IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

Particle Swarm Optimization Solution to Unit Commitment Problem

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Abstract— **This paper presents Particle swarm Optimization (PSO) solution to the Unit Commitment problem in comparison with standard Dynamic Programming (DP). The objective of Unit Commitment is to determine the optimal schedule of generating units subjected to all the constraints. PSO method uses particle information to control the mutation operation and is similar to the social society in that a group of leads to make better decision. By using PSO we try to reduce total operating cost in comparison with DP. The simulation of UC with PSO in comparison with DP on a standard IEEE39 bus system with 10 units is done by using Matlab.**

Keywords—Unit Commitment, Particle Swarm Optimization, Dynamic Programming.

I. Introduction

Unit commitment (UC) is a nonlinear optimization problem to schedule the operation of the generating units with minimum operating cost while satisfying the required load demand and other equality and inequality constraints. Several solution strategies provide quality solutions to the unit commitment problem which increases the savings of the power system operation. The committed units must meet the forecasted load demand of system and spinning reserve requirement at minimum operating cost, subjected to a large set of operating constraints. UC can be done using deterministic and stochastic search approach methods. Deterministic approach methods include the priority list method [1], dynamic programming [2] and Lagrangian Relaxation [3]. These deterministic methods are simple and fast but they suffer from numerical convergence and solution quality problems. The stochastic search algorithms such as particle swarm optimization (PSO) [4]-[7], genetic algorithm (GA) [8], evolutionary programming [9], simulated annealing [10], ant colony optimization [11] and tabu search [12] method are able to overcome the demerits of traditional optimization techniques. The above stochastic search methods can handle complex nonlinear constraints and provide good quality of solutions. Due to simplicity and less parameters are required for tuning, particle swarm optimization is used for solving the unit commitment problem. In this paper we have studied the algorithm of PSO and formulate the algorithm for solving unit commitment using PSO. We obtain results for the standard IEEE39 bus system using PSO we will find the variation in the total operating cost of the system in the given time period and compare it with the total operating cost of the classical dynamic programming method.

II. FORMULATION OF UC PROBLEM

The objective of the UC problem is to minimize the total power generation cost in the given specified time. The total costs consist of:

- Fuel costs.
- Start-up costs.
- Shut-down costs.

Fuel costs are calculated with the help of unit heat rate and fuel price information. Start-up costs are expressed as a function of the number of hours the unit has been down. Shut-down costs are defined as a fixed amount for each unit per shutdown.

The below constraints must be satisfied during the optimization process are:
(a) System power balance.
(b) Reserve requirements.
(c) Generating units initial conditions.
(d) Max and Min capacity of generating units.
(e) Minimum-up time.
(f) Minimum-down time.
(g) Unit rate limits.
(h) Unit start-up ramps.
(I) Unit shut-down ramps. etc.…

It is assumed that the production cost, PC_i for unit *i* at any given time interval is a quadratic function of the generator power output, p_i.

$$PC_i = a_i + b_iP_i + c_iP_i^2 \tag{1}$$

Where a_i, b_i, c_i are the cost coefficients. The generator start-up cost depends on the time the unit has been switched off prior to the startup, T_{off}. The start-up cost SC_i at any given time is assumed to be an exponential cost curve.

A. *UC using Dynamic Programming*

Dynamic programming is an important optimization technique with wider area of applications. It decomposes a problem into a string of smaller problems, solves them, and develops an optimal solution to the initial problem using step-by-step procedure. The optimal solution is developed from the sub problem recursively. In basic dynamic programming algorithm for unit commitment problem examines every possible state in every interval. Some of these states are found to be infeasible and hence they are rejected instantly. But even, for an average size utility, a large number of feasible states will exist and the requirement of execution time will be high. Many other techniques use only some part of simplification to the fundamental dynamic programming algorithm. Dynamic programming has many advantages except the high computational time. The chief advantage of this technique is the reduction in the dimensionality of the problem. Suppose we have found units in a system and any combination of them could serve the single load. A maximum of 2N-1 combinations are available for testing. The units are arranged as priority list based on the full load average cost rate would result in a theoretically correct dispatch and commitment only if

- No load costs are zero.
- Generating unit's input-output characteristics are linear between zero output and full load.
- There are no other restrictions.
- Start-up costs have a fixed amount.

In dynamic programming algorithm:

- A state consists of an array of units with only specified units operating at a time and rest remains offline.
- The start-up cost of a unit is independent on the time it has been offline.
- There are no costs for shutting down a unit.
- There is a strict priority order, and in each interval a specified minimum amount of capacity must be operating.

Feasible states are the states with which the load demand can be met with the committed units in the provided time period. DP algorithm can be executed from the initial hour to final hour and in converse. We need to set the algorithm to run forward in time from the initial hour to the final hour. Approach DP has ample amount of pros in solving the unit commitment problem. Approach of DP to the computation of units with the previous history in every stage. There are other practical reasons for going for D.P. The computation is carried out as along as the time period we required.

B. *UC using Particle Swarm Optimization*

Particle swarm optimization is a stochastic approach, population based search algorithm. Particle swarm optimization (PSO) was first introduced in 1995 by *James Kennedy and Russell C. Eberhart*. The PSO method have evolved rapidly, and the original version of the algorithm is rarely used now a days. The development of PSO algorithm is from the simplified social system such as fish schooling and birds flocking. The initialization of PSO is from population which is known as particles. Each particle in order to reach its minimum position, particles moves with certain velocity in search space. The particle's movement is influenced by cognitive and social information attained during its local and global exploration. It has very few tunable parameters and the evolutionary process is very flexible and well balanced mechanism. PSO algorithm can adjust the movement of the particles based on their performances with some velocity. The appropriate swarm size can be found by using parameter tuning. In this algorithm, the optimal solution can be found by using randomly sized particles moving in the search space. The local minimum is found after all the particles share their flying experiences. Particles simultaneously moves in swarm and associate with each other to decide the value of global minimum.

In PSO algorithm UC problem is solved by generating logical states for each particle. Particle is represented with logical state strings representing the on/off status of the generators at each hour of the scheduling period T. For each particle maximum of 2^n logical states having 1/0 as the numbers. 1 represents ON state and 0 represent OFF state of the unit. In PSO, each set of particles are initialized randomly in the decision space. Each particle has some velocity to move towards the local minimum. The local minimum kept in repository, and again the particles change their positions and move towards the global minimum with different velocities and reach the global minimum within the maximum number of iterations.

The optimization process can briefly understood from the below steps:

- Logical states Generation
- Initialization of particles
- Iteration process
- Evaluation of Total operating cost

After finding the best cost at first hour, repeat the logical states generation by adding status of all units at first hour to the initial state, then using the updated status of each unit carry out all steps. Repeat the same process for all time interval, we get total operating cost. We will calculate both the startup costs and fuel cost.

C. *PSO ALGORITHM*

- Initialize the swarm, *p*(*t*), of particles such that the position *xi(t)* of each particle . *p(t)* is random within the hyperspace, with *t* = 0.
- The fitness function of every particle is evaluated and we will find out *pbest*.
- Compare fitness value of every individual particle with its *pbest*. If the calculated fitness value is better than the *pbest* value, then set the calculated fitness value as the current particle's position, *xi*, as *pi*.
- The particle with best fitness value is identified and value is denoted as *gbest* with its position as *pg*.
- We have to update the velocities and positions of all the particles.

$$V_i(t) = V_i(t-1) + C_1\left(xpbest_i - x_i(t)\right) + C_2\left(xgbest - x_i(t)\right) \quad (2)$$

Where *C1* and *C2* are random variables. The second term above is referred to as the cognitive component, while the last term is the social component.

$$x_i(t) = x_i(t-1) + V_i(t) \quad (3)$$

III. UNIT COMMITMENT USING PSO

The basic idea behind PSO has briefed earlier. PSO is a population based searching algorithm. This approach simulates the simplified social system such as fish schooling and birds flocking. The initialization of PSO is done by a population of potential solutions which are known as particles. In search space each particle moves with a particular velocity. PSO has less tunable parameters and the evolutionary process is quiet simple. PSO has capacity to provide standard solutions to complex power system problems. One such type of complex power system problem is UC of thermal generating units. To decrease the total operating cost (TOC) we use PSO method of UC by committing the units with proper combinations which are feasible for the reliable operation of the power system without violating the constraints. We will mainly try to reduce the total fuel cost instead of the startup costs. In this paper the up and down time of the generating units are taken into consideration. The algorithm for UC is detailed as follows:

The below steps are used by the PSO technique to solve the unit commitment problem for the IEEE 39 bus system

- Population of particles *pi* and other variables are initialized. Each particle is generated randomly with in the specified range.

$$P_{i\,min} \leq P_i \leq P_{i\,max}$$

Here p_i represented as i_{th} unit in the power system.

- The parameters such as the population size, initial and final inertia weight, random velocity of particle, acceleration constant, the max generation, Lagrange's multiplier (λ_i), etc. are initialized.
- By using cost function we calculate fitness value of each individual of the initialized population.

$$OC_T = \sum_{t=1}^{T}\sum_{i=1}^{N} PC_{i,t}\,U_{i,t} + SC_{i,t}(1-U_{i,t-1})U_{i,t} \qquad (4)$$

Where $PC_{i,t}$ is represented as

$$F(P_i) = a_i + b_iP_i + c_iP_i^2 \qquad (5)$$

With equality constraint as

$$\sum_{i=1}^{n} P_i = P_D \qquad (6)$$

Where *Pi* is the i_{th} generators and P_D is the load or demand and inequality constraints as

$$P_{i\,min} \leq P_i \leq P_{i\,max} \qquad (7)$$

- The comparison of each individual's fitness value with its *pbest*. The best fitness value among *pbest* is denoted as *gbest*.
- The velocity of each individual particle is modified as

$$v^{(t)} = v^{(t-1)} + C_1 \times rand() \times (P_{pbesti} - P_i^{(t)}) + C_2 \times rand() \times (P_{gbest} - P_i^{(t)}) \qquad (8)$$

- The individual's position p_i is modified as

$P_i^{(t)} = P_i^{(t-1)} + P_i^{(t)}$

Where *i* is the *ith* unit and *t* is the hour

- If the evaluation value of each individual is better than the previous *ppbest*, the current value is set to be *ppbest*. If the best *ppbest* is better than *pgbest* the value is set to be *pgbest*.

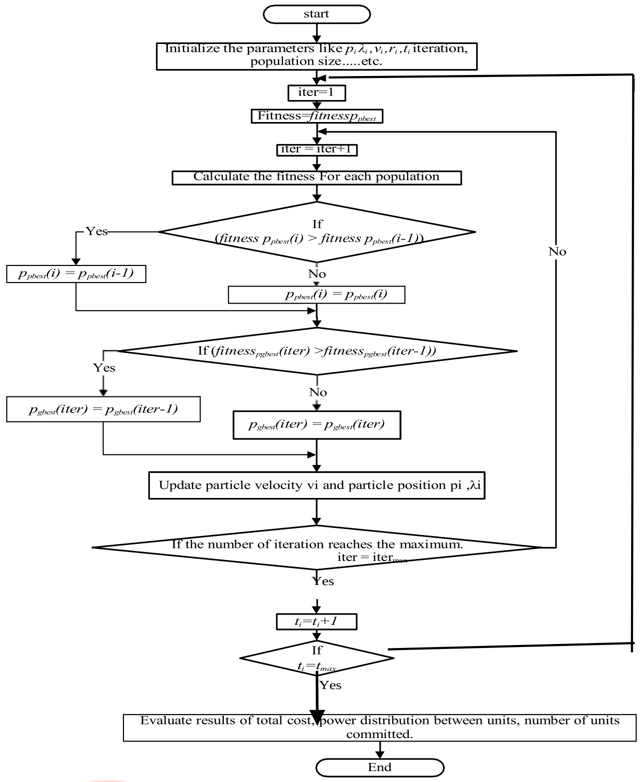

Fig: Flow Chart of PSO based Unit Commitment

- Modify the λ and α for each equality and Inequality constraint.
- For Inequality Constraint

$$\alpha = \max(inequality\ constraint, -\lambda\,(iter-1)/(2\times r)) \qquad (9)$$

$$\lambda(iter) = \lambda(iter-1) + (2\times r\times\alpha) \qquad (10)$$

- For equality constraint

$$\alpha = \max(inequality\ constraint, -\lambda\,(iter-1)/(2\times r)) \qquad (11)$$

- The fitness function is minimized using PSO method for the number of units running in the given particular time.
- The individual that generates the latest solution pertains to the optimal generation power of each unit with the minimum total generation cost.

IV. TEST SYSTEM

IEEE-39 Bus system contains ten generators and different loads at every hour of a day. For this system, start-up cost calculated by exponential start-cost method. The OFF and ON time periods of the each units is shown in TABLE-I. The production cost is calculated and calculation of start-up cost by exponential start-up cost is some complex because it depends on OFF time period of each unit.

Calculation of OFF time period is more complex to understand. OFF time period of each unit is calculated as follows. First check initial status of each unit, if it is in OFF mode then add these initial OFF period to OFF period time intervals up to the unit gets committed.

TABLE I. PARAMETERS OF 10-UNIT GENERATING SYSTEM

Unit	P^{max} (MW)	P^{min} (MW)	Initial status	Min up time	Min. down time
1	455	150	+8	5	5
2	455	150	+8	5	5
3	130	20	-5	2	2
4	130	20	-5	2	2
5	162	25	-6	2	2
6	80	20	-3	2	2
7	85	25	-3	1	1
8	55	10	-1	0	0
9	55	10	-1	0	0
10	55	10	-1	0	0
Unit	**HST**	**CST**	**Fuel cost**		
			a	***b***	***C***
1	4500	9000	1000	16.19	0.00048
2	5000	10000	970	17.26	0.00031
3	550	1100	700	16.60	0.00200
4	560	1120	680	16.50	0.00211
5	900	1800	450	19.70	0.00398
6	170	340	370	22.26	0.00712
7	260	520	480	27.74	0.00079
8	30	60	660	25.92	0.00413
9	30	60	665	27.27	0.00222
10	30	60	670	27.79	0.00173

TABLE II. LOAD DEMAND FOR 24 HOURS SCHEDULING PERIOD

Hour	Load Demand (MW)	Hour	Load Demand (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

V. SIMULATION RESULTS AND DISCUSSION

In this paper, the simulation of UC 10 unit system using DP and PSO is done using MATLAB software. The performance is benchmarked with the result obtained using DP. Table III shows the UC for standard IEEE39 bus system from hour 1 until hour 24 using DP.STC represents the start-up cost of generating unit. F-COST is the fuel cost of the generating unit. Here we concentrate on the total operating cost which is the sum of start-up cost and fuel cost. The results of optimal unit commitment obtained using PSO is presented in Table IV. In PSO we will emphasize on total operating cost and compare with DP and focus on computation of both the methods.

TABLE III. UC USING DP FOR IEEE39 BUS SYSTEM

T	PD	UNIT SCHEDULE	STC	F-COST
0	0	1 1 0 0 0 0 0 0 0 0	0	0
1	700	1 1 0 0 0 0 0 0 0 0	0	13683
2	750	1 1 0 0 0 0 0 0 0 0	0	14554
3	850	1 1 0 0 1 0 0 0 0 0	900	16809
4	950	1 1 0 1 1 0 0 0 0 0	560	19146
5	1000	1 1 0 1 1 0 0 0 0 0	0	20020
6	1100	1 1 1 1 1 0 0 0 0 0	1100	22387
7	1150	1 1 1 1 1 0 0 0 0 0	0	23262
8	1200	1 1 1 1 1 0 0 0 0 0	0	24150
9	1300	1 1 1 1 1 1 1 0 0 0	860	27251
10	1400	1 1 1 1 1 1 1 1 0 0	60	30058
11	1450	1 1 1 1 1 1 1 1 1 0	60	31916
12	1500	1 1 1 1 1 1 1 1 1 1	60	33890
13	1400	1 1 1 1 1 1 1 1 0 0	0	30058
14	1300	1 1 1 1 1 1 1 0 0 0	0	27251
15	1200	1 1 1 1 1 0 0 0 0 0	0	24150
16	1050	1 1 1 1 1 0 0 0 0 0	0	21514
17	1000	1 1 1 1 1 0 0 0 0 0	0	20642
18	1100	1 1 1 1 1 0 0 0 0 0	0	22387
19	1200	1 1 1 1 1 0 0 0 0 0	0	24150
20	1400	1 1 1 1 1 1 1 1 0 0	920	30058
21	1300	1 1 1 1 1 1 1 0 0 0	0	27251
22	1100	1 1 0 0 1 1 1 0 0 0	0	22736
23	900	1 1 0 0 0 1 0 0 0 0	0	17645
24	800	1 1 0 0 0 0 0 0 0 0	0	15427
Total			4520	560396
Total operating cost (TOC) = STC + Total F-COST				**564916**

STC---Startup Cost
F-COST---Fuel Cost

TABLE IV. GENERATOR SCHEDULING AND COMMITTED CAPACITY USING PSO

Hour	PD	Committed Capacity of Generators (MW)										STC	F-COST
		G1	G2	G3	G4	G5	G6	G7	G8	G9	G10		
1	700	455	245	0	0	0	0	0	0	0	0	0	13683
2	750	455	295	0	0	0	0	0	0	0	0	0	14554
3	850	455	370	0	0	25	0	0	0	0	0	900	16809
4	950	455	455	0	0	40	0	0	0	0	0	0	18498
5	1000	455	390	0	130	25	0	0	0	0	0	560	20020
6	1100	455	360	130	130	25	0	0	0	0	0	1100	22387
7	1150	455	410	130	130	25	0	0	0	0	0	0	23262
8	1200	455	455	130	130	30	0	0	0	0	0	0	24150
9	1300	455	455	130	130	85	20	25	0	0	0	860	27251
10	1400	455	455	130	130	162	33	25	10	0	0	60	30058
11	1450	455	455	130	130	162	73	25	10	10	0	60	31916
12	1500	455	455	130	130	162	80	25	43	10	10	60	33890
13	1400	455	455	130	130	162	33	25	10	0	0	0	30058
14	1300	455	455	130	130	85	20	25	0	0	0	0	27251
15	1200	455	455	130	130	30	0	0	0	0	0	0	24150
16	1050	455	310	130	130	25	0	0	0	0	0	0	21514
17	1000	455	260	130	130	25	0	0	0	0	0	0	20642
18	1100	455	360	130	130	25	0	0	0	0	0	0	22387
19	1200	455	455	130	130	30	0	0	0	0	0	0	24150
20	1400	455	455	130	130	162	33	25	10	0	0	920	30058
21	1300	455	455	130	130	85	20	25	0	0	0	0	27251
22	1100	455	455	0	0	145	20	25	0	0	0	0	22736
23	900	455	425	0	0	0	20	0	0	0	0	0	17645
24	800	455	345	0	0	0	0	0	0	0	0	0	15427
Total												4520	559747
Total Operating Cost (TOC) = STC + Total F-COST													**564267**

VI. CONCLUSION

This paper has proposed the application of PSO particle swarm optimization algorithm for solving the problem of UC. The problem of UC being a challenging problem requires algorithms that could effectively produce best results in terms of production cost and start-up cost. The optimal solution properties of the proposed methodology yields better UC results when compared to other results and those are tabulated. Particle Swarm Optimization is newly proposed population based stochastic optimization algorithm for different state particle formation. Compared with DP dynamic programming method, PSO has comparable or even superior search performance for some complex problems like UC in real power systems. Also the convergence behavior could be made faster by using special convergence values that can assist the particles to satisfy the equality demand constraint and to remove the excess reserve allocation. In recent research, some modifications to the standard PSO are proposed mainly to improve the convergence and to increase diversity like our new technique. As a result, the algorithm is capable of efficiently exploring the search space and generating quality and accurate solutions. The simulation results of both the methods is done by MATLAB software and we mainly concentrate on the total operating cost (TOC) of the generating units. Total operating cost includes the cost of startup cost and operating cost of each committed generator. By DP we got TOC as $564916 and by PSO we got TOC as $564267. The computational time required for PSO is much less than DP.

TABLE V. SUMMARIZED RESULTS FOR BOTH TECHNIQUES

Technique	TOC($)	Computation Time (Sec)
PSO	564267	285
DP	564916	1020

From the summarized results presented in Table V, it can be observed that the optimum total operating cost in 24 hoursobtained by using PSO is $564267 with the start-up cost of $4,520. Meanwhile, the total operating cost obtained using DP is $564,916 per day. There is significant reduction of fuel cost in PSO when compared to DP.

TABLE VI. FINAL COST TABLE

DP(TOC)	PSO(TOC)	Difference
564916	564267	649

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