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Optimized Power Generation using Clustered Gravitational Search Algorithm

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Abstract – *In this paper, a new clustering algorithm based on gravitational search algorithm (CGSA) for solving unit commitment (UC) problem is proposed. The UC problem is a combinatorial optimization problem that minimizing quadratic objective function under system and unit constraints. The GSA is a recent introduced algorithm to solve optimization problem that inspired by Newtonian law of gravity. A novel version of GSA, named Clustered-GSA (CGSA) is a flexible and well-balanced mechanism for enhancing exploration and exploitation abilities. The proposed algorithm is tested for standard 100 unit system, IEEE 118 bus system and practical Taiwan 38 bus power system. The effectiveness of proposed algorithm results are compared to those reported in the literature.*

Keywords – *clustered gravitational search algorithm, gravitational search algorithm, operating cost, optimization, unit commitment problem.*

1. INTRODUCTION

The “unit commitment problem”, is a binary-variable optimization problem which is to determine the generating units that need to be committed in order to satisfy load demand. Sub-problem, the “economic dispatch” is a real-variable optimization problem which is to determining the economical allocation of continuous power amounts to the generating units to meet the required forecasted load [1].

There are several methods to determine the status of the generating units in the unit commitment outputs but there are certain drawbacks of such methods. The conventional methods such as integer programming (IP) [2], Lagrangian relaxation (LR) [3], simulated annealing(SA)[4], genetic algorithm (GA) [5], particle swarm optimization (PSO)[7]-[8], [12] and Ant colony search [6], [12].From the literature survey, it is clear that each existing algorithm in the literature have some merits and limitations. The main limitation of most of the existing algorithm is to provide optimal solution within considerable computational time. Therefore, it is necessary to determine a simple and capable method for solving the UC problem independent of size of the power system.

Recently, a new optimization method known as gravitational search algorithm (GSA) [9] developed by Rashedi is successfully applied on various benchmark functions [10] by comparing it with other heuristic optimization algorithms and found to be encouraging. Hence, in this context, an attempt is made to solve UC problem using a gravitational search algorithm with Clustering approach.

2. MODELLING

2.1 Objective Function: Fuel Cost

Minimize

$$F=\sum_{t=1}^{T}\sum_{i=1}^{Ng}F(P(i,t))\times I(i,t)+S(i,t)-$$
$$\sum_{t=1}^{T}\sum_{i=1}^{Ng}\left(\left(a(i)+b(i)P(i,t)+c(i).P(i,t)^{2}\right)\times I(i,t)\right)+S(i,t) \quad (1)$$

2.2 Problem Constraints:

2.2.1 Power balance constraints

$$\sum_{i=1}^{N_g}(P(i,t)*I(i,t))=Load_t,\ t\in[1,T] \quad (2)$$

2.2.2 Spinning reserve constraints:

$$\sum_{i=1}^{N_g}(P(i,\max)*I(i,t))\geq Load(t)+SR(t), \quad (3)$$

2.2.3 Capacity limits of conventional generating unit

$$P(i,\min)\leq P(i,t)\leq P(i,\max) \quad \text{when } I(i,t)=1$$
$$P(i,t)=0 \qquad \text{when } I(i,t)=0 \quad (4)$$

2.2.4 Unit minimum ON/OFF durations

$$X_i^{on}(t)\geq MU_i \quad (5)$$

$$X_i^{off}(t)\geq MD_i \quad (6)$$

2.2.5 Unit ramp constraints

$$P(i,t)-P(i,t-1)\leq RU_i \quad (7)$$

$$P(i,t-1)-P(i,t)\leq RD_i \quad (8)$$

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Where;
F-Total operating cost;
$F(P(i,t))$- Fuel cost ($) of the generating unit i at hour;
a, b, c -Fuel cost coefficients of i^{th} unit;
N_g - Number of generating units;
T -Total number of hours considered;
$I(i,t)$- Status of unit i at t^{th} hour
$S(i,t)$- Startup cost of unit i at t^{th} hour;
$P(i,t)$-Generation power output of unit i at h^{th} hour;
$Load_t$ -Total system demand at t^{th} hour;
$P(i,max)$ and $P(i,min)$ –Maximum and Minimum limit of power output of unit i;
$SR(t)$-System spinning reserve in MW at t^{th} hour;
MU_i and MD_i -Minimum time that unit i should kept in ON and OFF status
$X_i^{on}(t)$ and $X_i^{off}(t)$ -Time period for which thermal unit i is ON and OFF status at t^{th} hour.

3. CLUSTERED GRAVITATIONAL SEARCH ALGORITHM

The GSA was proposed by Rashedi *et al.* [9] that uses the Newton's Gravitational Principle to search the optimum solution. In this algorithm, the coordinates or the agents in the search space are considered as masses.

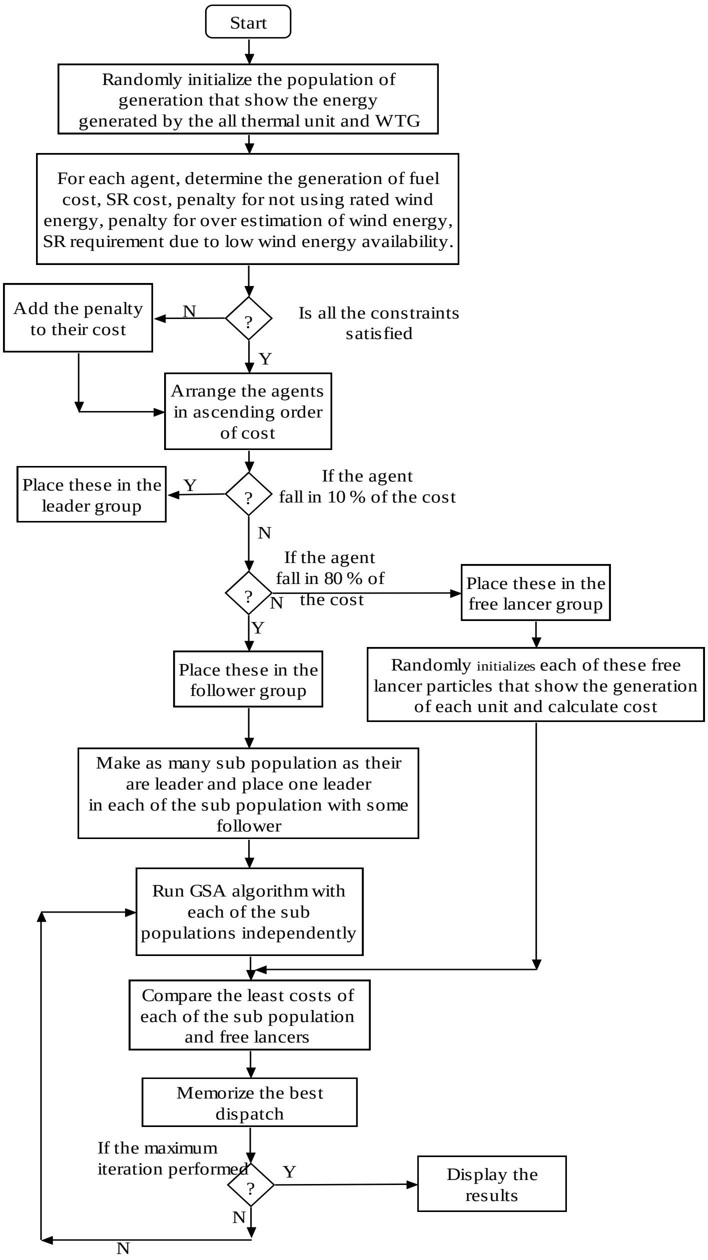

Fig. 1. Flowchart for UCP using CGSA.

All these masses attract each other according to laws of Gravity and form a direct means of communication through it. In the proposed CGSA is implemented to improve the convergence and solution quality of GSA. The flowchart for the implementation of CGSA in UC problem is shown in Figure 1.

In CGSA, the whole population is divided into three basic groups: namely Leader, Follower and

Freelancer. The Leaders (10%) are the best particles obtained at the end of the first iteration. Each leader particle shall lead a group of optimizers. The Leader and the optimizer work together like a simple GSA population thereafter. By this way there would be some independent GSA populations led by their leader that will search for the optimum solution. The last group, the freelancers (10%) shall be randomly initiated every iteration and keep the search alive. Each group those led by a leader and the freelancers shall have a best particle. The best out of these bests shall be the final best particle of the iteration. Depending on the requirements of the function, the ratio of the population of Leader, follower and the freelancer can be adjusted.

4. RESULT AND DISCUSSION

All the programs are developed using MATLAB R2007b. The UC problem is solved for three test systems such as 100 unit system, IEEE 118 bus system and practical Taiwan 38 bus power system. Unit commitment problem is solved for binary coded CGSA and Economic dispatch problem is solved for real coded CGSA. The control parameter for binary coded and real coded CGSA is given in Table 1.

4.1 System 1- 100 Unit System

The detailed system data and load profile for 100 unit system is taken in the reference paper [2]. The UCP status and hourly cost - 100 unit system is given in Table 2 and the comparison of results for 100 unit system is given in Table 3. It is observed from the Table 3, that the minimum cost so far reported in the literature is $ 5601991 by PSO [12] which is higher than the result obtained from the evolutionary algorithm. It should also be noted, that the computation time of PSO are higher than the CGSA.

4.2 System 2-IEEE 118 Bus System (54 units)

The system consists of 54 generating units. The detailed system data and load profile for IEEE 118 bus system are found in the reference paper [11]. The detailed status and hourly operating cost of 54 units using CGSA are given in Table 4. It is observed from Table 5 that the CGSA is able to give a better solution compared with existing methods available in the literature.

Table 1. Control parameters for binary coded and real coded CGSA

Binary coded CGSA				Real coded CGSA			
Control parameter	38 units	54 units	100 units	Control parameter	38 units	54 units	100 units
α	21	21	19	A	21	21	19
G0	90	90	100	G0	0.8	0.8	1
Population size	100	100	100	Population size	20	20	20

Table 2. UCP status and hourly cost - 100 unit system- CGSA.

Hour	Unit status 1,2,…..,100	Operating cost $
1	1111111111111111111100000000000000000000000000000000000000000000000000000000000000000000000000000000	136842.29
2	1111111111111111111100000000000000000000010000000000000000000000000000000000000000000000000000000000	146964.93
3	1111111111111111111100000000000000000000110000000000000000000000000000000000000000000000000000000000	164944.7
4	1111111111111111111100000000000000000000111111110010000000000000000000000000000000000000000000000000	191259.88
5	1111111111111111111100000000000000000011111111111110000000000000000000000000000000000000000000000000	199870.35
6	1111111111111111111100000000001111111111111111111110000000000000000000000000000000000000000000000000	227988.52
7	1111111111111111111110011110001111111111111111111100000000000000000000000000000000000000000000000000	235555.18
8	1111111111111111111111111111111111111111111111111100000000000000000000000000000000000000000000000000	247014.4
9	1111111111111111111111111111111111111111111111111100111111111111000000000000000000000000000000000000	272527.42
10	1111111111111111111111111111111111111111111111111111111111111111111111111111110000000000000000000000	303312.16
11	1111111111111111111111111111111111111111111111111111111111111111111111111111111111111111000000000000	318362.04
12	1111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111111100	338142.15
13	1111111111111111111111111111111111111111111111111111111111111111111111001111111100000000000000000000	299202.16
14	1111111111111111111111111111111111111111111111111111111111111110000000000000000000000000000000000000	267881.69
15	1111111111111111111111100000001111111111111111111111111111110000000000000000000000000000000000000000	243809.46
16	1111111111111111111111100000001111111111111111111100000000000000000000000000000000000000000000000000	210812.16
17	1111111111111111111111100000001111111111111111111100000000000000000000000000000000000000000000000000	202065.6
18	1111111111111111111111100000001111111111111111111100000000000000000000000000000000000000000000000000	219574.22
19	1111111111111111111111100000001111111111111111111111111110000000111000000000000000000000000000000000	246539.83
20	1111111111111111111111111111111111111111111111111111111111110000111000111111111111111101100000000000	308247.03
21	1111111111111111111111111111111111111111111111111111111111110000111000000000000000000000000000000000	267881.69
22	1111111111111111111100011111110000001100111111111100000001110000000000000000000000000000000000000000	219839.72
23	1111111111111111111100011111110000000000000000000000000000000000000000000000000000000000000000000000	176100.69
24	1111111111111111110000011111110000000000000000000000000000000000000000000000000000000000000000000000	156762.21
	Total operating cost ($)	5601500.48

Table 3. Comparison of results-100 unit system

Solution technique	Minimum operating cost ($)	Avg. com time (s)
DPLR [3]	5640488	12437.00
EP[3]	5623885	6120.00
GA[3]	5627437	15733.00
IPSO [8]	5619284	5750.00
MILP [2]	5605189	1023.00
ACS[12]	5602894	2968.7
PSO [12]	5601991	1388
CGSA	5601500	1012

Table 4. UCP status and hourly cost-54 unit system-CGSA.

Hour	Unit status 1,2,…..54	Fuel cost ($)	Startup cost ($)	Operating cost ($)
1	0001100001100000000110011011100000001001100111000000000	58185.04	0	58185.04
2	0001100001100000000110011011100000001001100111000000000	54100.04	0	54100.04
3	0001100001100000000110011011100000001001100111000000000	46276.04	0	46276.04
4	0001100001100000000110011011100000001001100111000000000	30844.04	0	30844.04
5	0001100001100000000110011011100000001001100111000000000	38983.04	0	38983.04
6	0001101001100000000110011011100000001001100111000000000	48248.04	50	48298.04
7	0001101001100000000110111011100000001001100111000000000	58252.04	50	58302.04
8	0001101001100001000110111011100000001001100111000000000	66790.04	50	66840.04
9	0001101001100001000110111011100000001101100111000000000	71253.04	50	71303.04
10	0001101001100001000111111011100000111011001110000001110	77998.04	250	78248.04
11	0001101001100001000111111011100000111011001110000001110	79143.04	0	79143.04
12	0001101001100001000111111011100000111011001110000001110	73469.04	0	73469.04
13	0001101001100001000111111011100000111011001110000001110	69022.04	0	69022.04
14	0001101001100001000111111011100000110011001110000001110	64691.04	0	64691.04
15	0001101001100001000111111011110001110011001110110011110	77976.04	195	78171.04
16	0001101001100001000111111111110001110011001110110011110	80234.04	50	80284.04
17	0001101001100001000111111111110001110011001110110011110	74597.04	0	74597.04
18	0001101001100001001111111111110001110011001110110011110	79087.04	59	79146.04
19	0001101001100001001111111111110001111011001110110011110	84766.04	50	84816.04
20	0001101001100101001111111111110001111011001110110011110	89354.04	50	89404.04
21	0001101001100101001111111111110001111011001110110011110	91679.04	0	91679.04
22	0001101001100100001111111111110000111011001110100000100	80269.04	0	80269.04
23	0001101001100100000111111011100000111011001110100000100	76875.04	0	76875.04
24	0001100001100100000111011011100000110011001110000000100	71253.16	0	71253.04
Total ($)		1643345	854	1644199.12

Table 5. Comparison of results- 54 unit system.

Solution technique	Total operating cost $
SDP [11]	1645445.00
CGSA	1644199.12

4.3 System 3- Taiwan 38 bus system

The UCP is executed under the same conditions as in the reference paper [11]. The detailed status and hourly operating cost are given in Table 6. Table 7 provides the comparison of the total operating cost obtained using evolutionary algorithms with respect to other techniques available in the literature.

The minimum cost so far reported in the literature is Million $ 196.73 [7] which is higher than that obtained using evolutionary algorithms. Out of 30 trials, the best total operating cost obtained using CGSA for the Taiwan Power 38 unit system for a 24 hour time interval is Million $ 195.918423.

Table 6. UCP status and hourly cost- 38 unit system-CGSA.

Hour	Unit no. 1,2,…38	Fuel cost $	Start-up cost $	Operating cost $
1	11111111000000000111111011000000000011	6882514.1	0	6882514.1
2	11111111000000000110111101100000000011	6248453.1	0	6248453.11
3	11111111000000000100111101100000000011	5669017.8	0	5669017.77
4	11111111000000000000111101100000000011	5221706.6	0	5221706.61
5	11111111000000000100111101100000000011	5452220.1	23000	5475220.14
6	11111111000000000000111101100000000011	5167783	0	5167782.99
7	11111111000000000000111101100000000011	5221706.6	0	5221706.61
8	11111111010000000100111101100000000011	6104231.6	425500	6529731.6
9	11111111011110001001111011000000000011	8050231.1	1380000	9430231.13
10	11111111111111110100111101100000000011	9883864.1	1552500	11436364.1
11	11111111111111110100111101100000000011	10107297	0	10107296.64
12	11111111111111110100111111100000000011	10353258	23000	10376258.33
13	11111111111111110100111101100000000011	8564783.9	0	8564783.86
14	11111111111111110110111101100000000011	10612000	23000	10634999.75
15	11111111111111110110111101100000000011	10764436	0	10764435.67
16	11111111111111110100111101100000000011	10107297	0	10107296.64
17	11111111111111110100111101100000000011	9810222.8	0	9810222.76
18	11111111111110110000111101100000000011	8678957	0	8678956.97
19	11111111111110110000111101100000000011	8262622.7	0	8262622.66
20	11111111111110110000111101100000000011	8968243.3	0	8968243.33
21	11111111111110110000111101100000000011	8678957	0	8678956.97
22	11111111111110000100111101100000000011	8206758.2	23000	8229758.2
23	11111111111110000000111101100000000011	7798878.7	0	7798878.7
24	11111111101100001001111011000000000011	7629985	23000	7652985
Total ($)		192445423	3473000	195918423.6

Table 7. Comparison of results- Taiwan Power (Taipower) 38 unit system.

Solution technique	Minimum operating cost (Million $)
DP [1]	210.50
LR [1]	209.00
CLP [1]	208.10
SA [1]	207.80
MRCGA [5]	204.60
MACO [6]	200.46
Twofold SA [4]	197.98
FAPSO [7]	196.73
CGSA	195.918423

5. CONCLUSION

The Clustered gravitational search algorithm has been successfully implemented to solve UC problem for standard 100 unit system, IEEE 118 bus system and practical Taiwan 38 bus power system. From the result, it is seen that the total operational cost obtained through CGSA is much lesser when compared to the results obtained through other evolutionary algorithms. This technique has the flexibility to achieve optimized results and give least operating costs for much larger systems as well. This algorithm could provide better solutions to the problem of unit commitment in deregulated power systems.

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