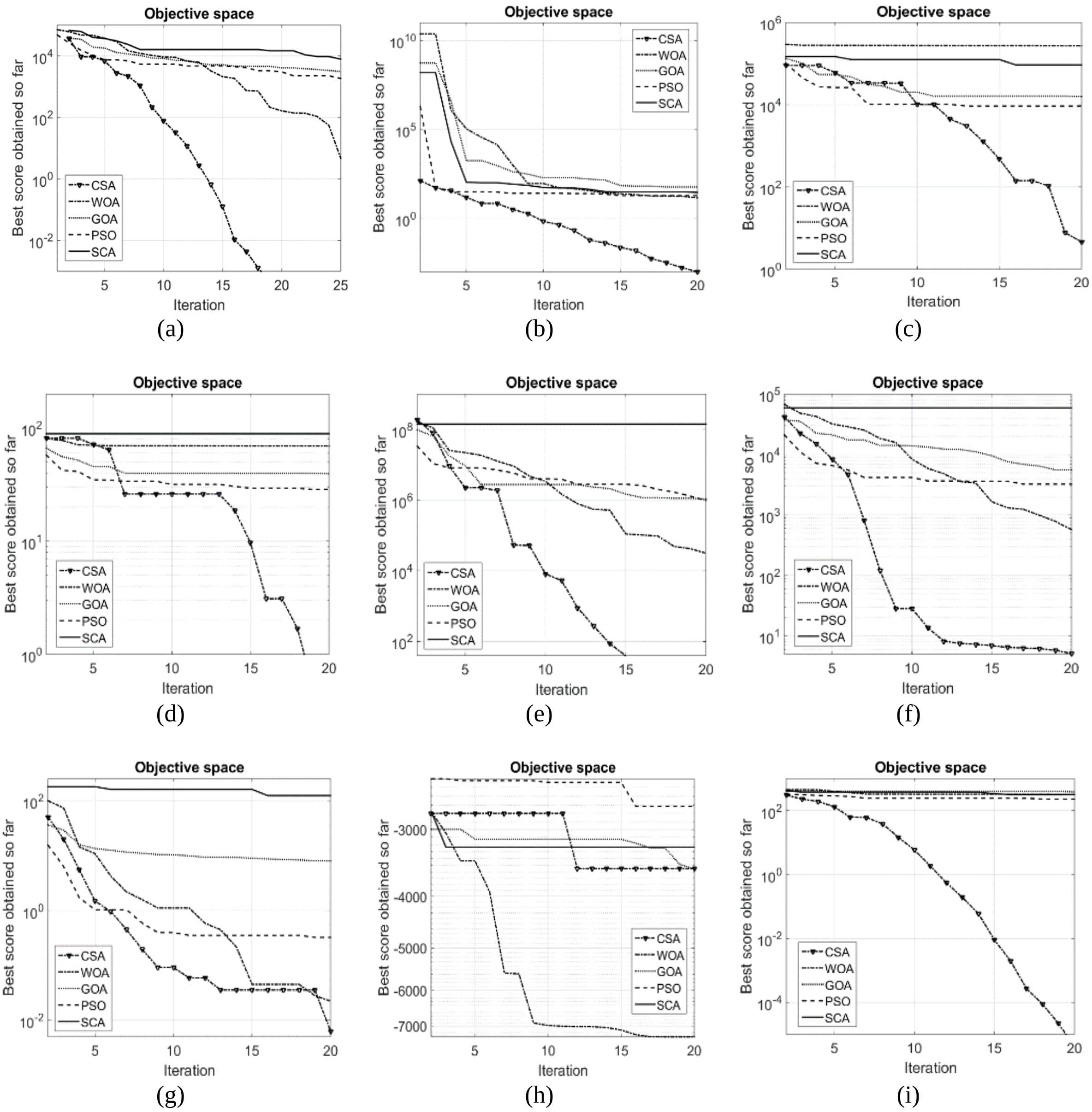

Figure 3. The convergence curve of benchmark function, (a) F1, (b) F2, (c) F3, (d) F4, (e) F5, (f) F6, (g) F7, (h) F8, and (i) F9

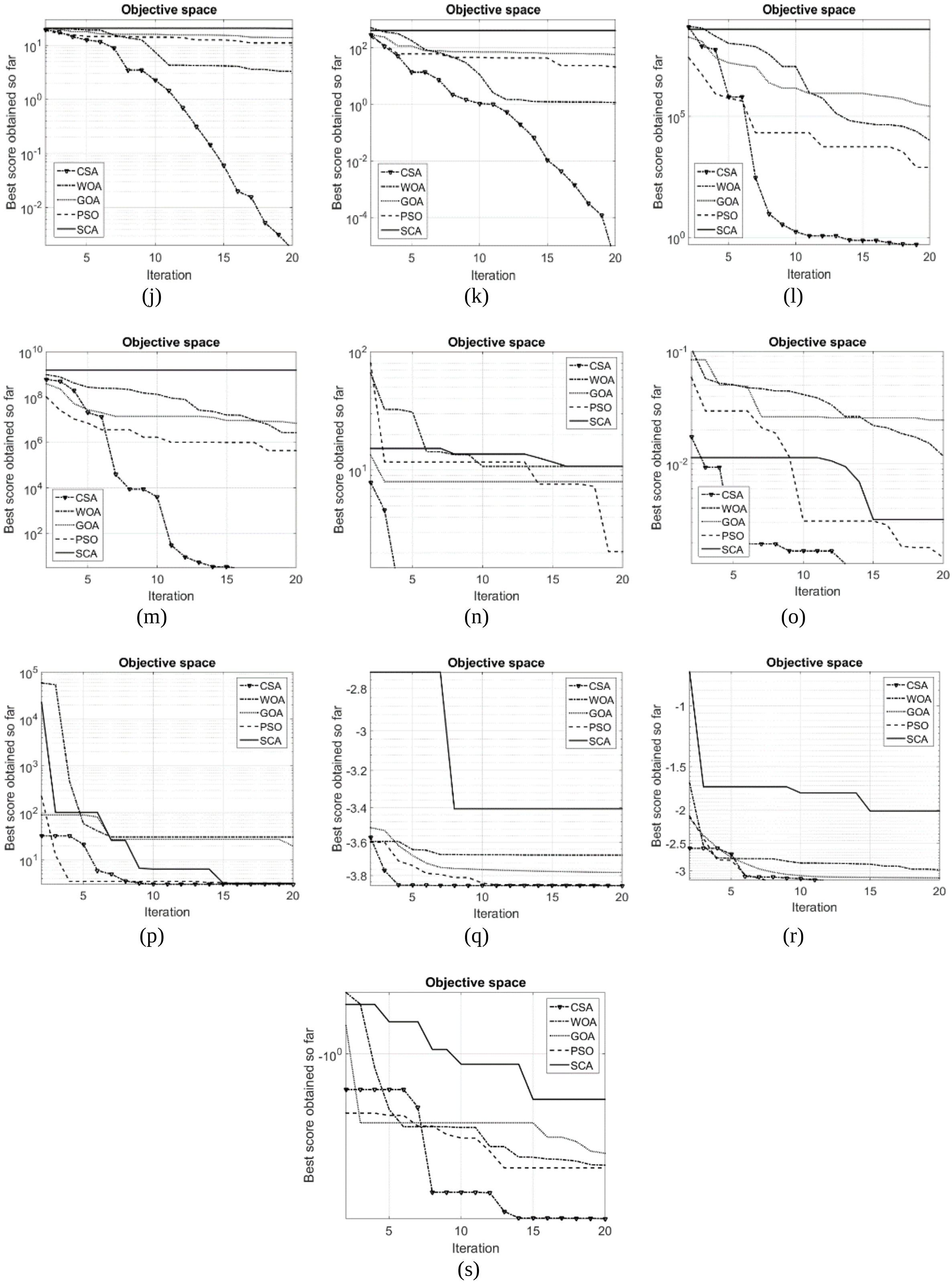

Figure 3. The convergence curve of benchmark function, (j) F10, (k) F11, (l) F12, (m) F13, (n) F14, (o) F15, (p) F16, (q) F17, (r) F18, and (s) F19 (continue)

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