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Implementation of Clustering based Unit Commitment Employing Particle Swarm Optimization

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ABSTRACT: Fuel cost savings can be obtained by proper commitment of available generating units. This paper describes a new approach to the unit commitment problem through classification of units into various clusters based on Particle Swarm Optimization. This classification is carried out in order to reduce the overall operating cost and 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 based on hybrid technique of genetic algorithm and simulated annealing 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, Particle Swarm Optimization, base load, intermittent load, semi peak load, peak load.

I. INTRODUCTION

Unit commitment is to determine the commitment and generation levels of generating units over a period of time to minimize the total operation cost. It is an important problem with significant economical impact. The Unit Commitment (UC) problems are well known in the power industry and have the potential to save millions of dollars per year in fuel and related costs. It is an area of production scheduling that relates to the determination of the ON/OFF status of the generating units during each interval of the scheduling period, to meet system load and reserve requirements and minimum cost, which are subjected to the variety of equipment, system and environmental constraints. The UC problem is a complex decision making process and it is difficult to develop any rigorous mathematical optimization methods capable of solving the entire for any real-size system. Also, multiple constraints should be imposed which must not be violated while finding the optimal or near-optimal commitment schedule [1,5,8,9].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 [10,12,13,14,15,19]. 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 linearzing 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 [21]. Some research interest has been focused on heuristic search methods based on Artificial Intelligent techniques. Intelligent methods have come to be popular tool for solving many optimization problems. Recent contributions in the area of intelligent methods for UC problem include application of Expert Systems like Neural

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Networks , Fuzzy Logic and Tabu Search, Basic Genetic Algorithm approach and Extended Priority List (EPL) method based on GA[2,3,4,6,7,11,16,20,22].These methods seem to be promising and are still evolving. Though the approaches have yielded attractive results, the linguistic descriptions for generating static crisp output under large number of time dependent constraints in UC may make the approaches highly complex and may even confusing[2]. The Particle swarm Optimization (PSO) approach iteratively evaluates the best solution each time the neighbourhood is updated. The method has good capability only for suboptimal search.

Inspired by the results of PSO method and to overcome the general difficulties in GA approach, 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. The operating costs are obtained by PSO, based on the operating costs of units clusters are formed and also useful for preparing the priority list. In the second stage, UC solution is obtained by developing Additive Cluster algorithm for increasing load pattern. Finally in the third stage a Divisive Cluster algorithm is developed for decreasing load pattern.

The remaining paper is organized as follows: Section 2 deals with problem formulation. The concept of Particle Swarm Optimization based cluster technique is discussed in Section 3. The new methodology using clustered based PSO has been presented in Section 4. Simulation results and discussions are carried out in Section 5 and finally conclusions are drawn in the Section 6.

II. PROBLEM FORMULATION

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 t^{th} hour; $P_i^{\max}, P_i^{\min}$: Maximum / Minimum output power (MW) of i^{th} unit; $D(t)$:Demanded power at t^{th} hour; $R(t)$:System reserve at t^{th} hour; T_i^{on} :Minimum up time of i^{th} unit; T_i^{off} : Minimum down time of i^{th} unit; $X_i^{on}(t)$:Duration during which i^{th} unit is continuously ON; X_i^{off} :Duration during which i^{th} unit is continuously OFF; $SC_i(t)$: Start-Up cost of i^{th} 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

A. Objective Functions and System Constraints

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

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

Where Fuel cost of i^{th} unit:

$$FC_i(t) = a_i + b_i P_i(t) + c_i P_i(t)^2 \qquad (2)$$

and Start-up cost

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

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

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

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:

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

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:

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

Generated Power Limits

The power output of each unit should satisfy:

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

Minimum Up/Down Time

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

$$T_i^{on} \leq X_i^{on}(t) \text{ or } T_i^{off} \leq X_i^{off}(t) \quad (8)$$

III. FORMULATION OF CLUSTERS EMPLOYING PSO

Particle Swarm Optimization is general purpose optimization technique based on principles inspired from the school of fish or swarm of birds [11-12]. PSO is a population based stochastic optimization technique inspired by social behaviour of bird flocking or fish schooling. In PSO, the search for an optimal solution is conducted using a population of particles, each of which represents a candidate solution to the optimization problem. Particles change their position by flying round a multidimensional space by following current optimal particles until a relatively unchanged position has been achieved or until computational limitations are exceeded. Each particle adjusts its trajectory towards its own previous best position and towards the global best position attained till then. PSO is easy to implement and provides fast convergence for many optimization problems and has gained lot of attention in power system applications recently. By using PSO the operating cost functions of each unit are obtained. Based on these cost function priority list is prepared and clusters are formed. 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 optimization criterion additive to clusters. Once the optimization 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.

A. Basic Additive Clustering Algorithm

- Compute operating cost (proximity) matrix;
- *Repeat;*
- Merge two closest clusters based on least distance value;
- Update the proximity Matrix to reflect the proximity between the new cluster and the original clusters;
- *Until* Only one cluster remains.

B. Basic Divisive Clustering Algorithm

- Compute operating cost (Proximity) Matrix;
- *Repeat;*

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- Separate a cluster from other clusters based on maximum distance value;
- Update the proximity Matrix to reflect the proximity between the clusters those remaining;
- *Until* all the clusters are removed.

IV. PROPOSED METHODOLOGY

The proposed methodology can be unfolded in to three stages.
Stage-1: In this stage objective cost function of each unit is obtained by using Particle Swarm Optimization. Priority list of units is prepared based on the minimum objective cost functions and clusters are formed.
Stage-2: 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 additive clustering technique is developed for increasing load pattern
Stage-3: This stage presents an algorithm for UC solution for the decreasing load condition. The algorithm is designed based on divisive clustering technique.
In this methodology Particle Swarm Optimization has been employed to form clusters. The operating cost of each plant is calculated and the plants are clustered based on their fitness values. In this way PSO is employed to bring out the best clusters so that they can be employed to take up the load.

A. 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. Figure 1 shows the flowchart of PSO employed for this purpose. 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 up to 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.

B. Preparation of priority list using PSO

In this stage the following steps are performed for preparing the priority list.
Step-1: The algorithm begins with the initialization of load patterns, unit characteristic along with the generation of initial population of particles, where each particle is corresponding to generation of a particular generator (P_g). The load pattern and unit characteristics are presented in table 1 & table 2.
Step-2: The binary coded particles are decoded into their corresponding decimal values of Pg by using linear mapping rule give by the equation (9).

$$p_i = p_i^L + \frac{p_i^U - p_i^L}{2^{li} - 1} \times decoded\ value\ of\ S_i \qquad (9)$$

p_i^U : Upper limit of generation of ith unit; p_i^L : Lower limit of generation of ith unit.

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

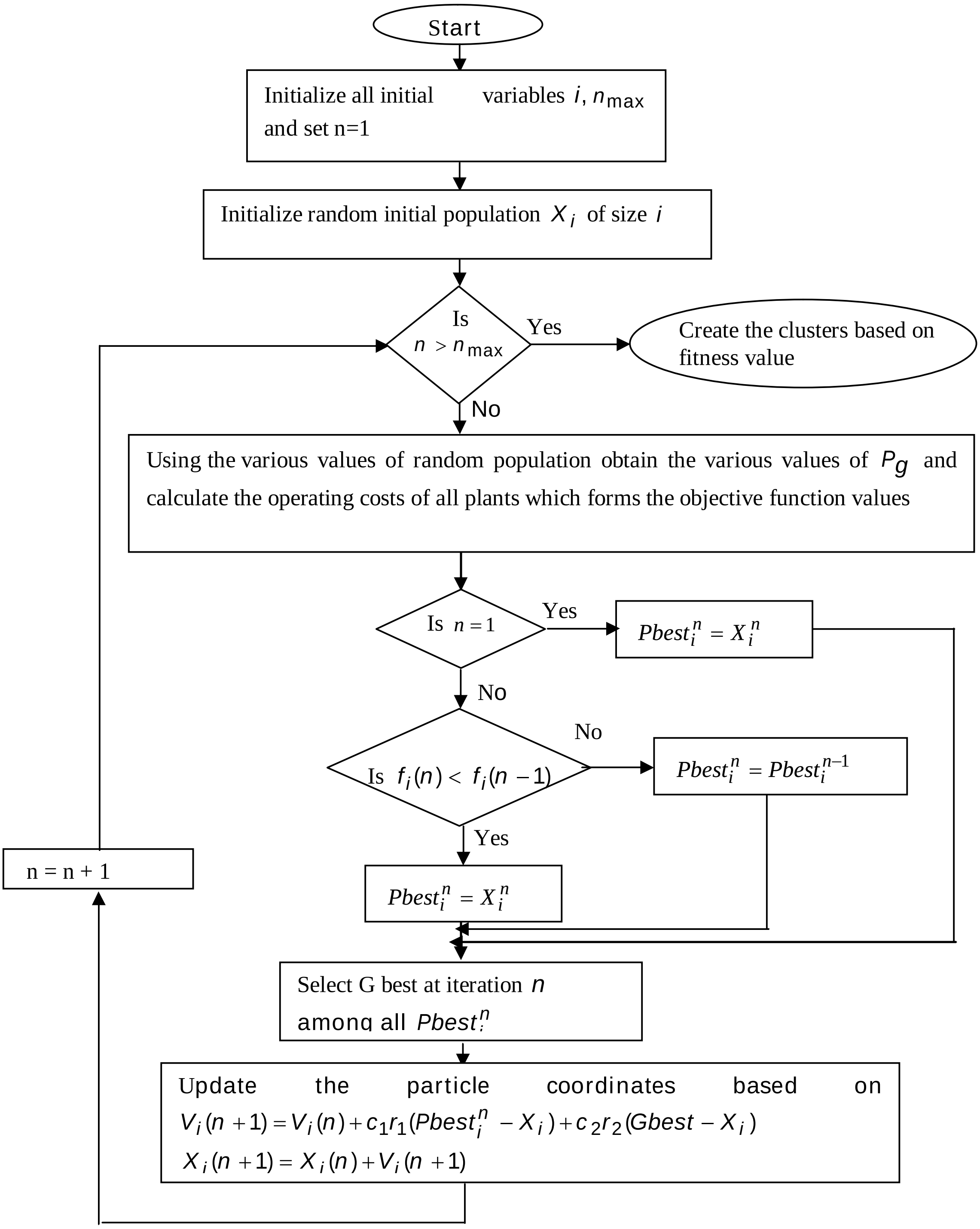

Figure 1: Flow chart of PSO employed for clustered based unit commitment

Step-3: These values are used to calculate the operating cost of each generator, which forms the objective function value. The various steps depicted in Figure 1 are followed to calculate the Gbest and Pbest.

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Step-4: The velocity and position of each particle is updated accordingly and this process continues until the termination criteria is met. The objective function values are brought out and given in table 3.
Step-5: 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 up to 1000MW duration; IL: Load between 1000MW to 1200 MW; SPL : Load 1200MW to 1400 MW; PL : Load 1400MW to 1500MW.
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.
Step-6: 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.
The entire process of clustering based unit commitment employing additive clustering and divisive clustering is shown in Figure 2.

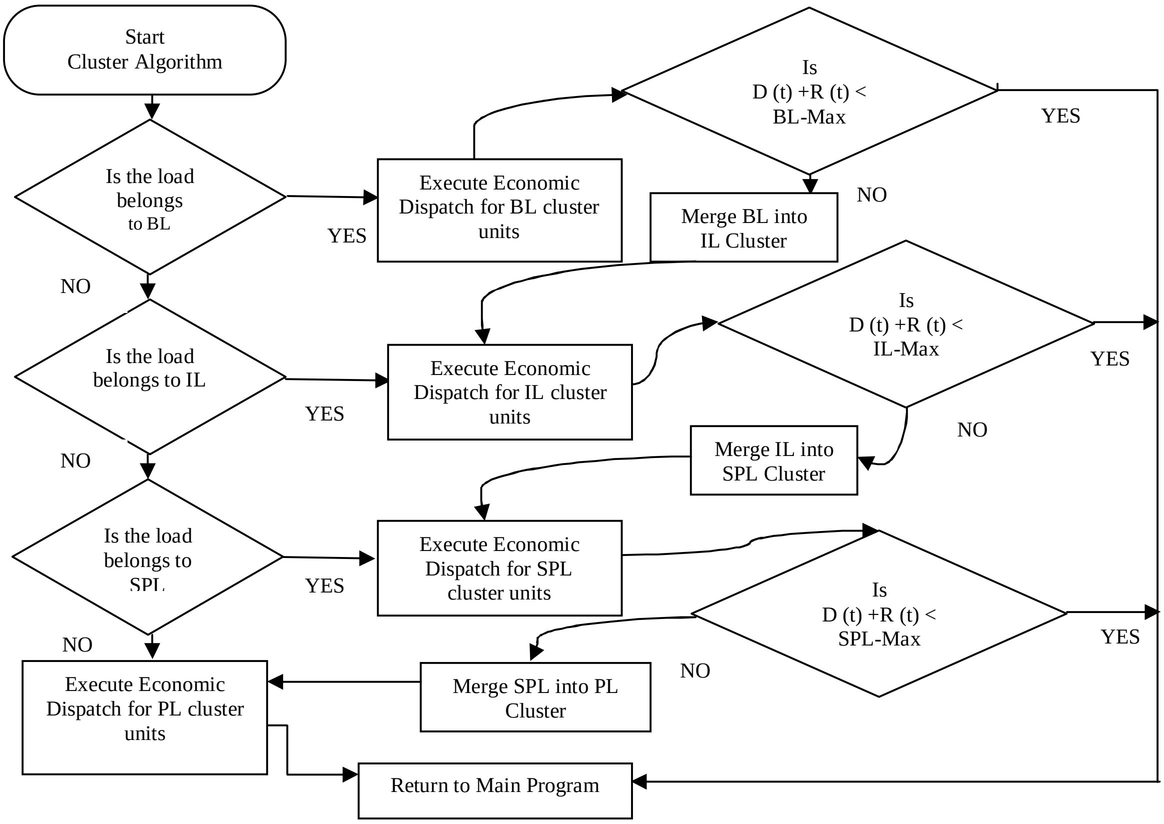

Figure.2 Proposed Algorithm for UC problem

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V. RESULT AND DISCUSSIONS

Table1 shows the daily load pattern on the plant.

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-2: UNIT CHARACTERISTICS AND COEFFICIENTS

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

Table 3 shows the values of operating costs of various generators which has been decoded from the randomly generated particles of PSO.

TABLE.3. MINIMUM COST FUNCTION OF EACH UNIT

Unit No	Cost Function	Unit No	Cost Function
1	0.0008	6	0.0012
2	0.0007	7	0.0015
3	0.0014	8	0.0009
4	0.0010	9	0.0018
5	0.0010	10	0.0012

Table 4 shows the priority order of various units corresponding to their operating costs with respect to additive clustering and divisive clustering.

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TABLE.4. PRIORITY LIST IS FORMED WITH MINIMUM OPERATION COST FOR AC & DC ALGORITHMS

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

Table 5 shows the segregation of all the 10 units in order to take up the daily load pattern

TABLE.5. DIVISION OF UNITS INTO CLUSTERS AND THEIR PRIORITY

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

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.

TABLE.6. GENERATION OF UNITS IN 24 HOUR SCHEDULE

		Commitment schedule										
S.No	Load (MW)	1	2	3	4	5	6	7	8	9	10	Operational cost ($)
1	700	416.8	283.1	0	0	0	0	0	0	0	0	12701.7
2	750	443.6	306.3	0	0	0	0	0	0	0	0	13585.7
3	850	455	170	0	130	45	0	0	50	0	0	16520
4	950	455	185	0	130	130	0	0	50	0	0	18278.3
5	1000	455	235	0	130	130	0	0	50	0	0	19145.3
6	1100	455	335	0	130	130	0	0	50	0	0	20909.3
7	1150	455	385	0	130	130	0	0	50	0	0	21806.3
8	1200	455	435	0	130	130	0	0	50	0	0	22713.3
9	1300	455	455	0	130	130	45	0	50	0	50	26080
10	1400	455	455	30	130	130	35	35	50	35	45	30293.3
11	1450	455	455	80	130	130	35	35	50	35	45	31295.3
12	1500	455	455	130	130	130	35	35	50	35	45	32312.9
13	1400	455	455	30	130	130	35	35	50	35	45	30293.3
14	1300	455	455	0	130	130	45	0	50	0	50	26080
15	1200	455	435	0	130	130	0	0	50	0	0	22713.3
16	1050	455	285	0	130	130	0	0	50	0	0	20022.3
17	1000	455	235	0	130	130	0	0	50	0	0	19145.3
18	1100	455	335	0	130	130	0	0	50	0	0	20909.3
19	1200	455	435	0	130	130	0	0	50	0	0	22713.3

20	1400	455	455	30	130	130	35	35	50	35	45	30293.3
21	1300	455	455	0	130	130	45	0	50	0	50	26080
22	1100	455	335	0	130	130	0	0	50	0	0	20909.3
23	900	455	229.4	0	130	35.54	0	0	50	0	0	17383.6
24	800	455	345	0	0	0	0	0	0	0	0	14475.2
Total Operating cost												**536659**

Table 7 shows the comparison in the total operating cost between the proposed method and other clustering methods employed in unit commitment. It can be observed that with the help of the proposed method the total operating cost becomes greatly reduced as compared with the other techniques.

TABLE 7. COMPARISON OF TOTAL OPERATING COST

Technique employed	Total operating cost
Proposed method	Rs 536659/-
GASA based clustered UC[22]	Rs 541254/-
GA based clustered UC[20]	Rs 544156/-
Conventional GA based UC[7]	Rs 565825/-

VI. CONCLUSIONS

The problem of unit commitment has been solved by employing a new PSO based clustering technique. The proposed method is more advantageous 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 operating 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 simulation results show that the operating cost greatly reduces with this technique and the obtained results are also compared with those of previous techniques. The strategy employed proved to be quite effective and satisfactory as evident through simulation results

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