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Unit Commitment by improved pre-prepared power demand table and Muller method

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ABSTRACT

This paper proposes a new methodology for solving Unit Commitment (UC) problem. In the proposed approach, Improved Pre-prepared Power Demand (IPPD) table solves the UC problem and then the Muller method solves the Economic Dispatch (ED) sub-problem. The proposed method has been tested on 3–, 10–, 38– and 40–100 units. Comparison of the simulation results of the proposed method with the results of previous published methods shows that the proposed method provides better solution with less computational time.

1. Introduction

The process of determining the start up or shut down schedule of generating units is referred as Unit Commitment (UC) [1,2]. The objective of the UC problem is to schedule the generating units to meet the predicted power demands at minimum operating cost. This schedule has to satisfy various constraints such as generator limits, Reserve, minimum up and minimum down time of the units. Mathematically, the UC problem is formulated as a non-linear, large scale, mixed integer combinatorial optimization problem with several constraints.

Earlier, classical methods such as Priority List (PL) [3], Dynamic Programming (DP) [4], Branch-Bound [5], Mixed Integer Programming (MIP) [6,7] and Lagrangian Relaxation (LR) [8] were used to solve the UC problem. Among these methods, the Priority List method is a simple method but the quality of solution is rough. The DP is a flexible method to solve the UC problem but more computational time is required in finding the optimal solution due to the curse of dimensionality. The LR method provides a fast solution but it suffers from problem of numerical convergence. In order to get better solution, Artificial Neural Networks (ANN) techniques such as Hopfield Neural Network (HNN) [9,10], Heuristics methods such as Genetic Algorithm (GA) [11,12] and Simulated Annealing [13,14], Meta-Heuristic methods like Evolutionary Programming (EP) [15], Particle Swarm Optimization (PSO) [16,17], Ant Colony Search Algorithm (ACSA) [18] and Tabu Search Algorithm (TSA) [19] have been effectively used for solving the UC problem. Hybrid methods such as Lagrangian Relaxation and Genetic Algorithm (LRGA) [20], Lagrangian Relaxation and Particle Swarm Optimization (LRPSO) [21], Evolutionary Programming with Tabu Search Algorithm (EP–TSA) [22] and LR–EP [23] have been used for solving the UC problem. These algorithms proved to be more effective than the single algorithms with reduced computational time.

It is observed from the literature survey that most of the existing algorithms have limitations to provide optimal solution within considerable computational time. Therefore, it is necessary to find a simple and efficient method for solving the UC problem independent of dimensionality and selection of solution specific parameters. In this context, a table called improved pre-prepared power demand (IPPD) table is prepared using the available information of generator limits and coefficients of fuel cost function(s). The IPPD table is a simple technique to find the commitment of units at specified power demand and then the Muller method, which is a conventional Root finding technique available in numerical methods [24] is used to solve the Economic Dispatch sub-problem. The proposed algorithm was implemented in MATLAB (Version 7.0). Rest of the paper is organized as follows. Formulation of the UC problem is introduced in Section 2. The description of the IPPD table and the Muller method for solving the UC problem is presented in Section 3. The simulation results of case studies are presented in Section 4. The conclusion of the work is presented in the last section.

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Nomenclature

a_i, b_i, c_i	coefficients of fuel cost of unit 'i'
CSU_i	cold start up cost of unit 'i'
D_i, E_i	start up cost coefficients of unit 'i'
F	total fuel cost ($)
$F_i(p_{i,t})$	fuel cost ($) of generating unit 'i' at 't' hour
HSU_i	hot start up cost of unit 'i'
i	index of thermal units
$U_{i,t}$	status of units
N	no of units
PD_t	power demand at hour 't'
$p_{i,t}$	output power of generating unit 'i' at hour 't'
$p_{i,min}$	minimum output power limit of generating unit 'i'
$p_{i,max}$	maximum limits of the generating unit 'i'
R_t	maximum Reserve requirement at hour 't'
SU_i	startup cost ($) of the unit 'i'
SO_i	cold startup cost ($) of unit 'i'
$T_{i,on}$	continuous on time duration of generating unit 'i'
$T_{i,up}$	minimum up time of the generating unit 'i'
$T_{i,off}$	continuous off time duration of generating unit 'i'
$T_{i,down}$	minimum down time of unit 'i'
$T_{i,cold}$	cold start hours of unit 'i'
t	time period
T	no of hours
λ_j	ascending order of incremental fuel costs (where $j = 1, 2, \ldots, 2 * N$)
$\lambda_{i,min}$	incremental fuel cost at minimum output power of unit 'i'
$\lambda_{i,max}$	incremental fuel cost at maximum output power of unit 'i'
x_{k-2}, x_{k-1} and x_k	three distinct approximations to a root of $f(x) = 0$
y_{i-2}, y_{i-1} and y_i	the corresponding values of $y = f(x)$ at x_{k-2}, x_{k-1} and x_k
A, B	co-efficients of second order polynomial used in Muller method
k	index of root

2. Unit Commitment problem

The UC schedule should be able to minimize the total operational cost to meet the predicted power demand and satisfy all constraints. Objective function and various constraints of the UC problem are explained in the following sections.

2.1. Objective function

The objective function of the UC problem is expressed as the sum of fuel cost, the start up and shut down cost of individual units for the given period subjected to various constraints.

$$Min\ F = \sum_{i=1}^{N}\sum_{t=1}^{T}[F_i(p_{i,t})U_{i,t} + SU_i\{U_{i,t}(1-U_{i,t-1})\} + SD_i\{U_{i,t}(1 - U_{i,t+1})\}] \tag{1}$$

The start up cost is considered as an exponential function of off time of a generating unit

$$SU_i = SO_i \cdot [1 - e^{(-T_{i,off}/D_i)}] + E_i \tag{2}$$

A simplified time dependant startup is as follows:

$$SU_i = \begin{cases} HSU_i; & T^t_{i,off} \leqslant T_{i,down} + T_{i,cold} \\ CSU_i; & T^t_{i,off} > T_{i,down} + T_{i,cold} \end{cases} \tag{3}$$

Fuel cost function of each unit is taken as a quadratic function.

$$F_i(p_{i,t}) = a_i + b_i p_{i,t} + c_i p_{i,t}^2 \tag{4}$$

2.2. Constraints

2.2.1. Power balance equation

The sum of the output powers of on line generators is equal to the forecasted power demand

$$\sum_{i=1}^{N} p_{i,t}U_{i,t} = PD_t \tag{5}$$

2.2.2. Limits of generating units

$$U_{i,t}p_{i,min} \leqslant p_{i\cdot t} \leqslant U_{i,t}p_{i,max} \tag{6}$$

2.2.3. Reserve constraints

$$\sum_{i=1}^{N} p_{i,max}U_{i,t} \geqslant PD_t + R_t \tag{7}$$

2.2.4. Minimum up time

$$T_{i,on} \geqslant T_{i,up} \tag{8}$$

2.2.5. Minimum down time

$$T_{i,off} \geqslant T_{i,down} \tag{9}$$

Minimum up and minimum down time constraints are incorporated in the Unit Commitment problem as follows:

$$U_{i,t} = \begin{cases} 1 & \text{if } T_{i,on} < T_{i,up} \\ 0 & \text{if } T_{i,off} < T_{i,down} \\ 0 & \text{or 1 otherwise} \end{cases} \tag{10}$$

2.2.6. Must run units

These units are included in the Unit Commitment due to Economic and System Reliability considerations.

3. Proposed methodology

To simplify the Unit Commitment problem, the problem has been analyzed thoroughly and arrived at an Improved Pre-prepared Power Demand table method with the following steps:

Step 1. At this step, generate improved pre-prepared power demand (IPPD) table that obtains the status of committed units for all power demands without imposing minimum up time and minimum down time constraints. The details of IPPD table are reported in Section 3.1.2. This table plays a key role in making the proposed method to be very effective for the solution of the Unit Commitment problem.
Step 2. Use a simple procedure to incorporate the no-load cost of the units and use a simple de-commitment procedure to de-commit the units, if over- reserve is observed.
Step 3. Now apply a simple technique to satisfy the minimum up time and minimum downtime and then decide the schedule of final commitment of units.