OPTIMUM UNIT COMMITMENT SOLUTION OF A POWER SYSTEM BASED ON SALP SWARM ALGORITHM

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Abstract: This paper presents an algorithm to solve the unit commitment problem in a power system. The proposed algorithm employs the Salp swarm algorithm technique to search the optimum unit schedule for a particular daily demand pattern and specific time horizon. Different constraints are taken into consideration, transition cost (start-up and shut down) cost, mean-up time, mean-down time, spinning reserve, and power balance. The proposed algorithm is applied to 10-units and 26-unit. The obtained results are compared with other methods. It reveals the robustness of the proposed algorithm in terms of minimizing overall running costs.

Keywords *Unit Commitment, Salp Swarm Algorithm, Minimum Operating Cost, Load Demand*

1. Introduction

The change in human lifestyle and the tremendous development in large industrial projects in recent years are among the factors that have led to an increase in electrical energy consumption. Under these circumstances, energy companies and investors are struggling to meet the evolution of energy consumption by making a trade-off between maintaining an adequate security margin and supplying the power with a low operational cost. To this end, an optimum unit commitment is aimed to support such activities. Based on a particular load forecast, the objective of optimum unit commitment analysis is to determine the

commitment schedule of start-up and shut-down of generating units over a specific time horizon to match the forecasted load with minimum operation cost. The time horizon of the analysis may be carried out daily (24 hours) or every week (126 hours) [1].

Generally, there are two types of constraints to be satisfied in solving the unit commitment problem UCP. The first kinds of these constraints are related to the power system such as transmission restrictions and power reserve restrictions which will be required in case of a sudden increase in demand or the generator disconnection from the power system due to emergency conditions. The second kinds of constraints are related directly with generating units such as slope limit, slope limit, and limit Lowest to highest and downtime [2].

UCP is a nonlinear optimization problem. In the past five decades, UCP has been addressed with different approaches. One of these approaches is the traditional optimization techniques such as priority list [3][4], dynamic programming.[5], Lagrange relaxation technique [6][7], branching and delimiting approaches [8], and mixed-integer linear program [9]. Other researchers have tackled the problem from a stochastic point

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of view[10]. Artificial intelligence techniques have been applied for solving UCP, evolutionary Programming [11], simulated annealing [12] particle swarm optimization [13], Genetic Algorithm (GA) [14], hybrid PSO, Grey Wolf Optimizer (PSO-GWO)[20], Particle Swarm Optimization (PSO) [21], priority list based evolutionary algorithm (PLEA) [25] and Ant Colony Search Algorithm (ACSA) [19]

This paper presents an optimum solution for the unit commitment problem based on Salp Swarm Algorithm [SSA], a proposed optimization technique, was used to solve the unit commitment problem for a 10-unit power system and a 26-unit power system. Mirjalili and colleagues proposed this algorithm in 2017[15]. It's a bio-inspired algorithm based on the salps' behavior. One of the benefits of this algorithm is that it can solve both uni-modal and multimodal functions equally well. The structure of the paper is as follows: The problem formulation is given in section 2. An overview of the Salp swarm algorithm is presented in section3. In Section 4, the application of the proposed algorithm to a typical system is described with the result obtained. The conclusion drawn by the proposed algorithm is given in section5.

2. Problem Formulation

2.1. Objective Function

The main objective of the unit commitment study is to reduce the total operating cost (fuel cost) and transitions costs (start-up and shut-down) costs of generating units in a power system over time while adhering to all restrictions. The mathematical equation for minimizing total costs can be formulated as in the form [16]:

$$PC_{total} = \sum_{t=1}^T \sum_{g=1}^N [f_{gk}(p_{gk}) + STC_{gk}(1 - U_{g(k-1)}) + SDC_{gk}(1 - U_{gk})] U_{gk} \quad (1)$$

The fuel cost function of the unit can be expressed as a second-order function as shown:

$$f_{gk}(p_{gk}) = a_g p_{gk}^2 + b_g p_{gk} + c_g \quad (2)$$

A thermal generation unit is not connected to the grid until the steam reaches a certain temperature and pressure, which increases the plant's performance. The fuel input to the unit from cold to the level that it can be connected to the grid produces no electric energy but is incredibly important, which is referred to as start-up cost. The startup cost is not fixed since it is determined by the unit's initial state. The start-up cost is highest if the unit was previously in a cold state. The start-up cost is much lower if the unit was recently turned off and is already close to running temperature and pressure the first one is known as cold start-up cost and the second is known as a banking start-up cost. The two types of start-up costs are described as follows:

$$STC_{gk} \begin{cases} HSC_g & \text{if } MDT_g \leq T_g^{off} \leq MDT_g + CSH_g \\ CSC_g & \text{if } T_g^{off} > MDT_g + CSH_g \end{cases} \quad (3)$$

2.2. The Constraints

The objective function of a unit's commitment must meet a list of restrictions, which can be classified into two types:

2.2.1. System constraints

System constraints or maybe called coupling constraints, The coupling constraints are related to the system conditions and all the generators that state ON in-service) :

2.2.1.1 The sum of the generator's output power $[P_{gk}]$ must be equivalent to the load demand $[LD_k]$ at each period:

$$\sum_{g=1}^N P_{gk} U_{gk} = LD_k \quad (4)$$

2.2.1.2 Spinning reserves are to deal with emergency and sudden disturbances that

occur in the power system, such as (interruption of generation and transmission lines or an unexpected increase in load demand), and it must be dealt with quickly to avoid problems in the electrical system or to deal with the scheduled plans of the system such as (maintenance operations Planned for generating units or transmission lines and for a certain period. therefore, The power reserve is being used to substitute for a reduction in the amount of power delivered:

$$\sum_{g=1}^N P_g^{max} \cdot U_{gk} \geq LD_k + SR_k \quad (5)$$

2.2.2. Generator constraints

Generator constraints or maybe called local constraints, it is related to generators conditions and classified into:

2.2.2.1 the power output of each generation unit must be within the maximum and minimum value of generator capacity, this constraint can be expressed as follow:

$$P_g^{max} \geq P_{gk} \geq P_g^{min}. \quad (6)$$

2.2.2.2 Minimum Up-time [MUT_g] and minimum Down-time [MDT_g] restriction: Once committed or de-committed, the unit cannot be turned ON or OFF immediately. The minimum downtime constraints specify the number of periods that must take before the unit's status can be changed

$$T_g^{on} \geq MUT_g \quad (7)$$

$$T_g^{off} \geq MDT_g \quad (8)$$

3. Salp Swarm Algorithm [SSA]

Complex optimization problems are commonly solved using swarm intelligence algorithms. In 2017 a new meta-heuristic algorithm was presented by Mirjalili et al[15]. called the Salp Swarm Algorithm. Salps, which are members of the salpidae tribe, have a translucent body and

resemble jellyfish; some scientists have discovered that it has a feature in swarming, which is the unique behavior of the subspecies. They attributed this behavior to the ability of the breeds to achieve better mobility and foraging. In the deep seas, salps almost create swarms known as salp chains. As seen in Figure 1, the salp chain population is split into two groups: leaders and followers. The leader is the first in the swarm, following the food source and guiding the rest of the swarm's followers.

Figure 1. Illustration of salp's chain and the concept of leader and follower [24]

The position of all salps is saved in a two-dimensional matrix known as X . The SSA algorithm assumes that there is a food source called F in the search space as the swarm target. The positions of salps can be represented as shown [15]:

$$X_j^1 \begin{cases} F_j + c_1 ((ub_j - lb_j) * c_2 + lb_j) & \text{if } c_3 \leq 0.5 \\ F_j - c_1 ((ub_j - lb_j) * c_2 + lb_j) & \text{if } c_3 > 0.5 \end{cases} \quad (9)$$

The parameters c_2 and c_3 are random numbers that are uniformly generated in the range $[0, 1]$. They determine the size of each step and the direction of the movement, positive or negative. The coefficient c_1 is the most important parameter in SSA. The equation that balances exploration and exploitation is:

$$c_1 = 2e^{-\left(\frac{4t}{itermax}\right)^2} \quad (10)$$

Where itermax. is maximum iterations and t is the current iteration. According to newton's motion law follower salps update position as:

$$X_j^i = \frac{1}{2}at^2 + v_0t^* \quad (11)$$

Where:

$j \geq 2$

X_j^i : position of i-th follower salps in jth dimensions.

t^* : time.

v_0 : Initial velocity

$$a = \frac{v_{final}}{v_0} \quad (12)$$

$$v = \frac{x - x_0}{t} \quad (13)$$

Since time in the optimization process denotes iteration, the variance between iterations equals 1, and considering $v_0 = 0$, Equation (11) can be rewritten as follows:

$$X_j^i = \frac{1}{2}(X_j^i + X_j^{i-1}) \quad (14)$$

The algorithm and flowchart of Salp Swarm Algorithm SSA are shown in Fig2.

3.1. Correlation between SSA and Problem statement:

The number of variables denotes the total number of generating units. Each search agent (salp) represents the random allocation of power output among different generating units to meet the load demand. A number of such salps constitute the population. Here, ub_j and lb_j are the maximum and minimum generation capacities of generators. The food source F is the best fitness (minimum cost) value among all the fitness values calculated using Eq. (1). F_j represents its distribution among all the generators. The allocated load demand among the generators for the first population is amended by Eq. (9). For the rest of the population, it is done by Eq. (14).

Algorithm of Salp Swarm Algorithm [SSA]

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Initialize a swarm of salp  $x_i$  ( $i=1,2,\dots,n$ )
While (iteration condition is not meet) do
  Calculate the fitness of each salp in swarm
  Set F as a position of best salp
  Update  $c_1$  by Eq. (10)
  For (each salp ( $x_i$ )) do
    If  $i=1$  then
      Update leader position by Eq. (9)
    else
      Update leader position by Eq. (14)
    end if
  end for
  check and return salps if go beyond  $ub$  and  $lb$  bonds
end while
Return F

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Figure 2. Flowchart of SSA

4. Results

Simulations are performed using the MATLAB of the test systems that consists of 10 – units and 26-units at a 1-day time with 10% spinning reserve for this horizon time.

4.1. Power system with 10-units

The number of population and maximum iterations are 20 and 100 respectively for system 10-unit that achieve minimum cost. In this case, the spinning reserve is specified as 10% from load Figure 3 shows the cost convergence characteristics. Table 1 shows demand load for 24h and Table 2 is clarifying the data and parameters of 10 generation units [3]. Table 3 represents the output power and scheduling of the generator and the total operation cost obtained by applying the salp swarm algorithm is (563937 \$/day) and computation time was (42.23 sec.) It represents the minimum operating cost for the system at 24h time horizon, as shown in table 4.

Table 1. load demand for 10-unit generation

Hour	LD [MW]	Hour	LD [MW]
1	700	13	1400
2	750	14	1300
3	850	15	1200
4	950	16	1050
5	1000	17	1000
6	1100	18	1100
7	1150	19	1200
8	1200	20	1400
9	1300	21	1300
10	1400	22	1100
11	1450	23	900
12	1500	24	800

Table 2. Data and parameters of 10-unit generation

	$P_{max.}$ (MW)	$P_{min.}$ (MW)	a_g (\$/h)	b_g (\$/MWh)	c_g (\$/MW ² h)	MUT (h)	MDT (h)	HSC (\$)	CSC (\$)	CS H (h)	In. stat (h)
Unit 1	455	150	1000	16.9	0.00048	8	8	4500	9000	5	8
Unit 2	455	130	970	17.26	0.0003	8	8	5000	10000	5	8
Unit 3	130	20	700	16.6	0.002	5	5	550	1100	4	-5
Unit 4	130	20	680	16.5	0.0021	5	5	650	1120	4	-5
Unit 5	162	25	450	19.7	0.0039	6	6	900	1800	4	-6
Unit 6	80	20	370	22.026	0.00071	3	3	170	340	2	-3
Unit 7	85	25	480	27.74	0.00079	3	3	260	520	2	-3
Unit 8	55	10	660	25.92	0.0041	1	1	30	60	0	-1
Unit 9	55	10	665	27.27	0.0022	1	1	30	60	0	-1
Unit 10	55	10	670	27.79	0.0017	1	1	30	60	0	-1

Table 3. output power and scheduling of the system 10-unit generation for 24h

H	Combination	Unit1	Unit2	Unit3	Unit4	Unit5	Unit6	Unit7	Unit8	Unit9	Unit10	load	R
1	1100000000	455	245	0	0	0	0	0	0	0	0	700	210
2	1100000000	455	295	0	0	0	0	0	0	0	0	750	160
3	1100100000	455	370	0	0	25	0	0	0	0	0	850	247
4	1100100000	455	455	0	0	40	0	0	0	0	0	950	122
5	1101100000	455	390	0	130	25	0	0	0	0	0	1000	202
6	1111100000	455	360	130	130	25	0	0	0	0	0	1100	232
7	1111100000	455	410	130	130	25	0	0	0	0	0	1150	182
8	1111100000	455	455	130	130	30	0	0	0	0	0	1200	132
9	1111111000	455	455	130	130	85	20	25	0	0	0	1300	197
10	1111111000	455	455	130	130	162	33	25	0	0	0	1400	152
11	1111111100	455	455	130	130	162	73	25	10	0	0	1450	157
12	1111111111	455	455	130	130	162	80	25	10	10	10	1500	162
13	1111111110	455	455	130	130	162	33	25	43	10	0	1400	152
14	1111111100	455	455	130	130	85	20	25	10	0	0	1300	197
15	1111100000	455	455	130	130	30	0	0	0	0	0	1200	132
16	1111100000	455	310	130	130	25	0	0	0	0	0	1050	277
17	1111100000	455	260	130	130	25	0	0	0	0	0	1000	332
18	1111100000	455	360	130	130	25	0	0	0	0	0	1100	232
19	1111100000	455	455	130	130	30	0	0	0	0	0	1200	132
20	1111111100	455	455	130	130	162	33	25	10	0	0	1400	152
21	1111111000	455	455	130	130	85	20	25	0	0	0	1300	197
22	1100111000	455	455	0	0	145	20	25	0	0	0	1100	137
23	1100010000	455	425	0	0	0	20	0	0	0	0	900	90
24	1100000000	455	345	0	0	0	0	0	0	0	0	800	110

Figure 3. Cost convergence characteristics of 10 units

Table 4 clarify compares the results of the operating cost of the unit commitment problem solved by different techniques and the Salp Swarm Algorithm [SSA]. Most of these methods have the problem of falling into the local minima .The difference between the total operating cost in [PLEA] and the total operating cost in [SSA] is (40 \$), This difference is due to the selection of the best operation of the units incertain periods of time and the extinguishing of other generating units and the distribution of their loads to units with lower operating costs, which affected the final result of the total operating cost

Table 4. Total operating cost compared the SSA and different methods for 10-unit

Method	Total Operation COST(\$/day)
LR[17]	565,673
PL[3]	564,835
ACSA[19]	564,049
GA[18]	566,404
PSOGWO[20]	565,210
PLEA[25]	563,977
SSA	563,937

4.2. Power System with 26-Units

The second system is used to check another system that consists of 26 different large generation units. Table 6 lists the unit data and parameters for these units [26]. Table 5 shows the load demand for 24h [26] and Table 8 shows the output power of each generation unit and the scheduling of these units at the time. The results obtained by applying the proposed algorithm Salp Swarm Algorithm is (721182 \$/day) at the number of population 20 and maximum iteration 100.computation time was (74.89sec.)

Figure 4 shows the cost convergence characteristics of 26 units Table 7 is clarified compares the result obtained from the salp swarm algorithm [SSA] with the other methods this shows there are differences in results and there is improvement and minimizing in the operation cost.

There are some observations are mentioned below to show how the suggested salp chain model and SSA algorithm are successful in solving optimization problems including UCP:

1. SSA algorithm saves the best solution obtained so far and assigns it to the food source variable.
2. The SSA algorithm only updates the position of the leading salp in comparison to the food source.
3. SSA algorithm updates relative positions of follower salps so that they gradually.
4. SSA algorithm uses follower slap movements to avoid local optima.
5. Parameter c_1 is decreased adaptively for iterations, so the SSA algorithm first explores the search space and then exploits it.
6. There is just one key control parameter in the SSA algorithm c_1 .
7. The SSA algorithm is simple, quick to use, and reliable when it comes to finding the best solution.

Table 5. load demand for 26-unit generation

Hour	LD [MW]	Hour	LD [MW]
1	1700	13	2590
2	1730	14	2550
3	1690	15	2620
4	1700	16	2650
5	1750	17	2550
6	1850	18	2530
7	2000	19	2500
8	2430	20	2550
9	2540	21	2600
10	2600	22	2480
11	2670	23	2200
12	2590	24	1840

Table 6. Data and parameters of 26- generation units

unit	$P_{max.}$ (MW)	$P_{min.}$ (MW)	a_g (\$/h)	b_g (\$/MWh)	c_g (\$/MW ² h)	MUT (h)	MDT (h)	HSC (\$)	CSC (\$)	CSH (h)	In.stat (h)
1	400	100	311.9102	7.5031	0.0019	8	5	500	500	10	10
2	400	100	310.0021	7.4921	0.0019	8	5	500	500	10	10
3	350	140	177.0575	10.8616	0.0015	8	5	300	300	8	10
4	197	68.95	260.176	23.2	0.0026	5	4	200	200	8	-4
5	197	68.95	259.649	23.1	0.0026	5	4	200	200	8	-4
6	197	68.95	259.131	23	0.0026	5	4	200	200	8	-4
7	155	54.25	143.5972	10.7583	0.0049	5	3	150	150	6	5
8	155	54.25	134.3179	10.7367	0.0048	5	3	150	150	6	5
9	155	54.25	143.0288	10.7154	0.0047	5	3	150	150	6	5
10	155	54.25	142.7348	10.694	0.0046	5	3	150	150	6	5
11	100	25	218.7752	18.2	0.006	4	2	70	70	4	-3
12	100	25	218.335	18.1	0.0061	4	2	70	70	4	-3
13	100	25	217.8952	18	0.0062	4	2	70	70	4	-3
14	76	15.2	81.6259	13.4073	0.0093	3	2	50	50	3	3
15	76	15.2	81.4681	13.3805	0.0091	3	2	50	50	3	3
16	76	15.2	81.298	13.3538	0.0089	3	2	50	50	3	3
17	76	15.2	81.1364	13.3272	0.0088	3	2	50	50	3	3
18	20	4	118.8206	37.8896	0.0143	0	0	20	20	2	-1
19	20	4	118.4576	37.777	0.0136	0	0	20	20	2	-1
20	20	4	118.1083	37.6637	0.0126	0	0	20	20	2	-1
21	20	4	117.7551	37.551	0.012	0	0	20	20	2	-1
22	12	2.4	24.8882	26.0611	0.0285	0	0	0	0	1	-1
23	12	2.4	24.7605	25.9318	0.0284	0	0	0	0	1	-1
24	12	2.4	24.6382	25.8027	0.028	0	0	0	0	1	-1
25	12	2.4	24.411	25.6753	0.0265	0	0	0	0	1	-1
26	12	2.4	24.3891	25.5472	0.0253	0	0	0	0	1	-1

Table 7. The total cost produced by the SSA and different methods for 26-unit

Method	Total Cost (\$/day)
ILR[22]	725996
QBPSO[23]	726037
BPSO[23]	721965
SSA	721182

Figure 4. Cost convergence characteristics of 26 units

Table 8. output power and scheduling of the system 26-unit generation for 24h

H	U1	U2	U3	U4	U5	U6	U7	U 8	U9
1	400	400	331.1455	0	0	0	114.6412	118.3165	122.5693
2	400	400	344.2678	0	0	0	118.7638	122.4906	126.8139
3	400	400	333.42	0	0	0	115.3558	119.04	123.305
4	400	400	336.7443	0	0	0	116.4002	120.0975	124.3803
5	400	400	350	0	0	0	122.2489	126.0192	130.4022
6	400	400	350	0	0	0	140.5688	144.5676	149.2643
7	400	400	350	0	0	0	155	155	155
8	400	400	350	68.95	68.95	68.95	155	155	155
9	400	400	350	68.95	68.95	68.95	155	155	155
10	400	400	350	68.95	68.95	80.9	155	155	155
11	400	400	350	70.7501	90.7972	110.4528	155	155	155
12	400	400	350	68.95	68.95	70.9	155	155	155
13	400	400	350	68.95	68.95	70.9	155	155	155
14	400	400	350	68.95	68.95	68.95	155	155	155
15	400	400	350	68.95	73.1313	92.7187	155	155	155
16	400	400	350	68.95	84.9086	104.5414	155	155	155
17	400	400	350	68.95	68.95	68.95	155	155	155
18	400	400	350	68.95	68.95	68.95	155	155	155
19	400	400	350	68.95	68.95	68.95	155	155	155
20	400	400	350	68.95	68.95	68.95	155	155	155
21	400	400	350	68.95	68.95	80.9	155	155	155
22	400	400	350	68.95	68.95	68.95	155	155	155
23	400	400	350	0	0	68.95	155	155	155
24	400	400	350	0	0	0	138.1262	142.0945	146.7494

H	U10	U11	U12	U13	U14	U15	U16	U17	U18
1	127.5276	0	0	25	15.2	15.2	15.2	15.2	0
2	131.8639	0	0	25	15.2	15.2	15.2	15.2	0
3	128.2792	0	0	25	0	15.2	15.2	15.2	0
4	129.3777	0	0	25	0	15.2	15.2	15.2	0
5	135.5297	0	0	25	15.2	15.2	15.2	15.2	0
6	154.7992	0	25	25	15.2	15.2	15.2	15.2	0
7	155	25	25	25	33.798	36.0876	38.184	40.5305	0
8	155	42.5362	49.7331	56.8807	76	76	76	76	0
9	155	79.9895	86.3296	92.831	76	76	76	76	0
10	155	100	100	100	76	76	76	76	0
11	155	100	100	100	76	76	76	76	0
12	155	100	100	100	76	76	76	76	0
13	155	100	100	100	76	76	76	76	0
14	155	83.3943	89.6565	96.0992	76	76	76	76	0
15	155	100	100	100	76	76	76	76	0
16	155	100	100	100	76	76	76	76	0
17	155	83.3943	89.6565	96.0992	76	76	76	76	0
18	155	76.5846	83.0026	89.5628	76	76	76	76	0
19	155	66.3701	73.0218	79.7581	76	76	76	76	0
20	155	83.3943	89.6565	96.0992	76	76	76	76	0
21	155	100	100	100	76	76	76	76	0
22	155	59.5604	66.3679	73.2217	76	76	76	76	0
23	155	25	25	25	65.3397	68.3919	71.0298	74.0886	0
24	152.2299	0	25	25	15.2	15.2	15.2	15.2	0

H	U19	U20	U21	U22	U23	U24	U25	U26
1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0
4	0	0	0	2.4	0	0	0	0
5	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0
7	0	4	0	0	2.4	2.4	0	2.4
8	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
10	0	0	0	0	0	2.4	2.4	2.4
11	4	4	4	2.4	2.4	2.4	2.4	2.4
12	0	0	0	0	0	2.4	2.4	2.4
13	0	0	0	0	0	2.4	2.4	2.4
14	0	0	0	0	0	0	0	0
15	0	0	4	2.4	2.4	2.4	2.4	2.4
16	0	4	4	2.4	2.4	2.4	2.4	2.4
17	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0
21	0	0	0	0	0	2.4	2.4	2.4
22	0	0	0	0	0	0	0	0
23	0	4	0	0	0	0	2.4	0
24	0	0	0	0	0	0	0	0

5. Conclusions

An algorithm was presented to solve the optimum unit commitment problem. From Table 4 and Table 8 the comparison between the proposed algorithm and the other shows differences in total operation cost, since artificial intelligence techniques are more effective than traditional approaches. The reasons for this superiority, as well as the parameters settings and system coding, are far more straightforward than old techniques. Moreover, some algorithms have disadvantages to the local minima solution. The optimization process was based on the Slap swarm algorithm. The different operational and transition constraints were taken into consideration. The proposed algorithm was applied to the power system of a 10-unit and 26-unit simulation over a 24-hour time horizon, and the operating cost was kept to a minimum. The results revealed that the Salp Swarm Algorithm [SSA] is more stable and capable of finding a solution, and it's able to solve the large power system. Furthermore, the proposed algorithm succeeded in satisfying all the restrictions of the UCP.

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Abbreviations

SSA	Salp Swarm Algorithm
UCP	Unit Commitment Problem
PC_{total}	total production cost
T	Period
N	Number of generation units
K	Index of time
g	Index of generator
f_{gk}	fuel cost function.
U_{gk}	generator state which is either 1 or 0 at period k (1=ON,

	0=OFF).
p_{gk}	output power from generator g at time k
STC_{gk}	the start-up cost of generator g at time k
SDC_{gk}	shut-down cost of generator g at time k
a_g, b_g and c_g	fuel cost coefficients of generator g
HSC_g	the hot start-up cost of generator g.
CSC_g	the cold start-up cost of generator g
CSH_g	Cold-start hour generator g.
MDT_g	minimum downtime
MUT_g	minimum uptime
T_g^{on}	time of the unit g is continuously ON.
T_g^{off}	time of the unit g is continuously OFF.
P_{gk}	generator's output power
LD_k	load demand at time k
$P_g^{max.}$	maximum power capacity of generator g
$P_g^{min.}$	minimum power capacity of generator g
SR_k	spinning reserve of the power system at time k
X_j^1	position of the first salp (leader) in j-dimension
F_j	food source position in j-dimension
ub_j and lb_j	upper and lower boundaries in j-dimension respectively
c_2, c_3	random numbers in the interval [0,1]
X_j^i	position of i-th follower salps in jth dimensions
t^*	time
v_0	initial velocity
itermax	maximum iterations
t	Current iteration

ILR	Improved Lagrangian Relaxation
QBPSO	Quantum Inspired Binary Particle Swarm Optimization
BPSO	Binary Particle Swarm Optimization

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