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SCHEDULING OF THERMAL UNIT ON HOURLY BASIS USING NOVEL HYBRID WOA-SOMA

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ABSTRACT

The effective utilization of available sources in equating the load demand on an hourly basis can be implemented using unit commitment. This paper presents the novel hybrid method which is the amalgamation of a whale optimization algorithm (WOA) and a self-organizing migrating algorithm (SOMA) for obtaining the optimal value of an optimization problem related to unit commitment. The WOA method is applied for assessing optimal strength population from the stochastically generated populations which is essential in a migrating loop. SOMA works on the strategy of ALL to ALL. Two test systems are considered to evaluate the potential of the proposed hybrid method. Initially, a four-unit system is conducted followed by IEEE 39 bus system. The obtained simulation outcome is made comparison with the literature methods to address the effectiveness of the proposed hybrid WAO-SOMA.

Keywords: unit commitment, migration loop, self-organizing migrating, whale optimization, optimization.

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1. INTRODUCTION

These days, it seems like everyone you meet has some connection to electricity. The production of electricity may make use of thermal units. Avoiding wasteful combustion requires efficient use, in order to convert thermal energy into usable electricity. As a direct result of this motivation, numerous academics have taken on the herculean challenge of finding ways to lower the overall cost while still adhering to the system's limits. It may be rather costly to keep all the heating and cooling systems running to meet a certain demand.

Costs may be reduced by better coordination of active power production among thermal units. Planning and scheduling of thermal units result in optimization difficulties which are frequently dubbed unit commitment (UC) in power systems [1]. Unit commitment includes an analysis of the shutdown and restart schedule of the power-producing unit. The two suggestions most closely linked to UC are economic dispatch and unit scheduling. The prediction of on/off generating units is represented by unit scheduling and the dispatching of generation among the thermal units is assessed by economic dispatch [2]. A non-convex, non-linear, mixed-integer combinatorial optimization problem [3] describes the UC optimization problem.

UC determines how well power plants are doing to keep up with demand. The ideal solution for the UC optimization issue requires the evaluation of viable combinations of generating units as the load fluctuates. The primary goal of finding a solution to the UC issue is to evaluate the best cost solution, which is constrained in several ways. The goal function, originally shown as a convex quadratic [4] in the absence of constraints, will be transformed into a non-convex one. Spinning reserve, ramp rate restrictions, personnel restraints, power capacity limits, etc. are all examples of limitations [5]. The issue of UC cost depreciation has been addressed in several ways. More processing time is needed to find the best solution using dynamic programming [6]. The priority list approach [7] saves time but produces suboptimal answers in each iteration. The generally used approach is the Lagrange relaxation [8] method but suffers from the quality of the solution and convergence; the aforementioned methods are concerned with traditional methods. Traditional approaches are inapplicable to the UC issue as its complexity grows owing to nonlinearity. Particle swarm optimization [9], genetic algorithm [10], ant colony optimization [11], simulated annealing [12], bacterial foraging [13], evolutionary programming [14], etc., are all examples of meta-heuristic approaches used to tackle difficult nonlinear optimization issues. Hybrid approaches may make up for the meta-heuristics dimensionality limitations, which prevent them from providing optimum solutions. Examples of hybrid techniques include the use of Lagrange relaxation in conjunction with a genetic algorithm [15], a genetic-based artificial neural network [16], a genetic algorithm based on simulated annealing [17], and a genetic algorithm based on non-dominated sorting [18].

This research makes use of a unique hybrid WOA-SOMA, which combines a whale optimization algorithm with a self-organizing migratory algorithm. Two test systems are used to implement the suggested approach and compare simulation results to those of existing techniques. This paper follows the following structure; the optimization problem of UC is mathematically formulated in Section 2. The solution to the UC issue is outlined in Section 3. In Section 4, the results of the simulation are discussed, and in Section 5, the conclusion is offered.

2. MATHEMATICAL FORMULATION

The main objective function is the scheduling of generating units for minimization of fuel cost maintaining all the constraints i.e. equality and inequality constraints.

The minimization of the cost function is presented in equation (1)

$$min \sum_{o=1}^{M} \sum_{t=1}^{T} F_u\big(P_u(t)\big)U_u(t) + SUC_u\big(1 - U_u(t-1)\big)U_u(t) \qquad (1)$$

The above objective function comprises the cost function, startup cost of the power units. $F_u\big(P_u(t)\big)$ is the cost function of uth thermal unit with real power generation at 't' hour. $U_u(t)$ indicates the on/off state of the uth generating unit at 't' hour. SUC_u is the startup cost of the uth thermal unit. M is the total number of thermal units and T is the time period. The cost function is formulated in quadratic form which is represented in equation 2.2.

$$F_u\big(P_u(t)\big) = a_u + b_u P_u(t) + c_u P_u^2(t) \qquad (2)$$

where a_u, b_u, c_u are the cost coefficients of uth generating unit. $P_u(t)$ represents the active power production of uth unit at 't' hour. The startup cost is defined as

$$\mathrm{SUC} = \begin{cases} \mathrm{HSC(t)}, & \text{if } \mathrm{T_{u,down}} \leq \mathrm{T_{u,off}} \leq \mathrm{H_{u,off}} \\ \mathrm{CSC(t)}, & \text{if } \mathrm{T_{u.off}} > \mathrm{H_{u,off}} \end{cases} \qquad (3)$$

$$H_{u,off} = T_{u,down} + T_{u,cold} \qquad (4)$$

where HSC(t), CSC(t) is the hot start cost and cold start cost at hour 't'. $T_{u,down}$ is the minimum downtime of unit 'u'. $T_{u,cold}$ is the cold start time of unit 'u'. Constraints are subjected to cost function.

2.1 Constraints

2.1.1 Power balance

The real power that is generated from thermal units must equate to the load demand over a period of time. As the load varies the generation of real power has to be varied. The summation of real power generated by all thermal units must be equalizing to the total load demand of that period. This constraint is termed an equality constraint.

$$\sum_{u=1}^{M} P_u(t) * U_u(t) = D(t) \qquad (5)$$

2.1.2 Spinning Reserve (SR)

SR is the reserve forecasted load demand to maintain desired reliability. The spinning reserve constraints are represented as

$$\sum_{u=1}^{M} P_u(t).U_u(t) \geq D(t) + SR(t) \qquad (6)$$

D(t) indicates the load demand at time 't' hour.

2.1.3 Power limits

The real power generated from generating units has to keep within the limits. The limits are associated with minimum power generation limits and maximum generation limits. The generated real power has to exist between minimum and maximum power limits.

$$P_u^{min} \leq P_u \leq P_u^{max} \qquad (7)$$

where P_u^{min}, P_u^{max} are the low and high power of 'uth' thermal unit. P_u is the real power generation of 'uth' thermal unit.

2.1.4 Minimum uptime limit

It is the minimum hours the thermal unit will online i.e. turned on position before the shutdown.

$$T_{u,on} \geq T_{u,up} \qquad (8)$$

where $T_{u,up}$ is the minimum uptime of thermal unit 'u'. $T_{u,on}$ is the on-time of thermal unit.

2.1.5 Minimum downtime limit

It is the minimum hours the thermal unit will be in off-line i.e. shutdown position before the commencement of turned on.

$$T_{u,off} \geq T_{u,down} \qquad (9)$$

where $T_{u,down}$ is the minimum downtime of thermal unit 'u'. $T_{u,off}$ is the off time of the thermal unit.

3. PROPOSED TECHNIQUE

3.1 Whale Optimization algorithm (WOA)

This technique is focused with a meta-heuristic algorithm that matches the biological behavior of mammals. In this paper, Lewis and Mirjalili suggest WOA. There are two methods used to illustrate humpback whales actively hunting. The former is connected with hunting, whereas the latter is tied to the bubble net assault strategy. The bubble net assault strategy involves surrounding the target and then updating its location in a spiral pattern. Before encircling their prey, humpback whales use precognition to pinpoint its whereabouts. In WOA [19], the first candidate solution during Prey's encirclement is favored since it is closer to the optimum answer. While some agents remain in one place while seeking, others move about to find the optimal one. The mathematical equations are provided to depict the following activities.

$$\vec{Y}(t+1) = \vec{Y}(\mathrm{t}) - \vec{A}.\vec{D} \qquad (10)$$

$$\vec{D} = \left|\vec{C}.\vec{Y}(\mathrm{t}) - \vec{Y}(t)\right| \qquad (11)$$

$\vec{Y}$(t) indicates the initial best position of iteration 't' and $\vec{Y}(t+1)$ represents the current position and $\vec{D}$ presents the space between prey and whale, the symbol $|\ |$ produces the absolute value. The vector coefficients are $\vec{A}$

and $\vec{C}$ whose values can be calculated using the equation below:

$$\vec{A}= 2.\vec{a}.\vec{r} + \vec{a} \tag{12}$$

$$\vec{C} = 2.\vec{r} \tag{13}$$

The value of $\vec{a}$ is reduced from a value 2 to 0 during the iteration process and $\vec{r}$ is the random number between [0, 1]. Based on the positions of whale and prey the spiral equations are developed which stimulate the helix shape movement of the whale.

$$\overrightarrow{\dot{D}} = \left|\vec{\dot{Y}}(\mathrm{t}) - \vec{Y}(t)\right| \tag{14}$$

$$\vec{Y}(t+1) = e^{bk}.\cos(2\pi \mathrm{k}) . \overrightarrow{\dot{D}} + \vec{\dot{Y}}(\mathrm{t}) \tag{15}$$

$\overrightarrow{\dot{D}}$ is the gap between prey and whale and k is the random number over the range of [-1,1]. During the process of algorithm, the probability of 50 percent is selected for choosing either spiral path movement or shrinking circle path by the humpback whale.

$$\vec{\mathrm{Y}}(\mathrm{t}+1) = \begin{cases} \vec{\mathrm{Y}} - \vec{\mathrm{A}}.\vec{\mathrm{D}}, & \text{if } \mathrm{p} < 0.5 \\ \mathrm{e}^{\mathrm{bk}}.\cos(2\pi\mathrm{k}).\overrightarrow{\mathrm{D}} + \vec{\mathrm{Y}}(\mathrm{t}) & \text{if } \mathrm{p} < 0.5 \end{cases} \tag{16}$$

p indicates the random number between [0,1].

The humpback whale uses a random search strategy to find its prey since the bubble net method's ideal design remains a mystery. The whale search agent will shift its focus away from the reference if necessary. Instead of a more effective search agent, the location of the agent will be adjusted based on a random selection.

$$\vec{D}=\left|\vec{C}.\overrightarrow{Yrand} - \vec{Y}\right|$$
$$\vec{Y}(t+1) = \overrightarrow{Yrand} - \vec{A}.\vec{D} \tag{17}$$

WOA provides a high convergence rate and prevents the local optima during the iteration process.

3.2 Self-Organizing Migrating Algorithm (SOMA)

SOMA [20] is a metaheuristic algorithm inspired by the biological technique related to swarm intelligence. SOMA works on the population relating to the cooperation between the individuals which is termed migration in reaching the global optimal solution. In the initial stage, parameters are defined like population size, PRT, step, path length, iteration, etc., and the population is generated randomly in the search space.

$$x_{p,i} = x_i^l + rand(0,1) * (x_i^h - x_i^l) \tag{18}$$

$x_{p,i}$ indicates the i^th^ variable of p^th^ population. x_i^l, x_i^h is the lower and upper power limits of i^th^ variable. Each population is associated with an m-dimensional vector of variables and each variable is subjected to power limit constraints. The strength of the individual population is predicted using the cost function and the leader is selected. All individuals migrate towards the leader position by jumping until a path length is achieved. Path length defines the closeness of individuals with the leader position. The new strength value is assessed for each jump of the individual population. Before jumping an individual a random number is produced and compared with a variable PRT to generate PRT Vector.

$$PRTVector = \begin{cases} 1 & if\ rand < PRT \\ 0 & if\ rand > PRT \end{cases} \tag{19}$$

The migration loop is referred to as the iteration loop and is used for the stopping process. The migration of an individual towards the leader position in each migration loop is represented by the equation

$$x_{p,i}^{Ml+1} = x_{p,i\,start}^{Ml} + (x_{B,i}^{Ml} - x_{p,i\,start}^{Ml}) * s * PRTVector \tag{20}$$

Ml indicates the migration loop, s is the step, $x_{p,i}^{Ml+1}$ is a vector representing the new position of the p^th^ individual of i^th^ variable migrating to the leader position with step s until greater than path length PL. PL indicates the trajectory path. $x_{B,i}^{Ml}$ is the leader position of B^th^ individual of i^th^ variable in migration loop Ml. The iteration is stopped when the migration loop reaches the maximum loop.

3.3 Hybrid Method

The hybrid method is the composition of two or more techniques applied to achieve a global optimal solution. WOA and SOMA combination is implemented as a hybrid method. The procedure applied to solve the optimization problem is represented in steps

a) Consider initial parameters are like population size, PRT, step, path length, and maximum iteration.

b) Before the commencement of the iteration process random population is generated and the fitness of each population is predicted.

c) Based on the strength of the population the best leader is selected using the whale optimization technique.

d) Encircling prey, mechanism of shrinking encircling, and spiral updating position are implemented using equations (10) to (17) in achieving better or leader solution.

e) Generate the PRTVector using equation (19) and all individuals migrate in the migration loop towards the leader position with the updation of the new position until the maximum iteration is reached, finally the optimal value is predicted. Flowchart of hybrid WOA-SOMA shown in Figure-1.

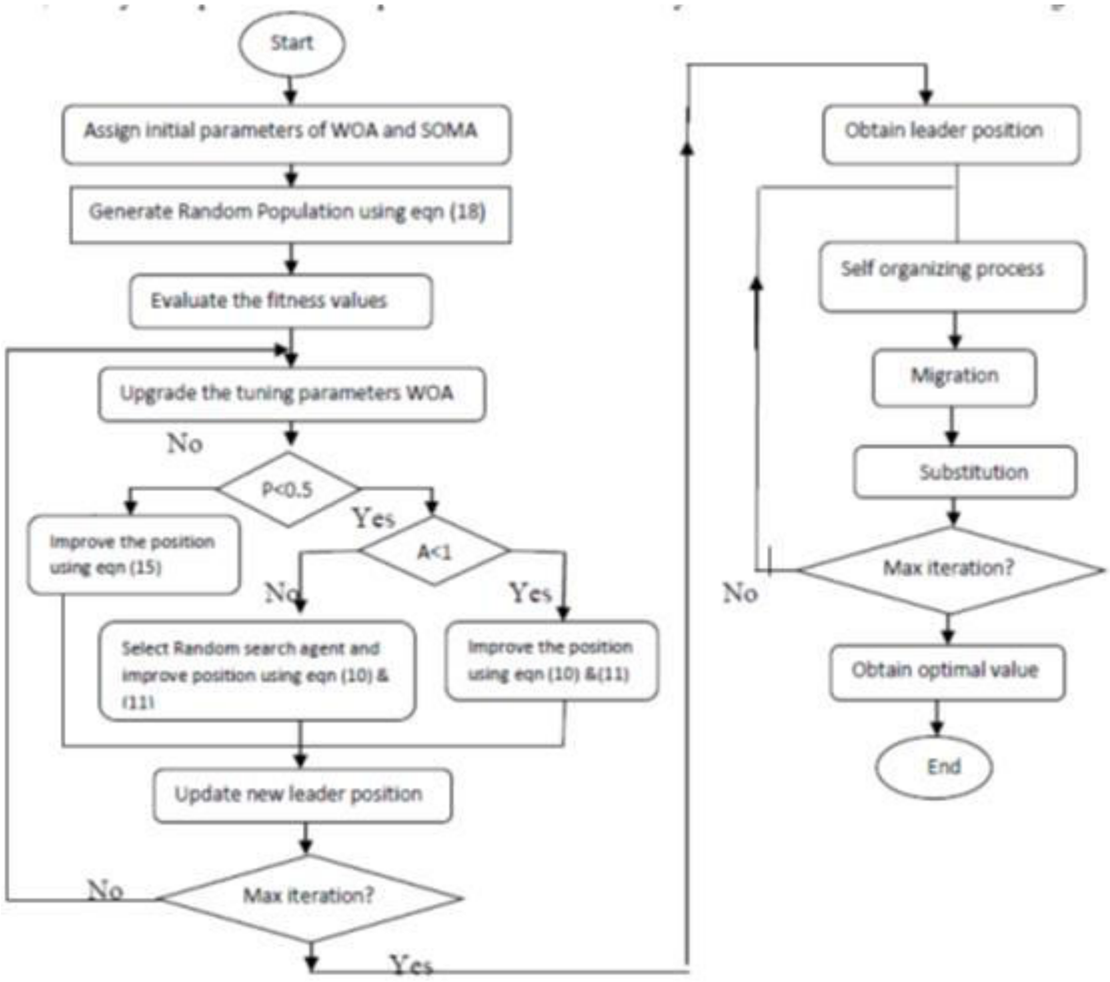

Figure-1. Flow chart of Hybrid WOA-SOMA.

4. NUMERICAL SIMULATION

The proposed hybrid method is applied to two test systems, the first system is a four-unit system with eight load demands and the second system is IEEE 39 bus system with ten thermal units.

Case (i) The maximum number of iterations 50, size of population 20, step value of 0.3, step length 3.0. Maximum and minimum power limits, cost coefficients, minimum uptime and downtime, cold start cost, and hot start cost are taken [21] which are shown in Table-1.

Table-1. Data related to four generator system.

P_{max} (MW)	P_{min} (MW)	a_u	b_u	c_u	HSC ($)	CSC ($)	MUT (h)	MDT (h)	CST (h)	Initial status(h)
300	75	684.74	16.83	0.0021	500	1100	5	4	5	8
250	60	585.62	16.95	0.0042	170	400	5	3	5	8
80	25	213	20.74	0.0018	150	350	4	2	4	-5
60	20	252	23.6	0.0034	0	0.02	1	1	0	-6

Different load demands for a four-unit system are given in Table-2. The on/off status of the power units is shown in Table-3. Thermal unit 3 is completely in off state and generating unit 4 will remain in off state except 3 hour. Dispatching of load demand among the thermal units and its corresponding cost values are shown in Table-4. The total cost obtained for a four-unit system is 73,732.660 ($). The obtained cost value is made in comparison with the existing literature methods which illustrate the better cost value. With the proposed hybrid WOA-SOMA the obtained cost value is less than compared with the harmony search algorithm, TLPSO, Binary differential evolution, LR with PSO which is shown in Table-5.

Table-2. Demand of four generator system on hour basis.

Hours	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**
Load (MW)	450	530	600	540	400	280	290	500

Table-3. On/off status of 4 unit system.

Hour	P_1	P_2	P_3	P_4
1	1	1	0	0
2	1	1	0	0
3	1	1	0	1
4	1	1	0	0
5	1	1	0	0
6	1	1	0	0
7	1	1	0	0
8	1	1	0	0

Table-4. Load sharing using Hybrid WOA-SOMA.

Hour (h)	G_1 **(MW)**	G_2 **(MW)**	G_3 **(MW**	G_4 **(MW**	**Cost ($)**
450	300	150	0	0	9,145.36
530	300	230	0	0	10,629.04
600	300	250	0	50	12,448.86
540	300	240	0	0	10,818.28
400	276.19	123.81	0	0	8,241.78
280	196.19	83.81	0	0	6,103.14
290	202.857	87.143	0	0	6,279.82
500	300	200	0	0	10,066.36
					73,732.66

Table-5. Comparison of cost value with existing methods.

Method	**Overall cost($)**		
	Best	**Average**	**Worst**
Improved Lagrangian relaxation [22]	75,232	--	--
A. SMP [23]	74,812	74,877	75,166
Lagrangian relaxing &Particle swarm optimization [22]	74,808	--	--
Binary Differential evolution [24]	74,676	--	--
Two Layer Particle swarm optimization (TLPSO) [21]	74,476	74,500	74,675
Hybrid WOA - SOMA	73,732	74,090	76,265

Case (ii)

In this case study, the constraint without spinning reserve and with spinning reserve is considered. The initial parameters are considered which are shown in Table-6 and the corresponding load demand for 10 unit thermal system [25] is given in Table-7. The scheduling of load dispatch with committed thermal units is shown in Table-8. The obtained total cost of all thermal units overload demand of thermal units is 5,64,196.4 ($). With the proposed hybrid technique the obtained cost value is made in comparison with the existing method which is shown in Table-9. For different spinning reserve values, the cost values vary. As the spinning reserve increases the cost value also increases which can be observed in Table-10.

With the variation of load demand the on/off status of the thermal unit varies. At a maximum load of 1500MW all the thermal units are in on state at the 12th hour generating the cost value of 33,890.16 ($). At minimum load of 700MW first and second thermal unit are on state and remaining thermal units are at off state and the associated cost value is 13,683.13 ($).

Table-6. Comparison of cost value with other existing methods.

Pmax (MW)	Pmin (MW)	au	bu	cu	Ton (Hr)	Toff (Hr)	SH ($)	SC ($)	TC (Hr)	Initial state
455	150	1000	16.19	0.00048	8	8	4500	9000	5	8
455	150	970	17.26	0.00031	8	8	5000	10000	5	8
130	20	700	16.6	0.002	5	5	550	1100	4	-5
130	20	680	16.5	0.00211	5	5	560	1120	4	-5
162	25	450	19.7	0.00398	6	6	900	1800	4	-6
80	20	370	22.2	0.00712	3	3	170	340	2	-3
85	25	480	27.74	0.00079	3	3	260	520	2	-3
55	10	660	25.9	0.00413	1	1	30	60	0	-1
55	10	665	27.2	0.00222	1	1	30	60	0	-1
55	10	670	27.79	0.00173	1	1	30	60	0	-1

Table-7. Load demand of IEEE 39 bus system over 24 hours.

Hour	Demand (MW)	Hour	Demand (MW)	Hour	Demand (MW)
1	700	9	1,300	17	1,000
2	750	10	1,400	18	1,100
3	850	11	1,450	19	1,200
4	950	12	1,500	20	1,400
5	1,000	13	1,400	21	1,300
6	1,100	14	1,300	22	1,100
7	1,150	15	1,200	23	900
8	1,200	16	1,050	24	800

Table-8. Scheduling of load of among 10 power units over 24 hours.

P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	Cost($)
455	245	0	0	0	0	0	0	0	0	13,683.13
455	295	0	0	0	0	0	0	0	0	14,554.5
455	265	130	0	0	0	0	0	0	0	16,923.29
455	340	130	0	25	0	0	0	0	0	19,176.85
455	390	130	0	25	0	0	0	0	0	20,051.16
455	360	130	130	25	0	0	0	0	0	22,387.04
455	410	130	130	25	0	0	0	0	0	23,261.98
455	455	130	130	30	0	0	0	0	0	24,820.34
455	455	130	130	85	20	25	0	0	0	27,251.06
455	455	130	130	162	33	25	0	10	0	30,075.86
455	455	130	130	162	73	25	10	0	10	31,926.21
455	455	130	130	162	80	25	43	10	10	33,890.16
455	455	130	130	162	33	25	0	10	0	30,075.86
455	455	130	130	95	0	25	10	0	0	27,556.79
455	455	130	130	30	0	0	0	0	0	24,820.34
455	310	130	130	25	0	0	0	0	0	21,513.66
455	260	130	130	25	0	0	0	0	0	20,641.82
455	350	130	130	25	0	0	10	0	0	23,131.86
455	455	130	130	30	0	0	0	0	0	24,820.34
455	455	130	130	162	33	25	0	10	0	30,075.86
455	455	130	130	85	20	25	0	0	0	27,251.06
455	340	130	130	0	20	25	0	0	0	23,084.56
										5,64,196.4

Table-9. Comparison of IEEE 39 bus system cost value.

Method	Cost Value($)	Method	Cost Value($)
PSO-LR[26]	565,869	EP[30]	565,352
LRGA[27]	564,800	SPL[31]	564,950
DP[28]	565,825	BPSO[32]	565,804
ALR[29]	565,508	WAO-SOMA	564,196

Table-10. SR of IEEE 39 system.

Spinning Reserve	Cost($)
5%	5,91,244.87
8%	6,17,496.02
10%	6,36,278.93

5. CONCLUSIONS

A novel hybrid WOA-SOMA is modeled for solving an optimization problem concerned to minimization of cost. To evaluate the potential of the hybrid method it is test on two test systems i.e., four unit system and IEEE 39 bus system with 10 thermal units. Equality and inequality constraints are considered in four unit system of optimization problem and an additional spinning reserve constraint was considered in IEEE 39 bus system. The obtained optimal value of cost using hybrid WOA and SOMA shows a better value compared with other existing methods.

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