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Solution of Unit Commitment Problem using Stochastic Algorithm

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Abstract— **In order to solve the unit commitment problem, the new method presented in this paper generates all conceivable logical states for generating units for each hour of the day. Every day's load demand is coded as an integer in the scheduling variables. The Particle Swarm Optimization (PSO) method is used to address and optimize the unit commitment problem by taking into account both production cost and transient cost. The solution to the issue must consider system constraints as well as generator constraints, which include minimum up/down times and maximum/minimum generation for each generating unit (such as reserve capacity). The proposed algorithm is explained in this paper and is used with various thermal and wind units. The outcomes were tallied and contrasted with thermal unit outcomes.**

Keywords—PSO, Transient cost, Unit commitment.

INTRODUCTION

The objective of unit commitment (UC), a non-linear complex mixed-integer optimization problem, is to distribute the entire demand of the test system across all generating units at the lowest operating cost, which includes both production cost and transition cost, while also satisfying all period-specific constraints, total load, system losses, and reserve requirements. The UC problem must first ascertain the on/off status of each producing unit at each hour of the planning period in order to calculate how demand and reserve capacity should be distributed among the committed units. UC has the most crucial role in maintaining the power networks. With an increase in producing units, the UC problems become exponentially more complicated, making it more challenging to solve them for power systems.

There have been several methods suggested for resolving the UC issue with the least amount of running expense, which will increase the power system operator's potential savings. However, they vary in terms of computational effectiveness and solution quality. These techniques are divided into deterministic and stochastic search algorithms. Dynamic programming (DP), modified dynamic programming (MDP), improved lagrangian relaxation (ILR), lagrangian relaxation differential evolution (LRDE), branch and bound methods (B&B), and lagrangian relaxation (LR) are examples of deterministic approaches. These techniques work quickly, precisely, and simple to solve power systems of average size. Convergence, solution quality, and complexity are problems for them. The heuristic or stochastic search algorithms, such as Genetic Algorithms, Tabu Search, Effective Hybrid Particle Swarm Optimization (EHPSO), Discrete PSO (DPSO), Hybrid PSO (HPSO), Fuzzy Adaptive PSO (FAPSO), Evolutionary Programming, Simulated Annealing, Ant Colony Optimization, Mixed integer PSO (MIPSO), Multi-objective PSO. Several hybrid algorithms are also suggested using the two types of algorithms mentioned above. These techniques can manage challenging linear and nonlinear constraints and deliver excellently optimized results. However, the accuracy problem afflicts all these methods. The increased problem size and number of generation units negatively effects the computational time and the quality of the solutions.

In this paper, a novel approach is suggested by generating all possible states of each unit for each particle at each time step. The power system operator can make excellent profits by using PSO to optimize these particle states as opposed to using any of the other methods mentioned above.

PROBLEM FORMULATION

The primary goal of the UC problem is to reduce overall operating costs, which are comprised of the costs of production, startup, and shutdown. This function can be optimized by considering all generator constraints and system constrains.

A. *Production cost*

The main component of the objective function of UC problem is to minimize the total production cost subjected to set of generator constraints over the scheduling period. The generator power output, Pi, and the production cost, PCi, for unit i at any given time are quadratic functions.

$$PC_i = a_i + b_i P_i + c_i P_i^2 \qquad (1)$$

Where a_i, b_i and c_i are the cost coefficients of unit i. P_i is the MW generated of committed unit i.

B. *Start-up cost*

The second component of the objective function is start-up cost. It depends on the OFF time period T^{OFF}. The start-up cost can be calculated by two methods, they are exponential start-up cost and cold/hot start-up cost. If cold start time is less than OFF time period TOFF, then start-up cost taken as hot-start cost else it taken as cold start cost. The start-up cost SCi at any given time period t, is

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given by equ.(2),

$$SC_i = \begin{cases} \sigma_i + \sigma_i \left(1 - e^{\left(-\frac{T_i^{off}}{\tau_i}\right)}\right) & when\ \tau\ is\ given \\ \sigma_i & when\ \tau\ is\ not\ given \end{cases} \quad (2)$$

$$\sigma_i = \begin{cases} \text{cold start cost,}\ CSC_i & when\ T_i^{off} \geq CT_i \\ \text{hot start cost,}\ HSC_i & when\ T_i^{off} \leq CT_i \end{cases} \quad (3)$$

$$T_i^{off} = \begin{cases} |INS_i| + D_i^{off} & \text{if unit is OFF at initial condition} \\ D_i^{off} & \text{if unit gets OFF from its ON state} \end{cases} \quad (4)$$

Where CTi is cold-start time, INSi is the initial status of unit i, HSCi is the hot start-up cost, CSCi is the cold start-up cost, i is the cooling time constant, and Di(off) is the off time before unit i get committed.

Power balance constraint

The power balance constraints ensure that power load in each time slice is satisfied by the sum of power generation from all types of generation units.

$$\sum_{i=1}^{N} P_{i,t} U_{i,t} = P_{D,t} + P_{L,t} \qquad t = 1,2,3, \dots T \quad (5)$$

where PD,t, and PL,t are the total system demand and the losses at hour t in MW.

C. Spinning Reserve Constraint

The spinning reserve is the amount of unutilized capacity in online energy assets that can make up for power outages or frequency fluctuations during a specific time period. For big synchronous generators, the spinning reserve is a traditional idea

$$\sum_{i=1}^{N} P_i^{max} U_{i,t} \geq P_{D,t} + P_{L,t} + P_{SR,t} \qquad t = 1,2,3, \dots T \quad (6)$$

where Pmax is the upper bound limit of the ith generator, and PSR is the spinning reserve at time t.

D. Prohibited Operating Zone (POZ)

The generators cannot generate real power in certain operating zones due to mechanical stress or sub synchronous oscillations leading to complete shut-down of the unit. These zones are called as Prohibited Operating Zones, causing discontinuities in the fuel-cost curve. During real-time, generators are restricted in POZ. The realistic operating zones of a generator can be described as follows,

$$P_{i,t} \in \begin{cases} P_i^{max} \leq P_i \leq P_{i,1}^{l} \\ P_{i,m-1}^{u} \leq P_i \leq P_{i,m}^{l} \\ P_{i,poz_i}^{u} \leq P_i \leq P_i^{max} \end{cases} \quad (7)$$

m=2,3,…, poz_i when, $U_{i,t}$=1

i= 1,2,…..,n_{poz}

where Pl, Pu are the lower and upper bound limits of the ith generator in the prohibited operating zones, pozi is the number of prohibited operating zones of the ith generator, and npoz is the number of units having prohibited zone.

E. Generator Boundary Constraint

The committed generators must operate between its upper and lower boundary limits as given here,

$$P_i^{max} \geq P_{i,t} \geq P_i^{min} \qquad when\ U_{i,t} = 1 \quad (8)$$

F. Minimum up/down time Constraint

The generators require minimum time to start from the cooling period and to shut down from the running condition as given in Eq. (9)

$$\left. \begin{aligned} (U_{i,t} - U_{i,t-1})(T_{on}(t-1) - MUT_i) \leq 0 \\ (U_{i,t} - U_{i,t-1})(T_{on}(t-1) - MUT_i) \geq 0 \end{aligned} \right\} \quad (9)$$

where MDTi ⁄MUTi is the minimum down/up time limits for the ith unit in hours, and Ton is the time at which the unit has been turned on before the hour. The value of Ton⁄Toff is expressed as,

$$\left. \begin{aligned} T_{on}(t) = (1 + T_{on}(t-1)) U_{i,t} \\ T_{off}(t) = (1 + T_{off}(t-1))(1 - U_{i,t}) \end{aligned} \right\} \quad (10)$$

H. Ramp rate constraint

The ramp up/down limit of a generator is mathematically given as,

$$\left. \begin{aligned} [P_{i,t-1} - DR_i(1 + U_{i,t})(U_{i,t-1})] \leq P_{i,t} \\ [P_{i,t-1} - UR_i(1 + U_{i,t-1})(U_{i,t+1})] \leq P_{i,t} \end{aligned} \right\} \quad (11)$$

SOLUTION USING PSO

A. Particle Formation

This algorithm creates logical states for each particle in order to solve the UC problem. In order to express the on/off status of the generators at each hour of the scheduling period T, Particle uses logical state strings. Maximum 2^n logical states with 1/0 as the numbers are possible for each particle. The unit's ON and OFF states are represented by 1 and 0, respectively. *PSO approach to optimize UC,*

$$Vel_i = w_i * Vel_i + x[\emptyset_1 * r_1(PBEST_i - Part_i) + \emptyset_2 * r_2(GBEST_i - Part_i)]$$

$$Part_i = Part_i + Vel_i$$

$$x = \begin{cases} \frac{2k}{\left|2 - \emptyset - \sqrt{\emptyset^2 - 4\emptyset}\right|} & if\ \emptyset \geq 4 \\ k & if\ 0 < \emptyset < 4 \end{cases}$$

Where 0 < k < 1 and $\emptyset = \emptyset_1 + \emptyset_2$

$$w_i = w_{max} - ((w_{max} - w_{min}) * iter)/iter_{max}$$

RESULT AND DISCUSSION

A. Test case-1

In the test case-1, a 10-unit system that contains 10 generators and different loads at every hour of a day is considered for implementation. The test data and load demand of the 10-unit system is given below in Table 1 and Table 2.

Table 1: Test data of 10-unit system

--	P max	P min	a_i	b_i	c_i	MUT	MDT	Shot	SCold	CSH	I.S
1	455	150	0.00048	16.19	1000	8	8	4500	9000	5	8
2	455	150	0.00031	17.26	970	8	8	5000	10000	5	8
3	130	20	0.002	16.60	700	5	5	550	1100	4	-5
4	130	20	0.00211	16.50	680	5	5	560	1120	4	-5
5	162	25	0.00398	19.70	450	6	6	900	1800	4	-6
6	80	20	0.00712	22.26	370	3	3	170	340	2	-3
7	85	25	0.00079	27.74	480	3	3	260	520	2	-3
8	55	10	0.00413	25.92	660	1	1	30	60	0	-1
9	55	10	0.00222	27.27	665	1	1	30	60	0	-1
10	55	10	0.00173	27.79	670	1	1	30	60	0	-1

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The Table 1 provides the test data for a 10-unit system that helps to solve the UC problem.

Table 2: Load data of 10-unit system

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

The Table 2 provides information of hourly load demand that should be matched with the output of the 10-unit system.

Table 3: Comparison of total cost of 10-unit system

TOTAL COST ($)	PSO
BEST	566136
AVERAGE (25 TRIAL CASE)	569687.2
WORST	575760

The Table 3 gives a comparative results of best cost, average cost and worst cost obtained for 25 trial cases using the 10-unit system data.

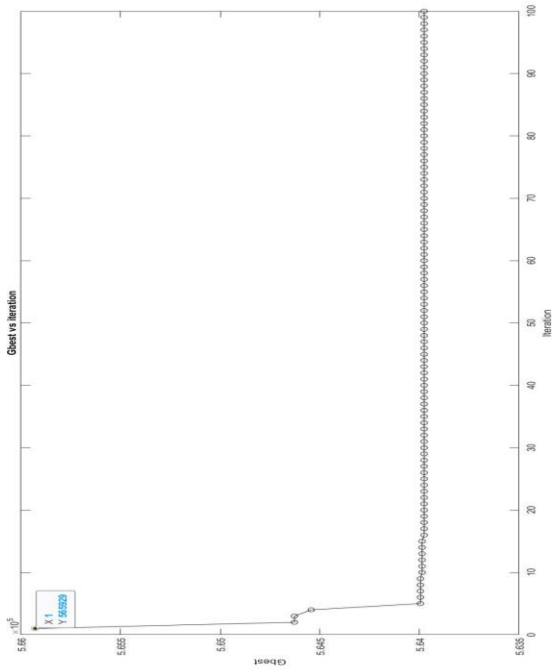

Fig 1: 10-Unit System GBest vs Iteration of PSO

The Fig 1 shows the graph plotted between Gbest and iterations that provides an information on the best data obtained through several iterations.

Table 4: ON / OFF Time period of 10-unit system

Hr-U_S	1 (MW)	2 (MW)	3 (MW)	4 (MW)	5 (MW)	6 (MW)	7 (MW)	8 (MW)	9 (MW)	10 (MW)	11 (MW)	12 (MW)	13 (MW)	14 (MW)	15 (MW)	16 (MW)	17 (MW)	18 (MW)	19 (MW)	20 (MW)	21 (MW)	22 (MW)	23 (MW)	24 (MW)	Cost ($)
1	90	83	109	120	150.7	170	327.33	257	201	286.447	234.76	183	189.56	189.44	195	151.34	145	151.34	259	298.77	251	201.45	258.3	165	10920
2	88	92	1O1	95.5	132	167.88	213.5	192	163	234	245.33	142.56	179.08	190	166.44	129	135	129	166.44	175	201	151.33	127.34	124	9256
3	0	72.3	99.3333	102	122	156	0	0	0	0	0	143	179.5	177	176	130	129.556	130	189	187	198	176.3	143	145	8920
4	87	82	100.27	99	119	142	361	101.334	0	0	0	0	0	181	183.33	127.45	130.45	127.45	0	0	0	0	0	0	8306
5	93	91	166	1O1	161	165	298.5	213	231	256.44	213	198.33	194.33	189.54	178	0	0	0	0	0	0	197.3	214	168	6978
6	0	84.7	109	89.5	0	0	0	197	129.3331	251	198.5	138	145.77	195	194	132.09	112.45	132.09	238	276.09	242	0	0	0	5432
7	101	89	83.6667	99	0	0	0	0	195	237.96	239.75	174	174	0	0	0	0	148.34	178	198.235	0	0	0	106	4123
8	85	83	0	85	134.3	154.12	0	0	143	0	210	169.5	169.78	179	0	148.34	109.22	125	194	189.87	223	0	169	0	3976
9	99	73	0	89	0	113	0	179	149.55	0	187	145	0	0	178	125	145	0	0	189	0	176.48	0	92	3218
10	72	0	101.73	75	181	102	0	169	198	233.65	0	159.34	169	0	0	169.55	102	169.55	0	0	195	198.86	0	0	2956

The Table 4 provides an hourly power output from each unit system and the total cost by each unit system.

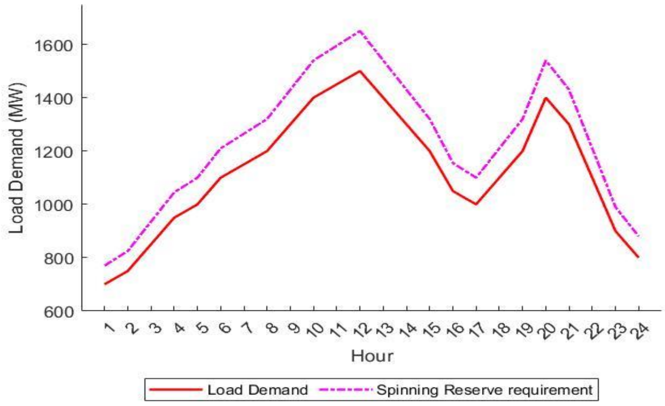

Fig 2: Load demand of 10-unit system

The Fig 2 shows a comparative graph between the load demand and a constraint applied load demand (spinning reserve).

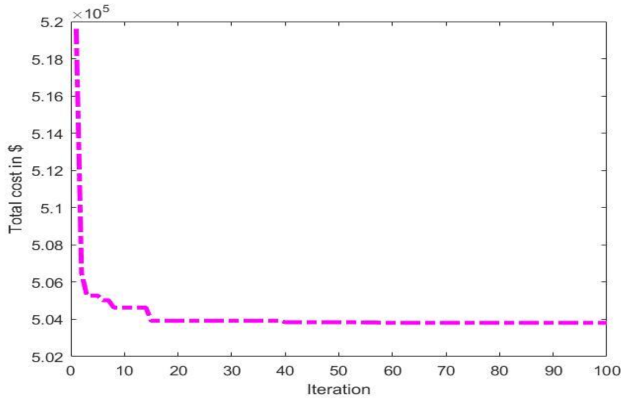

Fig 3: Total cost obtained in 10-unit system

The Fig 3 gives an information about the total cost obtained for each iteration.

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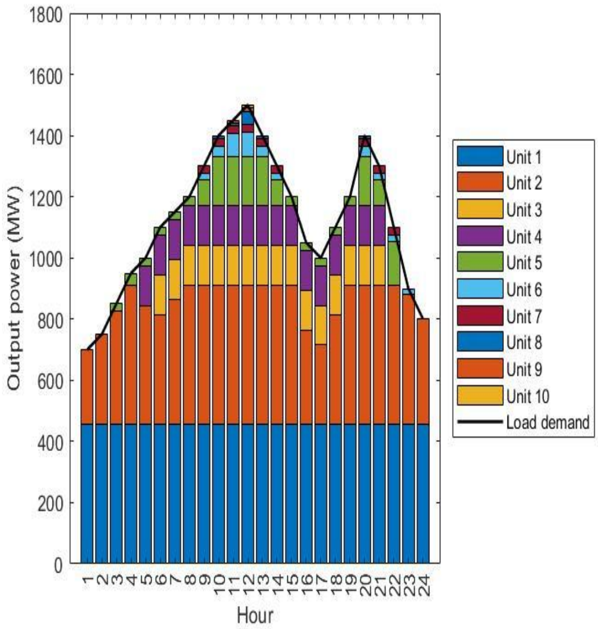

Fig 4: Output power in 10-unit system

Fig 4 shows the statistical data of hourly output power from 10-unit system.

B. *Test case-2*

In the test case-2, a 26-unit system that contains 26 generators and different loads at every hour of a day is considered for implementation. The test data and load demand of the 26-unit system is given below in Table 5 and Table 6.

Table 5: Test data of 26-unit system

Unit No	Pmax (MW)	Pmin (MW)	a ($ / MW²h)	b ($ / MWh)	c ($ / H)	MUT (H)	MDT (H)	HSC ($)	CSC ($)	Cold Start Time(H)	Initial Status (H)
1	400	100	0.0019	7.5031	311.9102	8	5	500	500	10	10
2	400	100	0.0019	7.4921	310.0021	8	5	500	500	10	10
3	350	140	0.0015	10.8616	177.0575	8	5	300	200	8	10
4	197	68.95	0.0026	23.2000	260.1760	5	4	200	200	8	-4
5	197	68.95	0.0026	23.1000	259.6490	5	4	200	200	8	-4
6	197	68.95	0.0026	23.0000	259.1310	5	4	200	200	8	-4
7	155	54.25	0.0049	10.7583	143.5972	5	3	150	150	6	5
8	155	54.25	0.0048	10.7367	134.3719	5	3	150	150	6	5
9	155	54.25	0.0047	10.7154	143.0288	5	3	150	150	6	5
10	155	54.25	0.0046	10.6940	142.7348	5	3	150	150	6	5
11	100	25	0.0060	18.200	218.7752	4	2	70	70	4	-3
12	100	25	0.0061	18.100	218.3350	4	2	70	70	4	-3
13	100	25	0.0062	18.000	217.8952	4	2	70	70	4	-3
14	76	15.2	0.0093	13.4073	81.6259	3	2	50	50	3	3
15	76	15.2	0.0091	13.3805	81.4641	3	2	50	50	3	3
16	76	15.2	0.0089	13.3538	81.2980	3	2	50	50	3	3
17	76	15.2	0.0088	13.3272	81.1364	3	2	50	50	3	3
18	20	4	0.0143	37.8896	118.8206	0	0	20	20	2	-1
19	20	4	0.0136	37.7770	118.4576	0	0	20	20	2	-1
20	20	4	0.0126	37.6637	118.1083	0	0	20	20	2	-1
21	20	4	0.0120	37.5510	117.7551	0	0	20	20	2	-1
22	12	2.4	0.0285	26.0611	24.8882	0	0	0	0	1	-1
23	12	2.4	0.0284	25.9318	24.7605	0	0	0	0	1	-1
24	12	2.4	0.0280	25.8027	24.6382	0	0	0	0	1	-1
25	12	2.4	0.0265	25.6753	24.4110	0	0	0	0	1	-1
26	12	2.4	0.0253	25.5472	24.3891	0	0	0	0	1	-1

The Table 5 provides the test data for a 26-unit system that helps to solve the UC problem.

Table 6: Load data of 26-unit system

Hour	1	2	3	4	5	6	7	8	9	10	11	12
Demand (MW)	2223	2052	1938	1881	1824	1825.5	1881	1995	2280	2508	2565	2593.5
Hour	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Demand (MW)	2565	2508	2479.5	2479.5	2593.5	2850	2821.5	2764.5	2679	2662	2479.5	2308.5

The Table 6 provides information of hourly load demand that should be matched with the output of the 26-unit system.

Table 7: Comparison of total cost of 26-unit system

TOTAL COST ($)	PSO
BEST	312432
AVERAGE (25 TRIAL CASE)	345536
WORST	354733

The Table 7 gives a comparative results of best cost, average cost and worst cost obtained for 25 trial cases using the 26-unit system data.

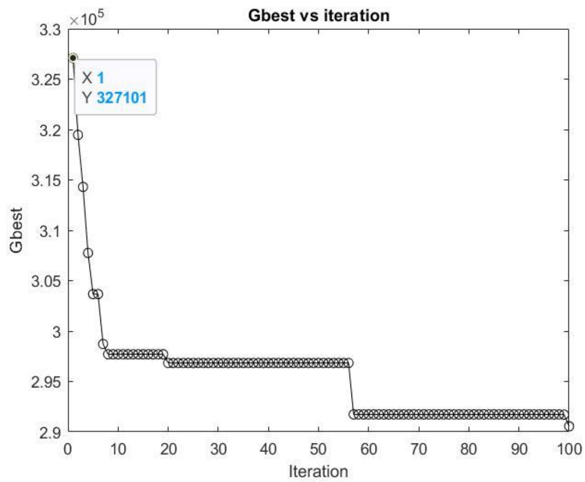

Fig 5- 26-UNIT SYSTEM GBest vs Iteration of PSO

The Fig 5 shows the graph plotted between Gbest and iterations that provides an information on the best data obtained through several iterations.

TABLE 8: ON/OFF TIME PERIOD OF 26-UNIT SYSTEM

Hr-U.Sys	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Cost
1	882.3	805.2	798.66	765	732	389	321	331	311.98	298	262.2	221.23	219.67	231.9	259.8	259.8	352	283	243	243	243	243	358	326.78	9599.6
2	716.23	710	689.33	654.83	641	324	301	308.23	300.2	234	219.24	209.8	211	226	240	240	345.88	272	238.9	238.9	238.9	238.9	342	312	9021.479
3	625	543	532	467	451.33	312.22	267.33	254.99	214.35	209.45	210	198.78	201.98	199.78	229	229	333	271.9	221	221	221	221	0	0	8934.87
4	0	0	0	0	0	299.55	201.3	217.5	209.67	199.28	189.78	187	0	0	0	0	0	261	219.68	219.68	219.68	219.68	0	0	8453
5	0	0	0	0	0	0	0	0	0	0	0	178	198	187.6	211.9	211.9	0	0	0	0	0	0	332.98	301	7904.98
6	0	0	0	0	0	0	0	0	0	178.34	156.9	171	191	173.34	0	0	0	0	0	0	0	0	0	0	6598
7	0	0	0	0	0	0	198	201	198	165.48	134	0	0	0	0	0	321	258.33	210	210	210	210	0	0	6100
8	0	0	0	0	0	0	0	0	179.45	159.45	132	169.23	185.89	164.35	201	201	301.73	251	206.58	206.58	206.58	206.58	0	0	5982.89
9	0	0	0	0	0	287	145	186.4	145.89	149.43	131.78	159	0	0	0	0	0	203.45	200.1	200.1	200.1	200.1	0	0	5689
10	0	0	0	0	0	0	0	0	0	0	0	143	174	154	198	198	0	0	0	0	0	0	310	298	5100.9
11	0	0	0	0	0	0	0	0	0	134.67	128.33	124.44	168.96	150.9	0	0	0	0	0	0	0	0	0	0	4980.79
12	0	0	0	0	0	0	125	108.45	139	123.98	129.45	0	0	0	0	0	267.9	198.37	198	198	198	198	0	0	4588
13	0	0	0	0	0	0	0	0	120.23	110.67	125	120	156	145	189	189	253.5	192	191.34	191.34	191.34	191.34	0	0	4109.78
14	0	0	0	0	0	109	101	101.23	107.25	101.68	123	101.23	0	0	0	0	0	189	187	187	187	187	0	0	3698
15	0	0	0	0	0	0	0	0	0	0	0	99.5	147	137.9	175.8	175.8	0	0	0	0	0	0	295	279.89	3169
16	0	0	0	0	0	0	0	0	0	98.75	112.64	87	138.4	129	0	0	0	0	0	0	0	0	0	0	2690.45
17	0	0	0	0	0	101.2	94	100.458	100.23	87.98	110.2	78	0	0	0	0	0	181.24	182	182	182	176	0	0	2459.09
18	0	0	0	0	0	0	0	0	0	0	0	64	123	121.98	168.9	168.9	0	0	0	0	0	0	287	278	2589
19	0	0	0	0	0	0	0	0	0	69.99	98.3	58	110.3	118	0	0	0	0	0	0	0	0	0	0	2198.8
20	0	0	0	0	0	0	65.34	85	98.45	54.89	88.2	0	0	0	0	0	223.5	154	177	177	123	123	0	0	2008
21	0	0	0	0	0	0	0	0	84.56	49.79	72	55.2	98.45	107.59	154	154	201.8	101	162	162	98	97	0	0	1978.98
22	0	0	0	0	0	72.5	62.23	74.35	64.9	38.77	53	52	0	0	0	0	0	73	0	0	0	0	0	0	1789
23	0	0	0	0	0	0	0	0	0	0	0	48	88.76	98	149	149	0	0	143	88	88	88	279.87	263	1609.88
24	0	0	0	0	0	0	0	0	0	34.98	49.3	41.23	79.67	87	0	0	0	0	0	0	0	0	0	0	1498.78
25	0	0	0	0	0	0	0	65	34.78	30.2	42.3	39	0	79.8	0	0	0	0	138.9	64	73	64	0	0	1239
26	0	0	0	0	0	0	0	0	0	0	0	32.4	75.68	68	130	130	0	0	0	0	0		276	250	1034.25

The Table 8 provides an hourly power output from each unit system and the total cost by each unit system.

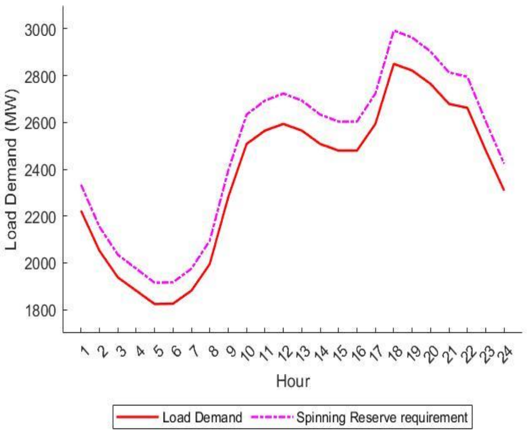

Fig 6- LOAD DEMAND OF 26-UNIT SYSTEM

The Fig 6 shows a comparative graph between the load demand and a constraint applied load demand (spinning reserve).

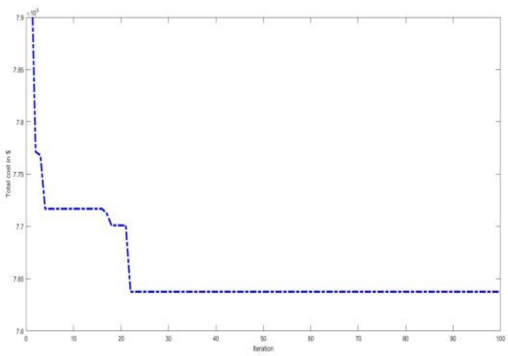

Fig 7: TOTAL COST OBTAINED IN 26-UNIT SYSTEM

The Fig 7 gives an information about the total cost obtained for each iteration.

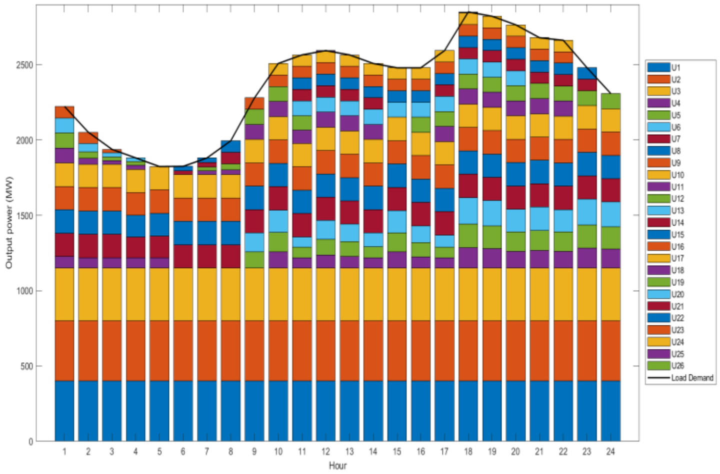

Fig 8: OUTPUT POWER OBTAINED IN 26-UNIT SYSTEM

Fig 8 shows the statistical data of hourly output power from 26-unit system.

CONCLUSION

Algorithms that might efficiently deliver the greatest outcomes in terms of manufacturing cost and start-up cost are needed to solve the hard challenge of UC. When compared to other findings, the suggested methodology's optimal solution properties produce better UC outcomes, which are tabulated. A recently proposed population-based stochastic optimisation approach for distinct state particle generation is called logical state particle swarm optimisation. For some difficult issues, such as UC in actual power systems, PSO has comparable or even better search performance when compared to other stochastic optimisation techniques. Additionally, by employing unique convergence values that can help the particles meet the equality demand restriction and get rid of the extra reserve allocation, the convergence behaviour could be sped up. According to current research, the standard PSO should be modified in order to boost variety and improve convergence, much like our new method does. As a result, the algorithm is able to explore the search area quickly and produce high-quality solutions. By taking into account the wind energy factors, the suggested algorithm can be further adjusted, creating a stochastic unit commitment problem. A proposed approach for the unit commitment problem in the current system makes use of a number of restrictions. We can create a stochastic unit commitment dilemma by including a second variable source (renewable energy - wind (or) solar). The suggested algorithm can be applied to a deregulated power system via the construction of a stochastic unit commitment problem. In a market that has been deregulated, the utility is in charge of managing distribution, maintaining cables and poles, and billing customers for these services. Retail electricity providers, or REPs, are companies that deliver electricity to customers in a deregulated electricity market. (the supply of electricity).

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