Particle swarm optimization technique to solve unit commitment problem

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Abstract

Unit commitment problem is one of the major problems in power system operation and control. The determination of time intervals at which a particular unit to be on and off, satisfying various constraints is a multi constrained complex optimization problem. In this paper we have used Particle swarm optimization technique which is population based global searching optimization technique is applied to solve unit commitment problem, for optimum unit commitment schedule. With the application of PSO algorithm it is easy to update the lagrangian multipliers, useful to sub divide the main problem in to a number of sub problem. Single unit dynamic programming is used to solve for each unit so that the total cost can be minimized over a scheduling period of time.

Keywords

1. Introduction

To meet up the cyclical nature of human activity, most of the systems supplying services to a large population will experience cycles. Power system is also one among them which experience cyclical nature to meet the load demand. The problem of optimally scheduling the enough number of generating units to meet up the load demand is unit commitment problem. The optimization problem involves determining the time intervals and power generation levels at each interval to minimize the total operating cost. In this paper a PSO technique in addition with dynamic programming is used to solve the unit commitment problem.

2. Preliminaries

Let OC = the total operating cost
t = the time interval, T = the total time period

N = number of generators,
PCi,t = ai + bi*pi+ ci*pi^2, Where ai,bi,ci are cost coefficients
Ui,t = the status of ith unit at time t
SCi,t = the start up cost of unit i at time t

(SCi,t) START UP COST MODEL: There are two types of start up cost models

a) Bringing the unit online from a cold start
The start up cost model when cooling can be expressed as $F_{sc}(t) = \left(1 - e^{-\frac{t}{\alpha}}\right)F + C_f$ ------- (1)

Where
F= the fuel cost, $F_{sc}(t)$ = the cold start cost for the cooling model
C_f = The fixed cost of generator operation including crew expense, maintenance expense.
t = the time that the unit was cooled
α = Thermal time constant for the unit

b) Bringing it from bank status

In this model the unit is turned off but still close to operating temperature
The start up cost model when banking can be expressed as a linear function as below:

$$F_{sb}(t) = F_o * t + C_f \quad \text{------- (2)}$$

$F_{sb}(t)$ = the start up cost for banking model

F_o = the cost of maintaining a unit at operating temperature. From the above parameters the unit commitment problem can be formulated as follows

$$OC = \sum_{t=1}^{T}\sum_{i=1}^{N} PC_{i,t}U_{i,t} + SC_{i,t}(1 - U_{i,t-1})U_{i,t} \quad \text{------- (3)}$$

This is a complex mathematical optimization problem is subjected to various constraints like

Loading constraint:

$$P_{load}^{t} - \sum_{i=1}^{N} P_i^t * U_i^t = 0 \quad \forall t = 1\dots\dots.T \quad \text{------- (4)}$$

Unit limits:

$$U_i^t * P_i^{min} \leq P_i^t \leq U_i^t * P_i^{min} \ \forall i = 1....N \ and \ t = 1......T$$

Unit minimum up and down time constraints:

$$\left. \begin{array}{l} (u_i(t) - u_i(t-1)(T_{on,t-1} - MUT)) \leq 0 \\ (u_i(t) - u_i(t-1)(T_{off,t-1} - MDT)) \geq 0 \end{array} \right\} \quad \text{------- (5)}$$

MUT = Minimum up time
MDT=Minimum down time
Ton = generator on time
Toff = generator off time

Unit ramp rate limits

$$\left. \begin{array}{l} \max(P_i^{min}, (P_{i,t-1} - DR_i)) \leq P_{i,t} \\ \min(P_i^{max}, (P_{i,t-1} + UR_i)) \geq P_{i,t} \end{array} \right\} \quad \text{------- (6)}$$

DR = ramp down limit
UR =ramp up limit

In addition to all the above constraints there are some other constraints like spinning reserve constraints and crew constraints and must run constraints that must be satisfied.

3. Problem Formulation

Formation of the Lagrange function
In a similar way to the economic dispatch problem

$$L(P, U, \lambda) = F(P_i^t, U_i^t) + \sum_{t=1}^T \lambda^t [P_{load}^t - \sum_{i=1}^N P_i^t * U_i^t] \quad \text{------- (7)}$$

Where $F(Pi^t, Ui^t)$ is the total operating cost (OC) as discussed earlier. Unit commitment requires that the minimization of the Lagrange function subject to all the constraints *The cost function and the unit constraints are each separated over the set of units, What is done with one unit does not affect the cost of running another unit as far as the cost function, unit limits, and the up-time and down-time constraints are concerned*

The loading constraint is a coupling constraint across all the units

The Lagrange relaxation procedure solves the unit commitment by temporarily ignoring the coupling constraint

The lagrangian relaxation procedure is as follows

Step 1: find a value for each λ^t which moves q(λ) towards a larger value

Step 2: assuming that λ^t found in step 1 is fixed, find the minimum of L by adjusting the values of $P^t \ and \ U^t$

Minimizing L

$$L = \sum_{t=1}^T \sum_{i=1}^N [F_i(P_i^t) + S_{i,t}] U_i^t + \sum_{t=1}^T \lambda^t P_{load}^t - \sum_{t=1}^T \sum_{i=1}^N \lambda^t P_i^t U_i^t$$

$$= \sum_{i=1}^N \sum_{t=1}^T \{[F_i(P_i^t) + S_{i,t}] U_i^t - \lambda^t P_i^t U_i^t \} + \sum_{t=1}^T \lambda^t P_{load}^t$$

------- (8)

Separation of the units from one another: the inside term can now be solved independently for each generating unit

$$\sum_{t=1}^T [F_i(P_i^t) + S_{i,t}] U_i^t - \lambda^t P_i^t U_i^t] \quad \text{------- (9)}$$
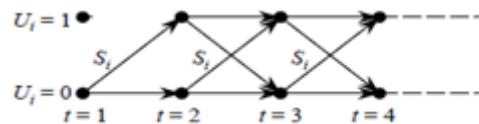
The minimum of the Lagrangian is found by solving for the minimum for each generating unit over all time periods

$$\min q(\lambda) = \sum_{i=1}^N \min \sum_{t=1}^T \{[F_i(P_i^t) + S_{i,t}] U_i^t - \lambda^t P_i^t U_i^t\}$$

----- (10)

Subject to the up-time and down-time cons

$$U_i^t * P_i^{min} \leq P_i^t \leq U_i^t * P_i^{min} \ \forall t = 1......T$$

This is easily solved as a two state dynamic programming of one variable

Minimizing the function with respect to P_i^t

At the $U_i^t = 0$ state, the minimization is trivial and equals zero

At the $U_i^t = 1$ state, the minimization with respect to P_i^t is:

$$\min[F_i(P_i) - \lambda^t P_i^t]$$

$$\frac{d}{dP_i^t}[F_i(P_i) + \lambda^t P_i^t] = \frac{d}{dP_i^t}[F_i(P_i^t) - \lambda^t] = 0$$

$$= \frac{d}{dP_i^t}[F_i(P_i^t)] = \lambda^t$$

There are three cases to be considered for P_i^{opt} and the limits

if $P_i^{opt} \leq P_i^{min}$ then $\min[F_i(P_i) - \lambda^t P_i^t] = F_i(P_i^{min}) - \lambda^t P_i^{min}]$

if $P_i^{min} \leq P_i^{opt} \leq P_i^{max}$ then $\min[F_i(P_i) - \lambda^t P_i^t] = F_i(P_i^{opt}) - \lambda^t P_i^{opt}]$

if $P_i^{max} \leq P_i^{opt}$ then $\min[F_i(P_i) - \lambda^t P_i^t] = F_i(P_i^{max}) - \lambda^t P_i^{max}]$

4. PSO

PSO is inspired by particles moving around in the search space. The individuals in a PSO thus have their own positions and velocities. These individuals are denoted as particles. Traditionally, PSO has no crossover between individuals and has no mutation, and particles are never substituted by other individuals during the run. Instead, the PSO refines its search by attracting the particles to positions with good solutions. Each particle remembers its own best position found so far in the exploration. This position is called the personal best and is denoted by P_{bi}^t. Additionally among these P_{bi}^t there is only one particle that has the best fitness, called the global best, which is denoted by P_{gi}^t. The velocity and position update equations of PSO are given by

$$v_i^t = wv_i^{t-1} + c1\,r1\,(p_{best\,i}^{t-1} - x_i^{t-1}) + c2\,r2\,(p_{gbest\,i}^{t-1} - x_i^{t-1})$$ ----- (11)

Where $x_i^t = x_i^{t-1} + v_i^t$ where   i $=1.........N_D$ (Number of dimension variables)

Where N_D = The dimension of the optimization problem (number of decision variables)
W = the inertia weight
C 1, C 2: The acceleration coefficients
N D: The dimension of the optimization problem
r 1, r 2: Two separately generated uniformly distributed random numbers between 0 and 1
x: The position of the particle
v_i^t: The velocity of the ith dimension

PSO has the following key features compared with the conventional optimization algorithms.

• It only requires a fitness function to measure the "quality" of a solution instead of complex mathematical operations like gradient, Hessian, or matrix inversion. This reduces the computational complexity and relieves some of the restrictions that are usually imposed on the objective function like differentiability, continuity, or convexity.

• It is less sensitive to a good initial solution since it is a population – based method.

• It can be easily incorporated with other optimization tools to form hybrid ones.

• It has the ability to escape local minima since it follows probabilistic transition rules.

More interesting PSO advantages can be emphasized when compared to other members of evolutionary algorithms like the following.

• It can be easily programmed and modified with basic mathematical and logic operations.
• It is inexpensive in terms of computation time and memory.
• It requires less parameter tuning.

Implementation:
The following steps are used by the PSO technique to solve the unit commitment problem

1. Initialize a population of particles p_i and other variables. Each particle is usually generated randomly with in allowable range. $p_{imin} \geq p_i \geq p_{imax}$ Where p_i represented i^{th} unit in the power system.

2. Initialize the parameters such as the size of population, initial and final inertia weight, random velocity of particle, acceleration constant, the max generation, Lagrange's multiplier (λi), etc.

$$OC_T = \sum_{t=1}^{T} \sum_{i=1}^{N} PC_{i,t} \, U_{i,t} + SC_{i,t} \, (1 - U_{i,t-1}) \, U_{i,t} \quad \text{----- (12)}$$

Where $PC_{i,t}$ is represented as $PCi,t = ai + bi*pi + ci*pi^2$, with equality constraint is $\sum_{i=1}^{N} P_{i,t} U_{i,t} = P_D$ where P_i is the ith generation and P_D is the load demand.

3. Compare each individual's fitness value with its *Pbest*. The best fitness value among P*best* is denoted as g*best*.

4. Modify the individual's velocity *vi* of each individual *pi* as

$$v_i^t = v_i^{t-1} + c1 \, rand() \, (p_{best,i} - p_i^t) + c2 \, rand() \, (p_{g \, best} - p_i^t) \quad \text{----- (13)}$$

5. Modify the individual's position *pi* as
$$p_i^t = p_i^{t-1} + p_i^t$$

6. 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*.

7. Modify the λ and α for each equality and Inequality constraint

For Inequality Constraint
α=max (inequality constraint,-λ (iter-1)/ (2*r))
λ (iter)=λ(iter-1) +(2*r*α)

For equality Constraint
λ (iter)=λ (iter-1)+(2*r*((equality constraint))

8. Minimise the fitness function using PSO method for the number of units running at that time.

9. If the number of iteration reaches the maximum then go to step 11. Otherwise go to step 3.

10. The individual that generates the latest is the optimal generation power of each unit with the minimum total generation cost.

5. Flow Chart
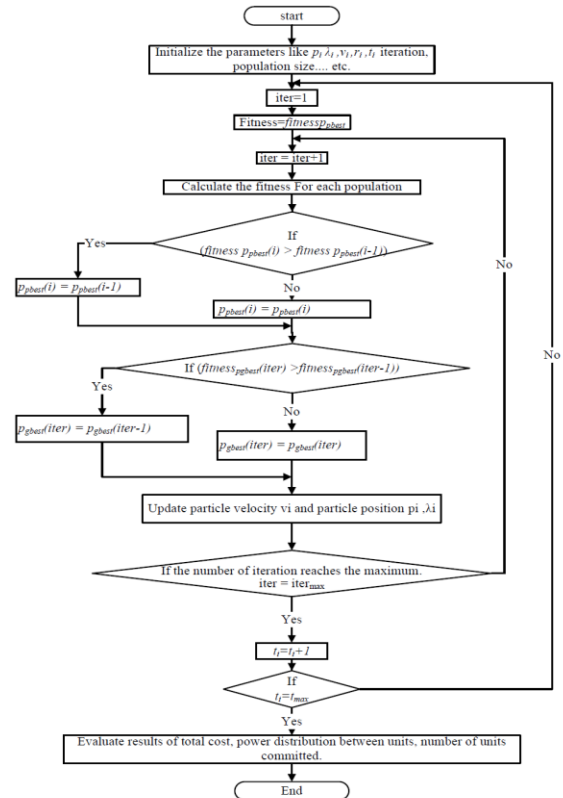
The above flow chart can be explained as follows
Step1: initialize all the parameters like power, iterations, number of particles, velocity of each particle, lemda etc.
step2: calculate the fitness value for each particle according to equation (12)
step3: find the best particle and represent it as p best
step4: find the global best of all particles
step5: update the velocity of each particle from the equation (13)

step6: evaluate the total cost of all the power generation limits until the number of iterations completed.'

6. Results

Units	Max (MW)	Min (MW)	No-Load Cost (R/h)	Full load Ave.Cost (R/mWh)	Minimum Up time (h)	Minimum Down Time (h)	Fuel cost component		
							Ai (R/h)	bi (R/M Wh)	ci (R/MW² h)
1	600	150	213.00	9.79	4	2	561	7.92	0.001562
2	400	100	585.62	9.48	5	3	310	7.85	0.00194
3	200	50	684.74	11.188	5	1	93.6	9.564	0.005784

Unit	Initial condition	Start up cost hot	Start up cost cold	Cold start Time(h)
1	-5	150	350	4
2	8	170	400	5
3	8	500	1100	5

Hour	1	2	3	4	5	6	7	8
Load	1200	1150	1100	1050	1000	950	900	850
Hour	9	10	11	12	13	14	15	
Load	800	750	700	650	600	550	500	

PSO Results

S.No	Load	Unit combination selected	Distribution of load among the units			Total Operating cost× 10⁴ (R)
1	1200	1 1 1	603.9896	399.5993	198.1366	13704.6339
2	1150	1 1 1	601.5616	400.5913	150.6513	25008.6212
3	1100	1 1 1	591.0499	398.3093	110.6391	35763.5278
4	1050	1 1 1	589.3339	393.5762	67.5547	45997.1254
5	1000	1 1 0	598.918	400.9325	0	55637.0474
6	950	1 1 0	549.9872	400.0272	0	64786.9488
7	900	1 1 0	505.8089	394.8238	0	73458.9761
8	850	1 1 0	456.5077	391.9949	0	81659.2328
9	800	1 1 0	416.9848	383.22	0	89395.5607
10	750	1 1 0	408.8343	340.5459	0	96670.1498
11	700	1 1 0	373.684	325.8019	0	103487.3111
12	650	1 1 0	350.6772	299.3466	0	109851.2888
13	600	1 0 0	600.0123	0	0	115726.6111
14	550	1 0 0	550.0049	0	0	121116.111
15	500	1 0 0	500.0048	0	0	126027.6111
		Total Operating Cost				126027.6111

7. Conclusion

It is recognized that the optimal unit commitment of thermal systems results in a great saving for electric utilities. Unit Commitment is the problem of determining the schedule of generating units subject to device and operating constraints. The formulation of unit commitment has been discussed and the solution is obtained by classical dynamic programming method. An algorithm based on Particle Swarm Optimization technique, which is a population based global search and optimization technique, has been developed to solve the unit commitment problem. The effectiveness of these algorithms has been tested on system comprising three units and verified for the total operating cost. It is found that the result obtained from the unit commitment using particle swarm optimization is minimum.

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