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Implementation of Fast technique for Unit Commitment Based on Unit Clustering

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Abstract

A new approach to the problem of large scale unit commitment is presented in this paper. The units are classified into various clusters based on their similar characteristics in order to reduce the computational time and also to satisfy the minimum up/down constraints easily. Unit commitment problem is an important optimizing task in daily operational planning of power systems which can be mathematically formulated as a large scale nonlinear mixed-integer minimization problem. A new methodology employing the concept of cluster algorithm called as additive and divisive hierarchical clustering has been employed along with particle swarm optimization in order to carry out the technique of unit commitment. Proposed methodology involves two individual algorithms. While the load is increasing, additive cluster algorithm has been employed while divisive cluster algorithm is used when the load is decreasing. The proposed technique is tested on a 10 unit system and the simulation results show the performance of the proposed technique.

Keywords: Unit commitment, additive clustering, divisive clustering**,** Lambda iteration method.

1. Introduction

Most economical operation has been required to enable the maximum profit to be generated in the electric industry. An optimal unit commitment is therefore an essential factor in planning and operation of power systems. The unit commitment (UC)problem is to schedule correctly the on/off status of all the units in the system. UC is defined mathematically as a nonlinear, mixed integer complex combinational optimization problem. The objective of UC solution is to minimize total production costs while observing large number of operating constraints. The exact solution of UC can be obtained by complete enumeration, which cannot be applied at real time environment due to excessive computational effort that shall lead to high computational time [1].

The most talked deterministic mathematical programming methods include: Priority List, Dynamic Programming, Lagrange Relaxation, Branch-and-Bound , Integer and Mixed- Integer methods and annealing method[2-9]. Mathematical methods are impractical in terms of computational effort, time and memory requirements when considering many units or a longer study period. It may be observed these methods have following general *limitations*: i) They are not guaranteed to converge to global optimum of the general non convex problems like UC. ii) Inconsistency in the results due to approximations made while Linearizing some of the nonlinear objective functions and constraints. iii) Consideration of certain constraints makes difficulty in obtaining the solution. iv) The process may converge slowly due to the requirement for the satisfaction of large number of constraints.

In order to overcome the general difficulties in various approaches, a novel method with the application of cluster algorithms has been proposed in this paper. The method uses Additive and Divisive Cluster Algorithms. The proposed methodology can be unfolded in to three stages. In the first stage, four clusters are formed namely base load, intermittent load, semi-peak load and peak load clusters. All the generating units of the plant are segregated into corresponding clusters based on operating costs. In the second stage, UC solution is obtained by developing Additive Cluster (AC) algorithm for increasing load pattern. Finally in the third stage a Divisive Cluster (DC) algorithm is developed for decreasing load pattern.

The remaining paper is organized as follows: Section 2 deals with problem formulation; General purpose additive cluster and divisive cluster algorithms are discussed in the Section 3. Simulation results and discussions are carried out in Section 4 and finally conclusions are drawn in the Section 5.

2. Formulation of Unit Commitment

Subject to the minimization of the cost-objective function in the unit commitment problem, certain units are stated to be as 'ON' and remaining as 'OFF'. The following are the various notations considered during the implementation of the problem

N :Number of generating units in the plant; T :Scheduling period in hours (h); i :Index of Unit (i = 1,2,….., N); t :Index of time (t = 1,2,….., T); $I_i(t)$:ith unit status at t^{th} hour (= 1, if the Unit is ON; =0, if the unit is OFF) ; $P_i(t)$: Generation of ith unit at tth hour; P_i^{max}, P_i^{min} : Maximum / Minimum output power (MW) of ith unit; $D(t)$:Demanded power at tth hour; $R(t)$:System reserve at t^{th} hour; T_i^{on} :Minimum up time of ith unit; T_i^{off} : Minimum down time of ith unit; $X_i^{on}(t)$:Duration during which ith unit is continuously ON; X_i^{off} :Duration during which ith unit is continuously OFF; $SC_i(t)$: Start-Up cost of ith unit; $FC_i(t)$:Fuel cost of ith unit; TC:Total Cost of generation; HC(i): Hot start cost of ith unit; CC(i): Cold start cost of ith unit; CS(i): Cold start hour of ith unit; ai , bi, ci : Fuel cost coefficients

Objective Functions

The objective function of UC problem is the minimization of the TC which has the components of FC and SC and is given by:

$$\text{Min } (TC) = \sum_{t=1}^{T}\sum_{i=1}^{N}(FC_i(t) + SC_i(t)) \tag{1}$$

Where Fuel cost of i^{th} unit:

$$FC_i(t) = a_i + b_i P_i(t) + c_i P_i(t)^2 \tag{2}$$

and Start-up cost

$$SC_i(t) = HC(i) : if\ T_i^{off} \le X_i^{off}(t) \le H_i^{off}(t) \quad \text{or}$$

$$= CC(i) : if\ X_i^{off}(t) \ge H_i^{off}(t) \tag{3}$$

$$\text{where } H_i^{off}(t) = T_i^{off} + CS(i) \tag{4}$$

System Constraints

The constraints, which must be considered during the optimization process of UC problem (1), are given below.

Load Demand

All the committed units must generate total power equal to load demand as:

$$D(t) = \sum_{i=1}^{N} P_i(t) \qquad (5)$$

Spinning Reserve

To maintain system reliability for sudden variation of loads, system should have adequate amount of spinning reserve capacity. In this paper 10% of the load demand is taken and which satisfies:

$$\sum_{i=1}^{N} I_i(t) \cdot P_i^{\max} \geq D(t) + R(t) \qquad (6)$$

Generated Power Limits

The power output of each unit should satisfy:

$$P_i^{\min} \leq P_i(t) \leq P_i^{\max} \qquad (7)$$

Minimum Up/Down Time

Once the unit is committed there is a minimum time before it is de-committed and viz.

$$T_i^{on} \leq X_i^{on}(t) \; or \; T_i^{off} \leq X_i^{off}(t) \qquad (8)$$

3. Proposed Methodology

The purpose of Cluster Algorithms (CA) can be stated as, to divide a given group of objects into a number of groups or clusters in order that the objects in a particular cluster would be similar among the objects of the other ones. In the first stage of CA, an attempt is made to place an N object in M clusters according to some criterion additive to clusters. Once the criterion is selected, CA searches the space of all classifications and finds the one that satisfies the optimization function.

The proposed methodology for UC problem considers two clustering techniques: Additive Clustering Technique and Divisive Clustering Technique. In the first type of cluster technique, initially individual data points are treated as clusters. Based on some criteria (nearest operating costs of units) successively two closest clusters are merged until there is only one cluster remains.

Basic Additive Clustering Algorithm

Step-1: Compute operating cost (proximity) matrix;

Step-2: *Repeat;*

Step-3: Merge two closest clusters based on least distance value;

Step-4: Update the proximity Matrix to reflect the proximity between the new cluster and the original clusters;

Step-5: *Until* Only one cluster remains.

In the Divisive type clustering technique, successively each cluster is separated from the others until a singleton cluster of individual point(s) remain. A suitable methodology is required to take the decision on which cluster must be removed from the others. The basic algorithm is given below.

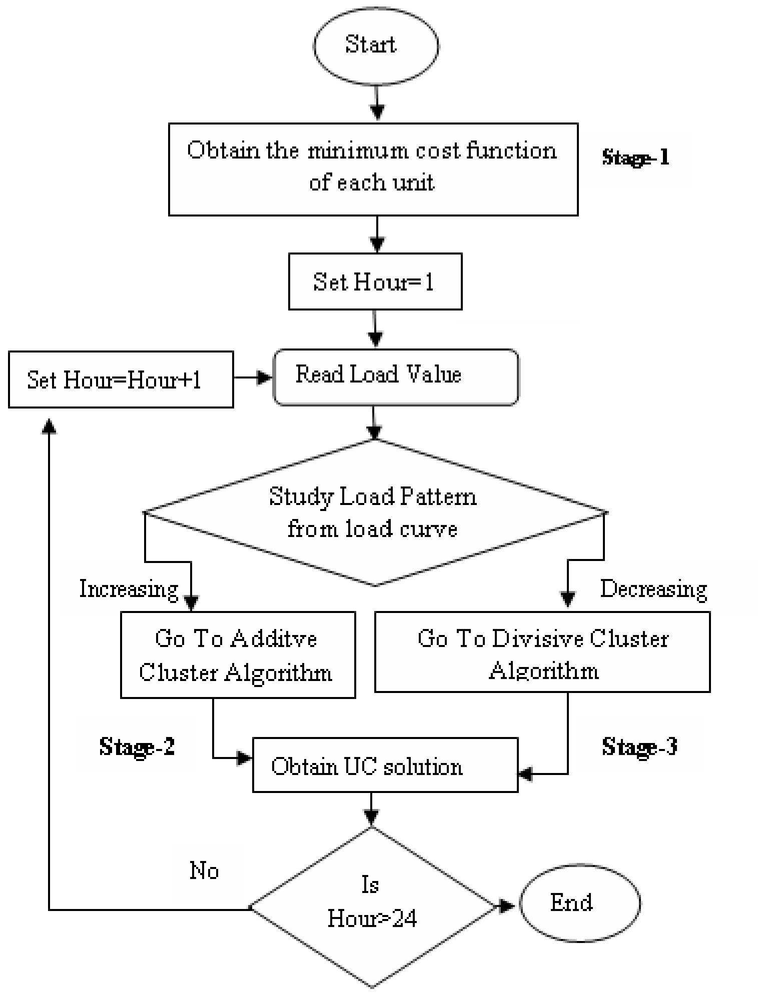

Figure 1. Methodology of additive and divisive cluster algorithm.

Basic Divisive Clustering Algorithm

Step-1: Compute operating cost (Proximity) Matrix;

Step-2: *Repeat;*

Step-3: Separate a cluster from other clusters based on maximum distance value;

Step-4: Update the proximity Matrix to reflect the proximity between the clusters those remaining;

Step-5: *Until* all the clusters are removed.

The flowchart for the above methodology can be observed from Figure 1.

The proposed methodology can be unfolded in to three stages.

- In this stage objective cost function of each unit is obtained by using genetic algorithm. Priority list of units is prepared based on the minimum objective cost functions and clusters are formed.
- The pattern of load variation on the plant is a cycle of increasing and then decreasing takes place. Two separate algorithms are designed for load increasing pattern and for decreasing pattern. In this stage, an algorithm based on agglomerative clustering technique is developed for increasing load pattern.

- This stage presents an algorithm for UC solution for the decreasing load condition. The algorithm is designed based on divisive clustering technique.

The operating cost of each plant is calculated and the plants are clustered based on their objective function values. In this way best clusters are brought out so that they can be employed to take up the load.

Characterization of the Units

Base load (BL) and Intermittent load (IL) units operate for long period in the day and they generate more number of units (MWH). Therefore, ideally speaking they should have minimum fuel cost, maximum generating capabilities but, can have high start-up costs and start-up times for the reason they are switched 'on' for the most of time. In addition, System reliability aspect is decided by the performance of these units. Semi-Peak Load (SPL) and Peak load (PL) units in contrast should have low start-up costs and start-up times as these units are rapidly switched 'on' and 'off' frequently. These units can have less generating capabilities and can have relatively high costs as they take up small loads above high base load and intermittent loads. Based on the generation cost functions, the closet cost function units are segregated into clusters as BL, IL, SPL and PL as given in table 5.

BL: Load upto 1000MW duration: 0-24 hours

IL: Load between 1000MW to 1200 MW, duration 0-18 hours

SPL : Load 1200MW to 1400 MW, duration 0-6 hours

PL : Load 1400MW to 1500MW, duration 0-3 hours

The maximum limits for the four loads as:

BL-Max: 1000 MW; IL-Max: 1200 MW; SPL-Max: 1400 Mw and PL-Max: 1500 MW.

For carrying out the additive cluster algorithm, objective function values are stored in ascending order and for divisive cluster algorithm the objective function values are stored in the descending order as given in table 4. The closest values are divided into four clusters as BL, PL, Semi PL and IL.

Design of Additive Clustering(AC) Algorithm for UC Problem

AC Algorithm:

Step-1: Read the load value *D(t)* . Spinning Reserve requirement *R(t).* Threshold values of four clusters. **Step-2:** From the load duration curve, identify the load as any: BL, IL, SPL or PL. **Step-3:** Commit the units in corresponding cluster by executing subroutine for Economic Dispatch (ED).

Step-4: Check the constraint: D (t) +R (t) < Cluster Threshold value. If condition is satisfied, go to main program. Else, go to next step. **Step-5:** Merge next priority list cluster to previous cluster. **Step-6:** Go to Step-4; **Step-7:** Return

The subroutine for ED is standard Lambda-Iteration Method. The ED has following steps.

ED by Lambda-Iteration Method:

Step-1: Set λ value. **Step-2**: Calculate P_i for i= 1,2 …n. Where n is the number of units in the cluster. P_i is calculated subject to the minimization of objective function (1) under the constraints (5)-(8). **Step-3:** Calculate error € value (difference between demanded load and sum of generations). **Step-4:** Check € with tolerance value. If yes Go to main program to print UC results. Else set new value of λ. Go To Step-2.

Design of Divisive Clustering (DC) Algorithm for UC Problem

This DC algorithm is proposed for UC when the load is decreasing after it stopped from increasing. The DCA starts at the point where some units in various clusters are already under 'on' condition. Now the requirement is to put some units under 'off' condition, so as to meet the present *D(t)*. The priority list is prepared based on the startup time/costs. The strategy is, to put off the unit with maximum generation cost.

DC Algorithm:

Step-1: Read the system load. **Step-2:** De-Commit the next unit with maximum generation cost according to priority list. **Step-3**: Commit the units in corresponding cluster by executing subroutine for Economic Dispatch (ED). **Step-4**: Check the constraint: D(t)+R(t) $\leq$ sum of all generations. If condition is satisfied, go to main program. Else, go to step-2. **Step-5:** Return

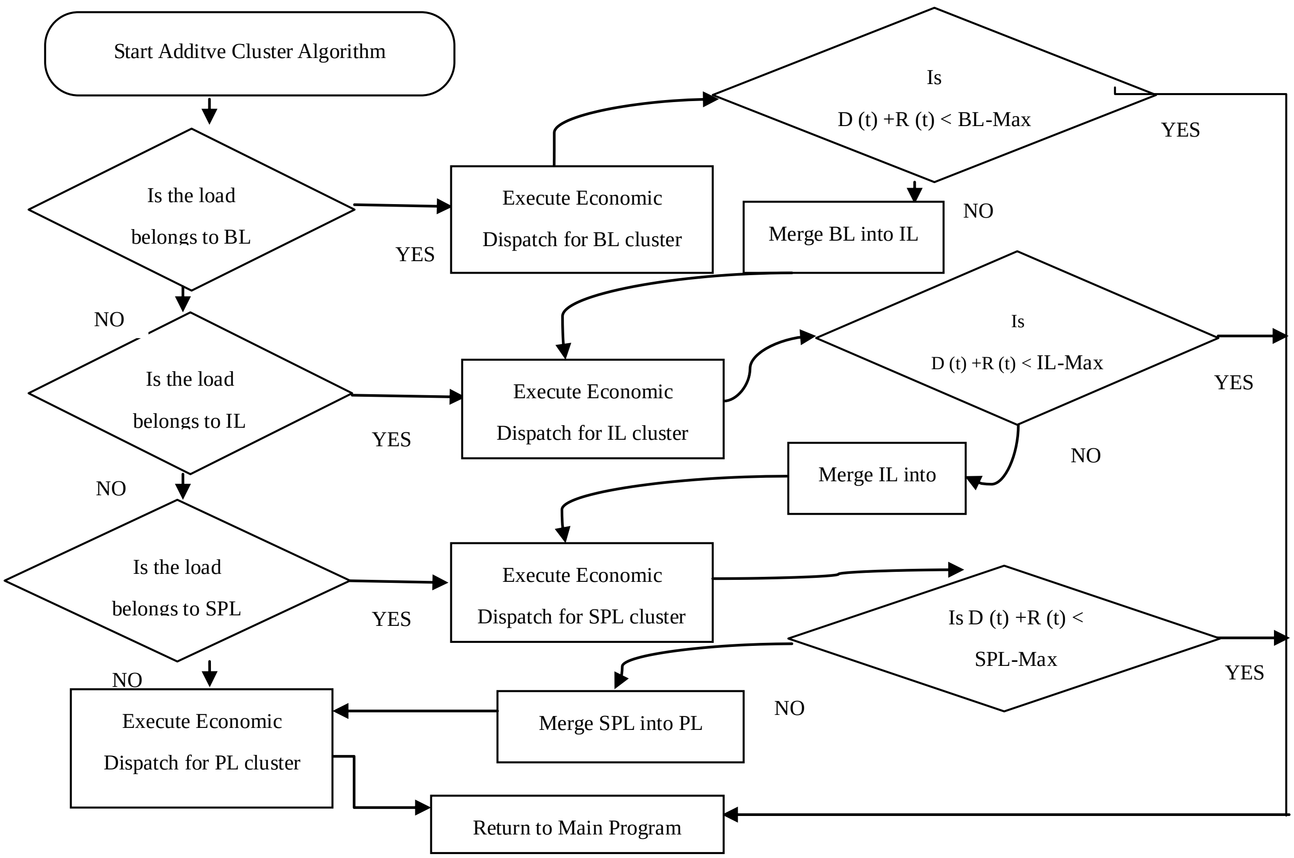

Figure 2. Implementation of cluster algorithm for unit commitment.

4. Results and Discussions

Table 1 shows the daily load pattern on the plant and Table 2 shows the operating characteristics of all the plants

Table-1: Daily Load Pattern on the Plant

Hour	Load (MW)	Hour	Load (MW)	Hour	Load (MW)	Hour	Load (MW)	Hour	Load (MW)	Hour	Load (MW)
1	700	5	1000	9	1300	13	1400	17	1000	21	1300
2	750	6	1100	10	1400	14	1300	18	1100	22	1100
3	850	7	1150	11	1450	15	1200	19	1200	23	900
4	950	8	1200	12	1500	16	1050	20	1400	24	800

The average fuel costs and start up costs for all the units can be calculated as follows:

A=Average fuel cost of system= $\dfrac{a_i + b_i\, p_{\max} + c_i\, p_{\max}^2}{p_{\max}}$

B=Average start up cost= $\dfrac{HC(i)}{p_{i\max}}$

The Euclidian costs of all the units can be calculated as follows:

Euclidian costs of the unit = $\sqrt{(A_i - A_{low})^2 + (B_i - B_{\max})^2}$

The above calculations of all the units have been tabulated in Table 3 and Table 4 respectively.

Table-2: Unit Characteristics and Coefficients

Unit No. (i)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
P_i^{max} (MW)	455	455	162	130	130	80	85	55	55	55
P_i^{min}(MW)	150	150	25	20	20	20	25	10	10	10
a_i	1000	970	450	680	700	370	480	660	665	670
b_i,	16.19	17.26	19.7	16.5	16.6	22.26	27.74	25.92	27.27	27.79
c_i	0.00048	0.00031	0.00398	0.00211	0.002	0.00712	0.00079	0.00413	0.00222	0.00173
T_i^{on}	8	8	6	5	5	3	3	1	1	1
T_i^{off}	8	8	6	5	5	3	3	1	1	1
HC(i) ($)	4500	5000	900	560	550	170	260	30	30	30
CC(i) ($)	9000	10000	1800	1120	1100	340	520	60	60	60
CS(i)	5	5	4	4	4	2	2	0	0	0
Ini.State	8	8	-6	-5	-5	-3	-3	-1	-1	-1

Table 3. Average fuel cost and start up cost of each unit

Unit No	1	2	3	4	5	6	7	8	9	10
A	18.606	19.533	23.123	22.005	22.245	27.455	33.454	38.147	39.483	40.067
B	9.8901	10.989	5.5556	4.3077	4.2308	2.125	3.0588	0.54545	0.54545	9.8901

Table 4. Euclidian cost of all units

Unit No	1	2	3	4	5	6	7	8	9	10
Euclidian cost	1.0989	0.92672	7.0654	7.4962	7.6754	12.525	16.833	22.157	23.343	23.867

Table 5 shows the priority order of various units corresponding to their Euclidian costs with respect to additive clustering and divisive clustering and Table 6 shows the segregation of all the 10 units in order to take up the daily load pattern

Table 4. Priority list is formed with minimum operation cost

Priority Order	1	2	3	4	5	6	7	8	9	10
For ACA	1	2	3	4	5	6	7	8	9	10
For DCA	10	9	8	7	6	5	4	3	2	1

Table 5. Segregation of 10 units into clusters and their priority

Cluster type	Base load	Intermittent load	Semi peak load	Peak load
Priority units in the cluster	1,2	3,4,5	6,7	8,9,10

Table 6 shows the allocation of generation to various units based on the daily load pattern and based on the clusters. It can be observed from the table that the clusters only take up the load allotted to them while the other generators do not take up the load until it falls into the other category. The operating costs of the generators taking the load can be observed from the table. It can be observed that the technique is quite simple and also the convergence time is also very less as compared to other techniques. Table 7 also shows the various comparison with the operating costs of other techniques over the present technique. It can be observed that the operating cost of the system employing clustering technique is quite less as compared to the other techniques.

Table 6. Generation of units in 24 hour schedule

S.No	Load (MW)	Commitment schedule										Operational cost ($)
		1	2	3	4	5	6	7	8	9	10	
1	700	342.4	357.5	0	0	0	0	0	0	0	0	14644.8
2	750	362.0	387.9	0	0	0	0	0	0	0	0	15623.4
3	850	370	159	162	130	29	0	0	0	0	0	18766.9
4	950	455	159	162	130	29	0	0	0	0	0	20479.6
5	1000	334.1	344.8	162	130	29	0	0	0	0	0	21563.4
6	1100	373.40	405.5	162	130	29	0	0	0	0	0	23522
7	1150	393.02	435.9	162	130	29	0	0	0	0	0	24515.4

8	1200	424	455	162	130	29	0	0	0	0	0	25519.3
9	1300	455	455	162	130	29	29	34	0	0	0	28605.8
10	1400	455	455	162	130	29	29	34	0	0	0	28605.8
11	1450	455	455	162	130	130	29	34	19	19	19	34194.6
12	1500	455	455	162	130	130	77	34	19	19	19	35299.3
13	1400	455	455	162	130	29	29	34	0	0	0	28605.8
14	1300	455	455	162	130	29	29	34	0	0	0	28605.8
15	1200	424	455	162	130	29	0	0	0	0	0	25519.3
16	1050	353.78	375.2	162	130	29	0	0	0	0	0	22538
17	1000	334.1	344.8	162	130	29	0	0	0	0	0	21563.4
18	1100	373.40	405.5	162	130	29	0	0	0	0	0	23522
19	1200	424	455	162	130	29	0	0	0	0	0	25519.3
20	1400	455	455	162	130	29	29	34	0	0	0	28605.8
21	1300	455	455	162	130	29	29	34	0	0	0	28605.8
22	1100	373.40	405.5	162	130	29	0	0	0	0	0	23522
23	900	420	159	162	130	29	0	0	0	0	0	19766
24	800	381.6	418.3	0	0	0	0	0	0	0	0	16611.3
Total Operating cost												**584325**

5. Conclusions

A novel method based on clustering technique is proposed to mitigate Unit Commitment problem. The proposed method is more realistic and less heuristic. Following load pattern, two individual algorithms based on Additive and Divisive cluster algorithms are proposed for increasing and decreasing load patterns. The Euclidian cost of generation of units is obtained and based on these costs the units are segregated in to clusters. Two separate priorities lists one for increasing and another for decreasing load conditions are prepared based on generation costs. A 10-thermal unit system is considered for simulation study. The strategy employed proved to be quite effective and satisfactory as evident through simulation results.

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