International Journal of Scientific & Engineering Research, Volume 4, Issue 7, July-2013 1428
ISSN 2229-5518

Optimal Unit Commitment Problem Solution Using Real-Coded Particle Swarm Optimization Technique

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Abstract— This paper present real-coded particle swarm optimization RPSO is proposed to solve unit commitment problem UCP. The unit commitment is the problem to determining the schedule of generating units subject to device and operating constraints. The problem is decomposed in two sub-problem are unit commitment and economic dispatch that are solved by RPSO. The UCP is formulated as the minimization of the performance index, which is the sum of objectives (fuel cost, startup cost and shutdown cost) and some constraints (power balance, generation limits, spinning reserve, minimum up time and minimum down time). The RPSO technique is tested and validated on 10 generation units system for 24 hour scheduling horizon.

Index Terms— Real-Coded PSO, power system constraints, economic dispatch problem, optimal unit commitment.

1. Introduction

Unit commitment problem UCP is used to economically schedule the generating units over a short term planning horizon subjected to the forecasted demand and other system operating constraints.

Generation scheduling involves the determination of the startup and shutdown time points and the generation levels for each unit over a given scheduling period (usually 24 hour). Unit commitment plays an important role in power system economic operation for reasonable scheduling will save larger amount of fuel cost and bring huge economic benefit [1, 2]. In solving the UCP, generally two basic problems are involved, namely the "unit commitment" decision and the "economic dispatch" decision. The unit commitment decision involves the determination of the generating units to be running during each hour of the planning horizon, considering the system capacity requirements, including the spinning reserve, start up and shutdown of unit constraints. The economic dispatch decision involves the allocation of system demand and spinning reserve capacity among the operating units during the each specific hour of operation. The unit commitment is considered as a non-linear, large-scaled, mixed integer combinatorial optimization problem. The Previous UCP method includes: priority list method, dynamic programming, integer and linear programming, Lagrangian relaxation, branch and bound, interior point optimization, tabu search, simulated annealing, artificial intelligence methods, evolutionary programming etc. But each method exist some difficulties such as: dimension disaster, searching algorithm and convergence. This paper presents the Real-Coded Particle Swarm Optimization technique for the solution of the Unit Commitment Problem on 10 units during 24 hour.

2. UCP mathematical formulation

The main objective of the UCP is to minimization cost turn-on and turn-off schedule of a set of electrical power generating units to meet a load demand while satisfying a set of operational constraints. Therefore the objective function of the unit commitment problem is expressed as the sum of fuel cost and startup cost for all of the units over the whole scheduling periods [1, 2].

For N generating units and T hours the objective function of the UCP can be written as follows:

$$F\left(P_i^t, U_{i,t}\right) = \min\left(\sum_{t=1}^{T}\sum_{i=1}^{N}\left[F_i\left(P_i^t\right) + ST_{i,t}\left(1 - U_{i,t-1}\right)\right]U_{i,t}\right) \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Where,

$F(P_i^t)$ is fuel cost of ith unit,

$F_i(P_i^t) = a_i P_i^2 + b_i P_i + c_i$

$$ST_{i,t} = \begin{cases} HST & \text{if } T_{i,down} < T_{i,off} < T_{i,cold} + T_{i,down}, \\ CST & \text{if } T_{i,off} > T_{i,cold} + T_{i,down} \end{cases} \quad \ldots\ldots\ldots (2)$$

P_i^t is amount of power produced by unit i at time t.

a_i, b_i and c_i are cost parameters of ith unit.

$U_{i,t}$ is a control variable of unit i at time t.

HST_i is hot startup cost of unit i (in dollars).

CST_i is cold startup cost of unit i (in dollars).

$T_{i,cold}$ is cold start hour of unit i (in hours).

$T_{i,off}$ is continuously off time of unit i (in hours).

$T_{i,down}$ is minimum down time of unit i (in hours).

ISSN 2229-5518

ST_i is start-up cost of ith unit,

t= 1, 2, 3, ….., T and i = 1, 2, 3, ……, N.

The minimization of the objective function is subjected to the following constraints:

2.1 Power balance constraints

Demand during interval t is equal to summation of all the generating units at same interval t.

$$P_{Load}^{t} - \sum_{i=1}^{N} P_i^t U_i^t = 0 \qquad \text{……………} (3)$$

Where, P_{Load}^{t} is load at time t (demand).

2.2 Generation limits constraint

Power generated by ith plant should be within minimum and maximum generating limit of ith plant.

$$P_i^{Min} \leq P_i^t \leq P_i^{Max} \qquad \text{…………..} (4)$$

2.3 Spinning reserve constraint

Spinning reserve is the term used to describe the total amount of generation available from all units synchronized (i.e., spinning) on the system, minus the present load and the losses being supplied.

$$P_{Load}^{t} + R^t \leq \sum_{i=1}^{N} P_i^{Max} U_i^t \qquad \text{………} (5)$$

Where, R^t is power reserve at time t.

2.4 Minimum up and down time constraints

Minimum up time: once the unit is running, it should not be turned off immediately. Minimum down time: once the unit is decommitted, there is a minimum time before it can be recommitted.

$$U_i^t = \begin{cases} 1, & \text{if } T_{i,on} < T_{i,up} \\ 0, & \text{if } T_{i,off} < T_{i,down} \\ 0 \text{ or } 1 & \text{otherwise} \end{cases} \qquad \text{………….} (6)$$

3. Particle Swarm Optimization

Particle swarm optimization PSO is a population based stochastic optimization technique developed by Elerhart and Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling [3]. PSO has its roots in artificial life and social psychology, as well as in engineering and computer science. It utilizes a "population" of particles that fly through the problem hyperspace with given velocities. At each iteration, the velocities of the individual particles are stochastically adjusted according to the historical best position for the particle itself and the neighborhood best position. Both the particle best and the neighborhood best are derived according to a user defined fitness function. The movement of each particle naturally evolves to an optimal or near-optimal solution [4, 5].

PSO has been successfully applied in many areas: function optimization, artificial neural network training, fuzzy system control, and other areas. One such area is the unit commitment of thermal units in the power system. It is used to minimize the total operating cost by committing those optimal combinations of the units which satisfy the constraints and gives the minimum cost corresponding to that combination.

The position of each particle is determined by the vector of x_i [3]:

$$\vec{x}_i(t) = \vec{x}_i(t-1) + \vec{v}_i(t) \qquad \text{………} (7)$$

And the velocity will be determined by:

$$\vec{v}_i(t) = \vec{v}_i(t-1) + \varphi_1 \left(\vec{P}_i - \vec{x}_i(t-1)\right) + \varphi_2 \left(\vec{P}_g - \vec{x}_i(t-1)\right) \qquad \text{……………} (8)$$

Where φ_1, φ_2 are two positive random numbers.

According to the formulation above, the procedure of Particle swarm optimization algorithm can be [4]:

- Initialize the swarm by assigning a random position in the problem hyperspace to each particle.
- Evaluate the fitness function for each particle.
- For each individual particle, compare the particle's fitness value with its Pbest. If the current value is better than the Pbest value, then set this value as the Pbest and the current particle's position, $\boldsymbol{x_i}$ as $\boldsymbol{P_i}$.
- Identify the particle that has the best fitness value. The value of its fitness function is identified as gbest and its position as Pg.
- Update the velocities and positions of all the particles using (1) and (2).
- Repeat steps 2-5 until a stopping criterion is met (e.g. maximum number of iterations or a sufficiently good fitness value).

4. Unit commitment using RPSO

The following steps are used by the RPSO technique to solve the unit commitment problem.

- Initialize the population of particles Pi and the parameters of RPSO such as the size of population, random$\boldsymbol{\varphi_1}$,$\boldsymbol{\varphi_2}$, and the parameters of the unit commitment.
- Evaluate the fitness of each particle in the population using the objective function equation (1) and checking the constraints of unit commitment.
- Evaluate the economic dispatch based RPSO depending on the constraints in equation (3, 4).
- Compare each particle's fitness value with its Pbest. The best fitness value among Pbest is denoted as gbest.

- Update Pbest and Pgbest: If the evaluation value of each particle is better than the previous Pbest, the current value is set to be Pbest. If the best Pbest is better than Pgbest the value is set to be Pgbest.
- Update velocity: Modify the particle's velocity of each particle Pi as equation (8) and the particle's position as equation (7).
- If one of the stopping criteria is satisfied then go to step 8. Otherwise, go to step 2.
- The particle that generates the latest is the optimal generation power of each unit with the minimum total generation cost.

5. Numerical results

This paper developed the real-coded particle swarm optimization algorithm using MATLAB 2012a. The 10 generation units were chosen along with a 24-h demand. The system data of 10 unit system and the load pattern for 24 hours are given in appendix A. Table 1 and 2 show the simulation results of the proposed method. Comparing the results with the other methods justifies the flexibility, effectiveness and applicability of the proposed method with regards to minimizing the total operation cost.

6. Conclusion

A real-coded particle swarm optimization algorithm has been proposed for unit commitment problem in this paper. The RPSO method is implemented on the 10 unit system. The results obtained by RPSO compare with other optimization methods, it's clearly show that the effectiveness of the RPSO in searching global or near global optimal solution to the UCP. Also the results show a better convergence and higher precision.

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ISSN 2229-5518

TABLE (1)

OPTIMAL DISPATCH OF GENERATION USING RPSO

# G. / Hour	1	2	3	4	5	6	7	8	9	10
1	455.0000	245.0000	0	0	0	0	0	0	0	0
2	455.0000	295.0000	0	0	0	0	0	0	0	0
3	455.0000	370.0000	0	0	25.0000	0	0	0	0	0
4	455.0000	455.0000	0	0	40.0000	0	0	0	0	0
5	455.0000	390.0000	130.0000	0	25.0000	0	0	0	0	0
6	455.0000	455.0000	130.0000	0	60.0000	0	0	0	0	0
7	455.0000	410..0000	130.0000	130.0000	25.0000	0	0	0	0	0
8	455.0000	455.0000	130.0000	130.0000	30.0000	0	0	0	0	0
9	455.0000	455.0000	130.0000	130.0000	105.0000	0	25.0000	0	0	0
10	455.0000	455.0000	130.0000	130.0000	162.0000	0	25.0000	0	33.0000	10.0000
11	455.0000	455.0000	130.0000	130.0000	162.0000	73.0000	25.0000	10.0000	10.0000	0
12	455.0000	455.0000	130.0000	130.0000	162.0000	80.0000	25.0000	43.0000	10.0000	10.0000
13	455.0000	455.0000	130.0000	130.0000	162.0000	48.0000	0	0	10.0000	10.0000
14	455.0000	455.0000	130.0000	130.0000	110.0000	20.0000	0	0	0	0
15	455.0000	455.0000	0	130.000	130.000	20.0000	0	10.0000	0	0
16	455.0000	440.0000	0	130.0000	25.0000	0	0	0	0	0
17	455.0000	390.0000	0	130.0000	25.0000	0	0	0	0	0
18	455.0000	455.0000	0	130.0000	60.0000	0	0	0	0	0
19	455.0000	455.0000	0	130.0000	115.0000	20.0000	25.0000	0	0	0
20	455.0000	455.0000	130.0000	130.0000	162.0000	33.0000	25.0000	0	10.0000	0
21	455.0000	455.0000	130.0000	130.0000	85.0000	20.0000	25.0000	0	0	0
22	455.0000	455.0000	130.0000	0	60.0000	0	0	0	0	0
23	455.0000	315.0000	130.0000	0	0	0	0	0	0	0
24	455.0000	215.0000	130.000	0	0	0	0	0	0	0

TABLE (2)

COMPARISON RESULTS OF VARIOUS ALGORITHMS

Algorithms	Minimum operating cost $
LR [6]	565825
EALR [7]	565508
GA [6]	565825
EP [8]	564551
ABRPSO [9]	563978
BRCSA [10]	563940
RPSO	563820

ISSN 2229-5518

APPENDIX (A)

TABLE A.1

UNIT DATA FOR THE 10 UNIT SYSTEMS

Unit	1	2	3	4	5	6	7	8	9	10
P_{max} (MW)	455	455	130	130	162	80	85	55	55	55
P_{min} (MW)	150	150	20	20	25	20	25	10	10	10
A	1000	970	700	680	450	370	480	660	665	670
B	16.19	17.26	16.60	16.50	19.70	22.26	27.74	25.92	27.27	27.79
C	0.00048	0.00031	0.002	0.00211	0.00398	0.00712	0.00079	0.00413	0.00222	0.00173
T_{up} (hr)	8	8	5	5	6	3	3	1	1	1
T_{down} (hr)	8	8	5	5	6	3	3	1	1	1
S_h hot start	4500	5000	550	560	900	170	260	30	30	30
S_C cold start	9000	10000	1100	1120	1800	340	520	60	60	60
T_{cold} hrs	5	5	4	4	4	2	2	0	0	0
Initial state hrs	8	8	-5	-5	-6	-3	-3	-1	-1	-1

TABLE A.2

LOAD DEMAND DATA

Hours	Load MW	Hours	Load 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