Particle swarm optimization technique to solve unit commitment problem

P.V. Rama Krishna¹, G. Poornachandra Rao², Sukhdeo Sao³
Department of Electrical and Electronics Engineering, Gitam University, Hyderabad, India¹
Department of Electrical and Electronics Engineering, VBIT, Hyderabad, India²
Department of Electrical and Electronics Engineering, BIET, Hyderabad, India³

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

Particle swarm optimization, unit commitment problem, cost minimization, dynamic programming and regulated environment.

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

\[ N = \text{number of generators,} \]
\[ PC_i,t = a_i + b_i * p_i + c_i * p_i^2, \text{Where } a_i,b_i,c_i \text{ are cost coefficients} \]
\[ U_{i,t} = \text{the status of } i^{th} \text{ unit at time } t \]
\[ SC_{i,t} = \text{the start up cost of unit } i \text{ at time } t \]

(\( SC_{i,t} \)) 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
\[ F_{sc_c}(t) = (1 - e^{-\frac{t}{\alpha}})F + C_f \quad \text{------- (1)} \]

Where
\( F = \) the fuel cost, \( F_{sc_c}(t) = \) 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
\( \alpha = \) 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:
\[ F_{sb_b}(t) = F_o * t + C_f \quad \text{------- (2)} \]

\( F_{sb_b}(t) = \) 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

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

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

Loading constraint:
\[ P_{\text{load}}^t - \sum_{i=1}^{N} P_{i,t} U_{i,t} = 0 \quad \forall t = 1, \ldots, T \quad \text{------- (4)} \]
Unit limits:

\[ U_i^t \cdot P_i^{min} \leq P_i^t \leq U_i^t \cdot P_i^{min} \quad \forall \ i = 1 \ldots N \text{ and } t = 1 \ldots T \]

Unit minimum up and down time constraints:

\[
\begin{align*}
(u_i(t) - u_i((t-1)) (T_{on,i-1} - \text{MUT})) & \leq 0 \\
(u_i(t) - u_i((t-1)) (T_{off,i-1} - \text{MDT})) & \geq 0
\end{align*}
\]

Where \( \text{MUT} = \text{Minimum up time} \)
\( \text{MDT} = \text{Minimum down time} \)
\( T_{on} = \text{generator on time} \)
\( T_{off} = \text{generator off time} \)

Unit ramp rate limits

\[
\begin{align*}
\max & (P_i^{min} \cdot (P_i^{t-1} - DR_i)) \leq P_i^t \\
\min & (P_i^{max} \cdot (P_i^{t-1} + UR_i)) \geq P_i^t
\end{align*}
\]

Where \( DR = \text{ramp down limit} \)
\( UR = \text{ramp up limit} \)

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

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

Where \( F(P_i^t, U_i^t) \) 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 \( \lambda^t \) which moves \( q(\lambda) \) towards a larger value

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

Minimizing \( L \)

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

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

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

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

The minimum of the Lagrangian is found by solving for the minimum for each generating unit over all time periods

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

Subject to the up-time and down-time constraints

\[
U_i^t \cdot P_i^{min} \leq P_i^t \leq U_i^t \cdot P_i^{min} \quad \forall \ t = 1 \ldots T
\]

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 $P_{gb}^t$. The velocity and position update equations of PSO are given by

$$v_i^t = w v_i^{t-1} + c1 r1 (P_{best_i}^{t-1} - x_i^{t-1}) + c2 r2 (P_{gbest}^{t-1} - x_i^{t-1}) \tag{11}$$

Where $x_i^t = x_i^{t-1} + v_i^t$ where $i = 1 \ldots N_D$

(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 $i^{th}$ 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 andrelieves 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. $p_{i_{\text{min}}} \geq p_i \geq p_{i_{\text{max}}}$, 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 ($\lambda_i$), etc.

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

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

3. Compare each individual’s fitness value with its $P_{\text{best}}$. The best fitness value among $P_{\text{best}}$ is denoted as $g_{\text{best}}$.

4. Modify the individual’s velocity $v_i$ of each individual $p_i$ as

$$v_i^t = v_i^{t-1} + c_1 \text{rand()} (p_{\text{best},t} - p_i^t) + c_2 \text{rand()} (p_{g_{\text{best}},t} - p_i^t) \quad \text{(13)}$$

5. Modify the individual’s position $p_i$ as

$$p_i^t = p_i^{t-1} + p_i^t$$

6. If the evaluation value of each individual is better than the previous $P_{\text{best}}$, the current value is set to be $P_{\text{best}}$. If the best $P_{\text{best}}$ is better than $P_{g\text{best}}$ the value is set to be $P_{g\text{best}}$.

7. Modify the $\lambda$ and $a$ for each equality and Inequality constraint

For Inequality Constraint

$\alpha = \max (\text{inequality constraint}, -\lambda \text{ (iter)-1}) / (2*r)$

$\lambda \text{ (iter)} = \lambda \text{ (iter)-1} + (2*r*\alpha)$

For equality Constraint

$\lambda \text{ (iter)} = \lambda \text{ (iter)-1} + (2*r*((\text{equality constraint}))$

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

<table>
<thead>
<tr>
<th>Units</th>
<th>Max (MW)</th>
<th>Min (MW)</th>
<th>No-Load Cost (R/Wh)</th>
<th>Full Load Ave. Cost (R/kW h)</th>
<th>Minimum Up time (h)</th>
<th>Minimum Down Time (h)</th>
<th>Fuel cost component</th>
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<tbody>
<tr>
<td>1</td>
<td>600</td>
<td>150</td>
<td>213.00</td>
<td>9.79</td>
<td>4</td>
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<td>561.78</td>
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<tr>
<td>2</td>
<td>400</td>
<td>100</td>
<td>585.62</td>
<td>9.48</td>
<td>5</td>
<td>3</td>
<td>110.85</td>
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<tr>
<td>3</td>
<td>200</td>
<td>50</td>
<td>684.74</td>
<td>11.188</td>
<td>5</td>
<td>1</td>
<td>93.6</td>
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</table>

PSO Results

<table>
<thead>
<tr>
<th>S.No</th>
<th>Load</th>
<th>Unit combination selected</th>
<th>Distribution of load among the units</th>
<th>Total Operating cost (000)</th>
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</thead>
<tbody>
<tr>
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<td>1200</td>
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<td>693.986 399.593 138.136</td>
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</table>

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.

References


P. V. Rama Krishna obtained B.E from Osmania University, Hyderabad. M.Tech from IIT Roorkee. He has total 10 years of teaching and industrial experience. Presently he is working as assistant professor in Gitam University. His areas of interest are Power Systems operation and control, application of artificial intelligence techniques to power systems, deregulation etc. He is life member of Indian Society for Technical Education (ISTE). He has published three papers In International Journals and various conferences to his credit.

G. Poornachandra Rao obtained B.Tech from Sreenivasa Institute of Technology & Management Studies, Chittoor. M.Tech from Sreenidhi Institute of Science & Technology, Hyderabad. He worked as Assistant Professor in Bharat Institute of Engineering & technology from 2008 to 2010. Presently he is working as assistant professor in Vignana Bharathi Institute of Technology. His areas of interest are Distribution Systems, Power Systems, and Distribution Automation. He is life member of Indian Society for Technical Education (ISTE), The Institution of Electronics and Telecommunication Engineers (IETE). He has published one paper in International Journal of Engineering Research and Development.