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Implementation of Additive and Divisive Clustering based Unit Commitment Employing Particle Swarm Optimization

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Abstract

The generating units that are available need to be properly committed in order to obtain good savings on Fuel Cost. The reduction of fuel cost employing a new methodology based on classification of units into different groups based on Particle Swarm Optimization has been proposed in this paper. The problem of Unit Commitment has indeed become a vital task in the day today operation of power systems and can be viewed as a mathematical problem involving large scale non linear mixed integers. A new methodologyengaging the idea of clustering algorithm involving additive and divisive clustering has been utilized built on Particle Swarm Optimization in order to solve the problem of unit commitment. An arrangement with generating units in the range of 10-100 has been employed to test the above technique and the simulation results indeed support the superior performance of the method.

Keywords: Unit Commitment, Particle Swarm Optimization, Divisive Cluster, Additive Cluster

INTRODUCTION

Generally the idea of Unit Commitment (UC) includes evaluating the values of generation of various generating units and their operational levels for a definite amount of time in order to obtain a lower cost of operation. The unit commitment indeed has a very worthyeffect on the economics of power generation. The ideology of UC is a familiar term in the electrical sector and definitely has the ability to save large amount of revenue every annum with respect to fuel costs and other additional expenses. Complex decisions are indeed involved in the implementation of problem of unit commitment which indeed make it difficult to design optimization techniques to solve the problem in real time. Numerous constraints which are multiple in nature need to be reflected while evaluating the exact commitment plan [1].

Generally the most employed mathematical methods which are deterministic in nature include: Mixed- Integer methods[10], Priority List [3,4], Dynamic Programming[5,6], Branch-and-Bound[2] and Lagrange Relaxation [7-9]. All these mathematical methods are simple in nature and have less implementation time but they suffer due to the problem of numerical convergence and possess the following disadvantages [1] : (i) As the problem of Unit Commitment is non convex, they cannot gaurentee the numerical convergence. (ii) The various constraints and objective functions considered for UC are non linear and as a result the solutions offered by these techniques are also in consistent due to the various estimations being thought upon. (iii) Lot of difficulty is also involved in attaining the solution due to the involvement of different constraints.

As a result, most of the research has been concentrated on various methods involving searching for best location, including Artificial Intelligent Techniques. These methods which are designed to be intelligent have indeed gained much prominence in solving numerous optimization issues. Recent studies indicate the contributions of such type of intelligent techniques to solve the problem of UC involving Neural Networks, Fuzzy Logic, and Tabu Search, Basic Genetic Algorithm approach and Extended Priority List (EPL) method based on GA[11-14]. It can be observed that these techniques are encouraging and are still being developed. It has been also observed that though these techniques have given good results in applications, these involve the linguistic explanations in order to generate crisp output in the presence of various constraints which are dependent on time, which turn the methods into complex and confusing in nature. The Particle swarm Optimization (PSO) approach iteratively assesses the topresult each time the locality is restructured. And also the technique has respectableability for suboptimal exploration.

In order to eliminate the difficulties involved in the implementation of GA and based on the advantages posed by PSO, a novel technique along with the implementation of cluster algorithms has been presented in this paper. The technique involving both additive and divisive algorithms has been developed in three stages. The first stage involves formation of 4 clusters namely Base load Cluster, Intermittent Load Cluster, Semi Peak Load Cluster and Peak Load Clusters. The various units of generation pertaining to the plant are divided into various clusters based on their different costs of operation. These operational costs are determined by PSO which are useful in preparing the priority list. The second stage involves employing the additive cluster algorithm for the load pattern which is increasing in nature. The third stage involves the development of divisive cluster algorithm for the load pattern which is decreasing in nature.

This paper is presented as follows: The formulation of the problem is represented in Section 2. The concept of Particle Swarm Optimization based cluster technique is explained in Section 3. The new methodologyemploying clustered based PSO has been explained in Section 4. Section 5 involves the presentation of Simulation results and deliberations and the inferences are represented in Section 6.

FORMULATION OF PROBLEM

Keeping in view the idea of minimization of objective function involving the cost, some of the units are considered to be in 'ON' position while the remaining units are considered to be in 'OFF' position. The following are the various notations which have been considered for the problem implémentation

N :Number of units for generation in the system

T :Duration for running the arrangementin hours (h);

i :Unit Count (i = 1,2,….., N);

t : TimeCount(t = 1,2,….., T);

$I_i(t)$:status of i^{th} unit at t^{th} hour (considered as 1, if Unit is ON; or 0, if the unit is OFF) ;

$P_i(t)$: Generation of Power of i^{th} unit at t^{th} hour;

$P_i^{\max}, P_i^{\min}$: Maximum / Minimum power output (MW) of i^{th} unit;

$D(t)$: Demand of Load at t^{th} hour;

$R(t)$:Reserve capability of the system at t^{th} hour;

T_i^{on} :Minimum up time limit of i^{th} unit;

T_i^{off} : Minimum down time limit of i^{th} unit;

$X_i^{on}(t)$: Duration for which the i^{th} unit is continuously ON;

$X_i^{off}(t)$: Duration for which i^{th} unit is continuously OFF;

$SC_i(t)$: Start-Up cost of i^{th} unit;

$FC_i(t)$:Fuel Cost of i^{th} unit;

RU_i : *Ramp up rate of unit i*

RD_i : *Ramp down rate of unit i*

TC:Total generation cost;

HC(i): Hot start cost of i^{th} unit;

CC(i): Cold start cost of i^{th} unit;

CS(i): Cold start hour of i^{th} unit;

τ:Time Step of Unit Commitment: 60 min

a_i , b_i, c_i : cost coefficients of Fuel

Objective Functions

The majorpurpose of the idea of UC is to reduce the Total cost (TC) which involves thedifferentmodulesof FC and SC represented by:

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

Where cost of Fuel 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

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

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

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

System Constraints

The following are the various constraints, that need to be considered during the implementation of technique of Unit Commitment.

Load Demand

The units that have been included need to produce the total power which should be the similar as that of load demand given by:

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

Spinning Reserve

Sufficient capacity of Spinning Reserve needs to be maintained in order to ensure that the system stays reliable during sudden changes of load.

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

Power Limits of Generators

The output of every generator indeed must compulsorily lie between the maximum and minimum values given by:

$$P_i^{\min} I_i(t) \le P_i(t) \le P_i^{\max} I_i(t) \tag{7}$$

Rampup/down Rates

The generation of powerrelating todifferent units is restricted by the following time dependent operating limits

$$P_i^{\max} I_i(t) = \min\left\{P_i^{\max} I_i(t), P_i I_i(t-1) + \tau \cdot RU_i\right\}$$
$$P_i^{\min} I_i(t) = \max\left\{P_i^{\min} I_i(t), P_i I_i(t-1) - \tau \cdot RD_i\right\} \quad (8)$$

Minimum Up/Down Time

The unit needs to be operated for minimum time period before it is being brought into OFF position which is given by.

$$T_i^{on} \le X_i^{on}(t) \ or \ T_i^{off} \le X_i^{off}(t) \quad (9)$$

PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization is generalized optimization technique dependent on ideas gained from the school of fish or swarm of birds[15]. PSO has indeed been developed based on the social behaviour that has been observed in flock of birds or school of fish. The best solution is obtained in PSO, based on population of particles,each which represent a possible solution for the problem to be optimized. These particles indeed update their position throughout the search space basing upon their velocity until their position does not change over iterations or until the limits of computation are crossed. Every particle also keeps a track of its best position alongwith the global best position attained till thatiteration. This technique can be implemented easily along with faster rate of convergence and also has achieved lot of prominence in the sector of power systems. The cost of operation relating to each unit are obtained employing the idea of PSO. The priority list along with the clusters are created based on these operation costs. The main logic of cluster Algorithms involves segregating a group of similar objects into clusters so that the members of that cluster are identical to each other. As indicated in the first stage of Cluster Algorithms, an attempt is made to place an N object into M cluster employing an optimization technique. Once the optimization technique is finalized, the cluster algorithm searches the space and identifies the one that satisfies the optimization function. Such two clustering techniques which have been employed in this work are Additive Clustering and Divisive Clustering.

Basic Additive Clustering Algorithm

- Calculate the cost of operation (proximity) matrix;
- *Repeat;*
- Combine the two clusters which are closest employing the smallest distance value;
- Renew the proximity Matrix to replicate the closenessamong the fresh cluster and the original clusters;
- *Until* Only one cluster remains.

Basic Divisive Clustering Algorithm

- Calculate the cost of operation (Proximity) Matrix;
- *Repeat;*
- Divide a cluster from other clusters employinglargest distance value;
- Renew the proximity Matrix to replicate the closeness among the clusters that are lasting;
- *Till* entire clusters are eliminated.

PROPOSED METHODOLOGY

The idea that has been proposed can be implemented in 03levels.

Level-1: In this level, the objective functional cost of each unit is determined employing the concept of Particle Swarm Optimization. Based on the value of minimum objective cost function, the priority list is formed and the clusters are determined.

Level-2: Generally the load pattern of a plant will be increasing or decreasing. Seperate algorithms have indeed been designed for each of increasing pattern and decreasing pattern. In this level, algorithm based on additive clustering will be implemented based on load pattern which is increasing.

Level-3: An algorithm for the load which is decreasing in nature called as Divisive clustering algorithm will be developed in this level.

In this methodology Particle Swarm Optimization has been used to form clusters. The operating cost of each unit is evaluated and the units are clustered depending on their fitness values. In this way PSO is employed to form the best clusters in order to take up the load.

Characterization of the Units

It is to be observed that generally Base load (BL) and Intermittent load (IL) units are the ones which are operated for long hours in the day and more number of units (MWH) are also generated from these units only.

Therefore, it is important to indeed ensure that these units have less fuel cost and maximum capabilities of generation but, at the same time can result in huge start-up costs and start-up times due to the fact that they are being kept in 'On' state for large intervals of time. Additionally the reliability of the system also need to be considered which depends on the performance of these units. On the other hand, Semi-Peak Load (SPL) and Peak load (PL) units need to have less costs during start-up and start-up times due to the fact that they are switched 'on' and 'off' frequently. These units can possess fewer capabilities of generation and also can have relatively high costs as they take up small loads which are above base load and intermittent loads. Figure 1 shows the flowchart of PSO employed for this purpose. Depending on the values of generation cost functions, the various units are divided into various clusters as BL, IL, SPL and PL as represented in table 5.

Base Load: Load upto 1000MW time interval: 0-24 hours

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

SPL : Load between 1200MW to 1400 MW, time interval 0-6 hours

PL : Load between 1400MW to 1500MW, time interval 0-3 hours

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The following are the maximum limits for the four loads:

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

In order to implement the additive cluster algorithm, the various objective function values of various units are listed in ascending order whereas they are listed in descending order for Divisive cluster algorithm as represented in table 4.

Preparation of priority list using PSO

In this juncture the subsequent steps are executed for making the priority list.

Step-1: The algorithm initiates with the formulation of load patterns, unit characteristics along with the assumption of initial population of particles, where each particle corresponds to generation of a specific generator (P_g). The pattern of load and the characteristics of various units are presented in table 1 & table 2.

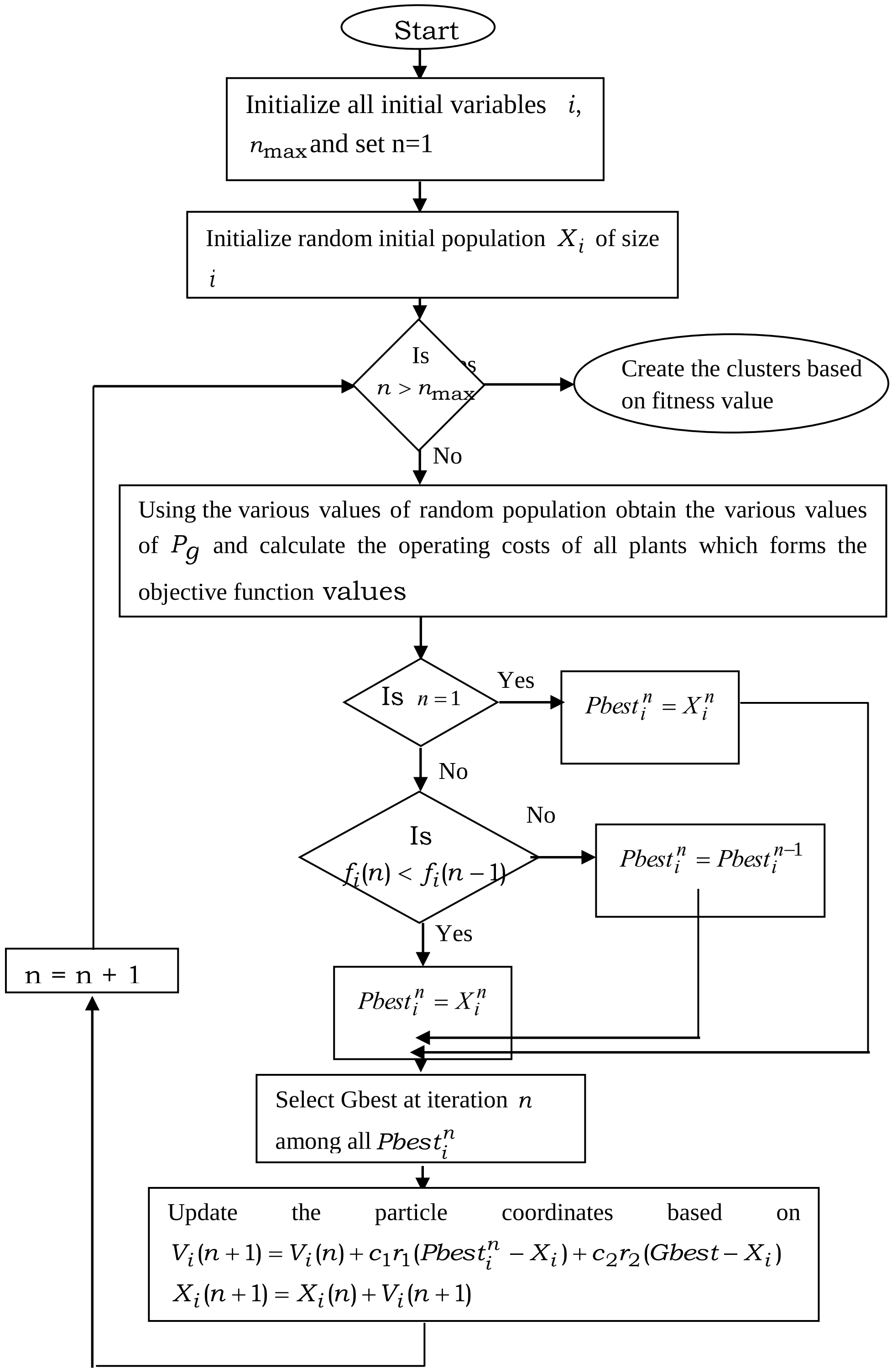

Figure 1. Flow Chart of implementation of PSO

Step-2: The binary coded particles are decoded into their equivalent decimal values of Pg by using linear mapping rule given by equation 10.

$$p_i = p_i^L + \frac{p_i^U - p_i^L}{2^{li} - 1} \times decoded\ value\ of\ S_i$$

(10)

p_i^U :Upper limit of generation of i[th] unit; p_i^L :Lower limit of generation of i[th] unit.

S_i :Sub-string of i[th] unit; li :Length of the string.

Step-3: These values are employed to calculate the operating cost of each generator, which becomes the objective function value. The different steps portrayed in Figure 1 are followed to calculate the Gbest and Pbest.

Step-4: The velocity and position of each particle is reorganized accordingly and this process continues until the termination conditions are met. The objective function values are brought out and given in table 3.

Step-5: Depending on the value of generation cost functions, the units with close functional values are segregated into various clusters as BL, IL, SPL and PL as shown in table 5.

Step-6: In order to carry out the additive cluster algorithm, the various objective function values of the units are segregated in ascending order while they are segregated in descending order for divisive cluster algorithm.

Figure 2 depicts the entire procedure of implementation of additive and divisive clustering based unit commitment.

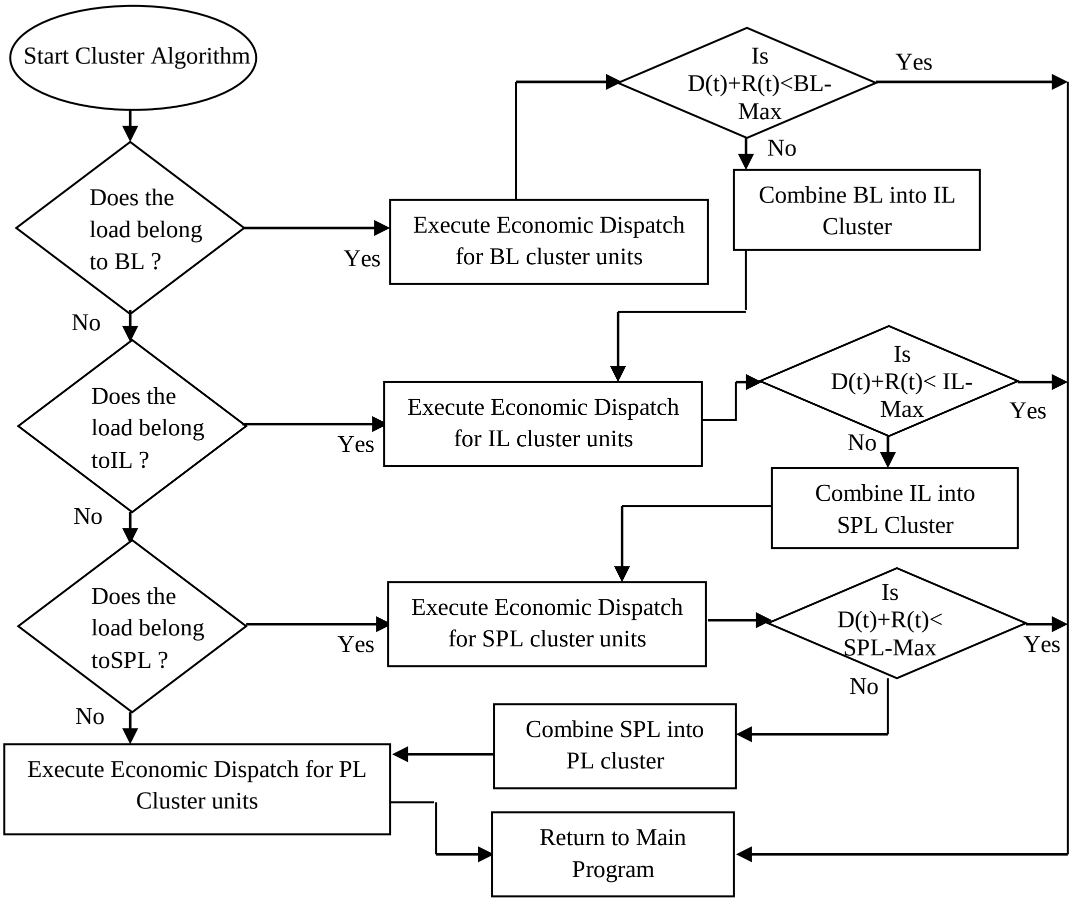

Figure 2:Algorithm proposed for problem of Unit Commitment

RESULTS AND DISCUSSIONS

The daily load pattern of the system is represented in Table 1 and the various operating characteristics of the units being considered are given in Table 2 [7]. The operating costs of various units which have been decoded from the randomly generated particles of PSO have been represented in Table 3. Table 4 represents the priority order pertaining to various units relating to their operating costs with respect to additive clustering and divisive clustering.The division of all the 10 units for taking up the daily load pattern has been shown in Table 5. The allotment of generation to various units based on the daily load pattern and clusters has been represented in

Table 6. It can be summarized from the table that the units in various clusters take up the load allotted to them while the other units do not participate in the load sharing until it falls into the other category. The various costs of operation relating to the units taking the load can be seen from the table. Table 7 shows the overall total operating costof the ssytem over the range of 10-100 units for the proposed method employed in unit commitment. It can be observed that the total cost of operation gets reduced drastically through this technique when verified with the other ones.

Table 1: 24 Hour Load Pattern on The Plant

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

Table 2: Characteristics and Coefficients Of Units

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. Minimum cost function of each unit

Unit No	**Cost Function**	**Unit No**	**Cost Function**
1	0.000984	6	0.001904
2	0.001005	7	0.002301
3	0.002334	8	0.001123
4	0.001489	9	0.0016193
5	0.001346	10	0.001801

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Table 4. Formation of Priority List with less operation cost for AC & DC algorithms

Priority Order	1	2	3	4	5	6	7	8	9	10
For Additive	1	2	8	5	4	9	10	6	7	3
For Divisive	3	7	6	10	9	4	5	8	2	1

Table 5. Formation of clusters and their priority

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

Table 6. Overall Generation of units under schedule of 24 hours

S.No	Load (MW)	Commitment schedule										Operational cost ($)
		1	2	3	4	5	6	7	8	9	10	
1	700	430.29	269.7	0	0	0	0	0	0	0	0	12137.7
2	750	446.34	303.6	0	0	0	0	0	0	0	0	13008.3
3	850	455	180	0	30	130	0	0	55	0	0	15999.3
4	950	455	190	0	120	130	0	0	55	0	0	18104.6
5	1000	455	240	0	120	130	0	0	55	0	0	19112.4
6	1100	455	340	0	120	130	0	0	55	0	0	20775.4
7	1150	455	390	0	120	130	0	0	55	0	0	21698.3
8	1200	455	440	0	120	130	0	0	55	0	0	22699.8
9	1300	455	455	0	130	130	0	0	55	45	30	25489.3
10	1400	455	455	35	130	130	25	25	55	45	45	32375.2
11	1450	455	455	55	130	130	40	40	55	45	45	33414.5
12	1500	455	455	105	130	130	40	40	55	45	45	34412.5
13	1400	455	455	35	130	130	25	25	55	45	45	32398.2
14	1300	455	455	0	130	130	0	0	55	45	30	25489.3
15	1200	455	440	0	120	130	0	0	55	0	0	22699.8
16	1050	455	290	0	120	130	0	0	55	0	0	19998.3
17	1000	455	240	0	120	130	0	0	55	0	0	19112.4
18	1100	455	340	0	120	130	0	0	55	0	0	20799.4
19	1200	455	440	0	120	130	0	0	55	0	0	22699.8
20	1400	455	455	35	130	130	25	25	55	45	45	32398.2
21	1300	455	455	0	130	130	0	0	55	45	30	25479.3
22	1100	455	340	0	120	130	0	0	55	0	0	20799.4
23	900	455	240	0	50	100	0	0	55	0	0	17320.3
24	800	455	345	0	0	0	0	0	0	0	0	14025.2
Total Operating cost												**542446.9**

Table 7. Operating cost over range of 10-100

No.of Generating Units	Base load	Intermittent load	Semi peak load	Peak load	Total Operating Cost
10	1,2	8,5,4	9,10	6,7,3	**542446.9**
20	1,2,11,12	8,5,4,18,15,14	9,10,19,20	6,7,3,16,17,13	1158380
40	1,2,11,12,21,22,31,32	8,5,4,18,15,14, 28,25,24,38,35, 34	9,10,19,20,29,30,39,40	6,7,3,16,17,13,26,27,23,36,37,33	2228560
60	1,2,11,12,21,22,31,32,41,42, 51,52	8,5,4,18,15,14, 28,25,24,38,35, 34,48,45,44,58, 55,54	9,10,19,20,29,30,39,40,49,50,59,60	6,7,3,16,17,13,26,27,23,36,37,33,46,47,43,56,57,53	3474516
80	1,2,11,12,21,22,31,32,41,42, 51,52,61,62,71,72	8,5,4,18,15,14, 28,25,24,38,35, 34,48,45,44,58, 55,54,68,65,64, 78,75,74	9,10,19,20,29,30,39,40,49,50,59,60,61,62,71,72	6,7,3,16,17,13,26,27,23,36,37,33,46,47,43,56,57,53,66,67,63,76,77,73	4596997
100	1,2,11,12,21,22,31,32,41,42, 51,52,61,62,71,72,81,82,91, 92	8,5,4,18,15,14, 28,25,24,38,35, 34,48,45,44,58, 55,54,68,65,64, 78,75,74,88,85, 84,98,95,94	9,10,19,20,29,30,39,40,49,50,59,60,61,62,71,72,89,90,99,100	6,7,3,16,17,13,26,27,23,36,37,33,46,47,43,56,57,53,66,67,63,76,77,73,86,87,83,96,97,93	5799673

CONCLUSION

A clustering technique involving Particle Swarm Optimization has been recomended in order to solve the issue of Unit Commitment. It can be observed that the recomended method is indeed realistic in nature and easy to be implemented. Based on the load pattern of 24 hours, two separate algorithms have been proposed i.e., Additive cluster and Divisive cluster have been recomended for increasing and decreasing load patterns respectively. The various units of the system are indeed divided into various clusters based on the operating cost of units. A priority list is also prepared exclusively for both increasing load and decreasing load respectively based on the various costs of generation. A thermal system with the unit range between 10-100 has been evaluated for the study. The method engaged has indeed demonstrated to be quite efficient and acceptablewhich is proved through simulation results.

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