A Solution to the Unit Commitment Problem Applying a Hierarchical Combination Algorithm

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Unit commitment problem (UCP) is an essential concept in electricity generation due to various economical and environmental concerns. This paper presents a hierarchical combination algorithm for solving the UCP which is able to minimize the simulation time as well as the operational cost. Furthermore, the binary decision variables, determining the state of unit (on/off), are produced in each hour considering the demand and spinning reserve requirements (SRRs). Minimum up and down time constraints are applied in order to reduce the solution space. Finally, the economic dispatch (ED) is carried out for the feasible commitments obtained in each interval respect to the power generation limitations. In addition, the Priority List (PL) and Exhaustive Enumeration (EE) methods are implemented during the load increases and decreases, respectively. The proposed method has been implemented and applied to the standard power systems and the obtained results verify the relevant acceptable computational time with the optimal cost compared to the other wellknown methods in the literature.

keywords: *Dynamic programming, Hierarchical combination, Power generation scheduling, Priority list, Unit commitment problem.*

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DEFINITION OF TERMS:

$ASCA$	Ant Colony Search Algorithm
BCA	Bee Colony Algorithm
DP	Dynamic Programming
EE	Exhaustive Enumeration
GSA	Gravitational Search Algorithm
ICA	Imperialistic Competition Algorithm
PSO	Particle Swarm Optimization
$SFLA$	Shuffled Frog Leaping Algorithm
UCP	Unit Commitment Problem
BF	Bacterial Foraging
DE	Differential Evolution
ED	Economic Dispatch
FFA	Firefly Algorithm
HSA	Harmony Search Algorithm
LR	Lagrangian Relaxation
PL	Priority List
$TLBO$	Teaching Learning Based Optimization
$Cost_{NH}$	total cost of N generators during H hours
$FC_i(P_{ih})$	Fuel cost of ith unit with output P_{ih} at the hth hour
STC_i	Startup cost of ith unit
SDC_i	shutdown cost of ith unit
U_{ih}	On/off status of ith unit; $U_{ih} = 0$ and $U_{ih} = 1$ are for off and on statuses respectively
H	Number of hours
P_{Dh}	load demand at the hth hour
$P_{i(min)}$	Minimum generation limit of the ith unit
$P_{i(max)}$	Maximum generation limit of the ith unit
MUT_i	Minimum up-time of the ith unit
MDT_i	Minimum down-time of the ith unit

X_i^{on} Duration that the ith unit is continuously on

X_i^{off} Duration that the ith unit is continuously off

$Cs - hrs_i$ An additional duration to MDT_i that the ith unit needs (Csc) to be committed again after it; Cold-start hours

Csc_i Required cost to operate the ith unit after MD_i plus $Cs - hrs_i$; Cold-start cost

Hsc_i Required cost to operate the ith unit after MD_i an ending the $Cs - hrs_i$i; Hot-start cost

Inc Initial condition

1. INTRODUCTION

Over the last decade, a trend to electricity usage has been grown, so the operators must schedule the power plants correctly to meet the actual demand considering the environmental and technological con-strains. Effective scheduling of the available energy resources in order to meet the load demand has become an important task in the modern power systems by which million dollars are saved per year for the large scale utilities [1].

The objective of UCP is the optimally scheduling of the available generating units over a dispatch interval. Generally, this problem is a non-convex, nonlinear, large-scale and mixed integer optimization problem subject to some equality and inequality constraints. The solution of UCP consists of two main procedures for each time horizon. The first procedure is known as UC, determines the status of generating units to be on/off with the binary variables (1/0) during each period. The second one which allocates the load among available units is called ED.

A large effort has been spent over the last decades on developing efficient methods for UCP solving, focusing on the cost and executing time minimization. Generally, these methods are categorized as the deterministic and meta-heuristic methods. The deterministic techniques such as the Exhaustive Enumeration (EE) [2], Priority List (PL) [3, 4], Dynamic Programming (DP) [5], and Lagrangian Relaxation (LR) [6] suffer from the inability to solve the large-scale problems. To deal with this problem, the meta-heuristic methods such as Genetic Algorithm (GA) [6], Evolutionary Programming (EP) [7], Simulated Annealing (SA) [8], Particle swarm optimization (PSO) [9–11] have been reported as the second category. The meta-heuristic methods have more chance to find the glob-al optimum point, but they are usually time consuming.

The best method in solving UCP is EE which enumerates all the possible combination of generators. However this method suffers from the high dimensional and computing time [2]. PL is the earliest, fast, and simple suggested method, usually leads to a higher operational cost [3, 12]. DP has the ability to maintain the solution feasibility, but it usually faces with the matter of dimensionality and increased calculation time to find the global optimal solution [4]. LR has more flexibility to manage the additional constraints, but the duality inherent of the algorithm is the ma-jor obstacle to obtain the feasible solution [5].

GA is one of the powerful meta-heuristic methods which is inspired from the genetic biology. It should be noted that there is no guarantee in finding the optimal solution convergence in GA [6]. Un-like GA which preferably operates on the bit strings, EP imposes no restrictions on coding [7]. SA is a general-purpose stochastic optimization technique, which can converge asymptotically to a global optimum [8]. PSO is more efficient than GA, which can obtain the global optimum solution with much more possibility [9–11]. Mutation is internally generated from the difference among the solution vectors and it just works with the continuous variables in the DE method [13, 14]. GSA as a memory-less algorithm based on the Newton's law of gravity and the law of motion has an adaptive learning rate and the good and fast convergence [15, 16].

ASCA, SFLA and FFA are the methods based on observing, imitating, and modeling the behavior of a group of animals, searching for the location with the maximum amount of available food [17–21]. These methods have a high convergence speed. HSA is inspired from the music world [22, 23]. TLBO is also a population based algorithm to attain a global optimal solution. The population is assumed as a group of learners and the obtained result by the learner corresponds to the fitness of an objective function [24]. BF is based on the fact that the natural selection tends to eliminate the animals with the poor foraging strategies indicating a satisfactory performance with respect to the quality of the feasible solutions [25]. The main drawback of all iterative and population based methods is that they are usually time consuming.

In the course of time, several hybrid techniques have been introduced as combination of two or more mentioned methods, such as GA-LR and PSO-LR, to reduce the search space and improve the optimization effectiveness [26–34]. Nevertheless, no technique has been reported as the best solution, so some researchers try to propose the innovative methods [35–42].

In this paper, it is tried to solve UCP using a hybrid algorithm which can overcome the high computational time and lead to the minimum cost, simultaneously. In this way, the units committed by the priority list method, while trying to satisfy demand and reserve constraints and then detect violations related to the minimum up/down time. This primarily procedure leads to production of a set of solutions that are feasible for each interval, so ED is applied in reduced space in the final step.

The proposed method is acceptable in terms of the solution accuracy and computational time, simultaneously. The main advantage of the proposed method is considering the various constraints before the power dispatching process, reducing the computing time seriously and effectively. The proposed method is more suitable to apply on micro-grid planning. Hence its application on large scale power systems need to further analyzing mainly due to computing time.

The main contributions of this paper are organized as follows. Section 2 detailed the concept of the UCP formulation and its various constraints. Methodology of the proposed solution is described based on the 4 unit system as a simplest case study in section 3. In section 4, the proposed solution is verified with applying on 10 and 20 unit benchmark systems and compare the results with other related papers in both operational cost and computing time. Finally the paper is concluded in section 5.

2. PROBLEM FORMULATION

The objective function of UCP is the minimization of the total cost including the operating, startup, and shutdown costs of all the units for the entire time horizon subject to the related constraints as given in (1).

$$\begin{aligned} Cost_{NH} = \sum_{h=1}^{H} \sum_{h=1}^{H} [FC_i(P_{ih}) + STC_i(1 - U_{i(h-1)}) \\ + SDC_i(1 - U_{i(h+1)})]U_{ih} \end{aligned} \tag{1}$$

The scheduling horizon is divided into one-hour periods, and the shut down costs are not considered in this formulation for the sake of simplicity. Final Cost (FC) is usually a quadratic polynomial function which is defined by (2) where α_i, β_i and γ_i are the fuel cost coefficients of the thermal unit i.

$$FC_i(P_{ih}) = \alpha_i + \beta_i P_{ih} + \gamma_i P_{ih}^2 \tag{2}$$

STC is the startup cost which is usually a function of the number of periods that the unit has been offline before the startup and is formulated as [33]:

$$STC_i = \begin{cases} HSC & X_i^{off} \leq MDT_i + Cs - hrs \\ Csc & X_i^{off} > MDT_i + Cs - hrs \end{cases} \tag{3}$$

During the optimization process, some essential constraints including the system and generator constraints must be met. Some prevalent constraints of UCP are described as follows.

- System power balance:

The total power generated in each hour must supply the load demand.

$$\sum_{i=1}^{N} P_{ih} = P_{Dh} \tag{4}$$

- Generator capacity limitation:

The unit maximum and minimum power limits should not be violated.

$$P_{i(\min)} \leq P_{ih} \leq P_{i(\max)} \tag{5}$$

- Spinning reserve requirements (SRRs):

Considering the reliability aspects in the unpredicted situation, the operating units should be able to generate the power more than the actual demand to create the power safe margin.

$$\sum_{i=1}^{N} P_{i(\max)} U_{ih} \geq P_{Dh} + SR_h \tag{6}$$

where SR_h is the reserve at the hth hour, and usually it is considered as a percentage of the actual demand.

- Minimum up/down-time:

Once a unit starts up or goes out, its status can't change immediately because of some practical constraints. Any change in the unit status should be done according to a predefined duration.

$$MUT_i \leq X_i^{on} \tag{7}$$

$$MDT_i \leq X_i^{off} \tag{8}$$

- Initial conditions:

The initial status of units at the first hour of scheduling should be taken into account. The positive and negative numbers indicate that the related units were on or off beforehand.

3. THE SOLUTION METHOD

In this section, the proposed solution is presented in details, in the context of application to the UCP. Generally, random initialization method is used for generating the initial population but in the proposed, PL is used to generate the initial population. According to PL, the generating units are committed on ascending order to meet the demand and reserve requirements.

Table 1. Priority definition of the units

Unit No	G_n	CF_n	Priority order
1	187.5	20.68	1
2	155	21.37	2
3	52.5	24.89	3
4	40	30.03	4

Generators with the higher capacity will be at the higher priority. If generators have the same capacity (same Pmax and Pmin values), one with the lower Cost Factor (CF) which is obtained from (9) and (10), will be selected as a prior unit.

$$G_n = \frac{P_{\max_n} + P_{\min_n}}{2} \quad \forall n \in N \tag{9}$$

$$CF_n = \frac{a_n + b_n \times G_n + c_n \times G_n^2}{G_n} \quad \forall n \in N \tag{10}$$

Obviously, units are committed in an ascending order by CF_n during increasing the demand period. For clarification, a simple 4-unit test system in the 8 hour time horizon is assumed as a case study. The data of units and load is extracted from [33]. For the first hour, initial population based on CF ordering is generated.

$$Initial population = \begin{vmatrix} 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 0 \\ 1 & 1 & 1 & 1 \end{vmatrix} \tag{11}$$

While some combinations are not feasible, considering the SRRs constraint (6). Also some units' statuses are not allowed to be changed for the present hour, considering initial condition, MUT and MDT constraints (7- 8), so some combinations will be omitted and the size of the solution space is reduced. Afterwards, λ iteration method perform the power dispatching between active units in each combination and the operational costs are calculated. Consequently, the combination with minimum operational cost selected as an initial condition for the next hour. This method solve the UCP in acceptable cost and time. Although EE solves UCP with the minimum total cost (74241$), but it is time consuming (943.178 sec). Similarly, applying PL on this case, leads to the higher operational cost (74812$) in the less time (141.773 sec). Consequently, the combination of these mentioned methods can take the equilibrium between the cost and time. Applying PL over the time intervals when load increases, EE over the time intervals when load decreases, and DP over the whole time horizon, lead to the 74241$ total operational cost in 2.12 seconds. The proposed method comprises of several steps which are presented in Fig. 1 and are subsequently discussed hereafter.

Step 1-priority definition:

Table 1 demonstrates the priority order of units obtained with (9- 10). It is clear that the first unit has the highest priority and the forth unit has the lowest one.

Step 2- Determining the peak and valley hours:

In this step, the time horizon is divided by 8 part which is lasts for an hour. Peak and valley times can be determined by scanning the load profile. If the load changes is positive (load>0),

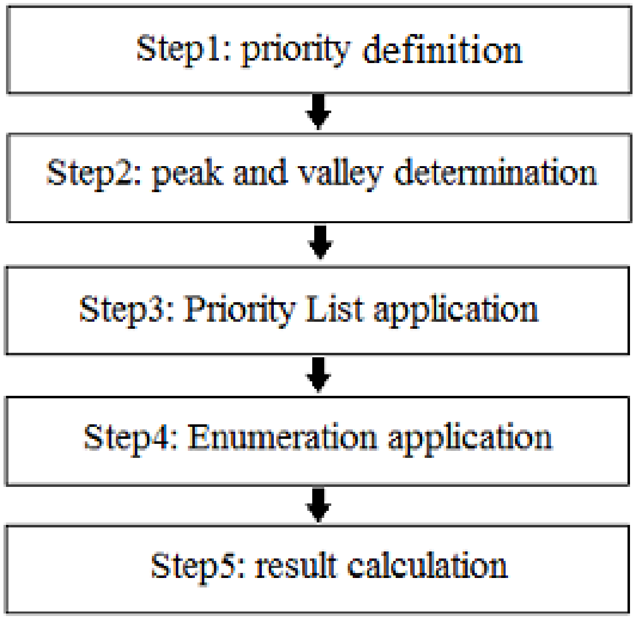

Fig. 1. Stages of the proposed method

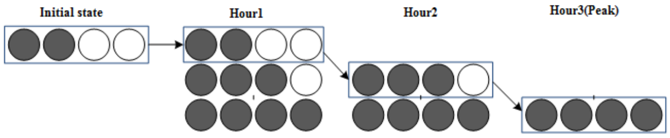

Fig. 2. Applying PL on the 4-unit power system

this hour is considered as the peak, and it is considered as the valley, in contrast.

Step 3- Applying the PL technique:

Following the rising curve, the units must be turned on based on their priority to meet the demand. Obviously, a unit with the higher priority leads to the less cost, so applying the PL method in each hour is beneficial.

It is clear in Fig.2 that each hour has several feasible states, satisfying the constraints. As it is shown, the minimum cost belongs to the state with the higher priority units, so considering its situation as the initial state for the next hour leads to the minimum total cost.

Step 4- Applying the enumeration algorithm:

To reduce the generation in the falling part of the load curve, some committed units must be turned off while SRRs, MUT, and MDT are met. Considering the condition of units in the latest reviewed hours as the initial states for the next period, all combination of feasible states must be checked out with respect to the limitations to achieve the total cost minimization. As it is shown in Fig. 3, considering the optimal solution of the 3^{th} hour as an initial condition for the 4^{th} and various limitations such as SRRs, MUT, and MDT, will be led to some infeasible combinations, which will be omitted. Consequently, the minimum cost is chosen after applying ED on the all feasible states.

Step 5- Results calculation:

The total cost is the summation of the fuel and startup cost of each period within the studied time horizon. Fig.4 shows the flowchart of the proposed algo-rithm in details. The description of the flowchart is as follows:

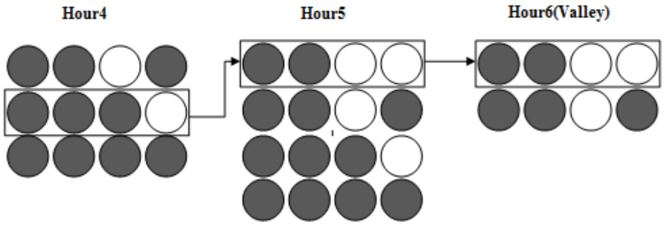

Fig. 3. Applying EE on the 4-unit test system

Table 2. Generation schedule of the 4-unit test system with the 10% reserve

H	U1	U2	U3	U4	Total Cost ($)	STC ($)
1	300	150	0	0	9109.4	0
2	300	205	25	0	11006.3	150
3	300	250	30	20	12534.56	0.020
4	300	215	25	0	11043.4	0
5	276	124	0	0	8205.8	0
6	196	84	0	0	6067.2	0
7	203	87	0	0	6243.9	0
8	300	200	0	0	10030.4	0
Total Cost ($)					74240.96	150.02

1-Gathering input data such as: the number of units, initial condition, MUT, MDT, hot and cold startup hour, generation limits and etc.

2- Getting the ball rolling on the first hour (W=1) and its load, considering the Final Cost (FC) equal to zero.

3- Considering the initial condition and Committing the units based on their priority (9-10).

4- Assuming a fixed percentage of the load as the spinning reserve (5% or 10%) and eliminate the infeasible combi-nation which do not satisfy the SRRs. It should be noted that the generation capacity must be greater than the summation of the load and reserve quantity.

5- Applying the MUT and MDT constraints by (7- 8), in order to reduce the search space.

6- Implementing ED and the cost calculation due to the unit power limitations and selecting the optimal solution with the min-imum total cost for the proposed time interval.

7- Considering the optimal solution as the initial state for the next hour, setting FC as the summation of last FC with the minimum cost, and going to the next hour.

8- Checking the next hour load for detect peak or valley.

9- Using priority or enumeration via positive or negative load changes, respectively.

10- Checking different conditions and re-peating the algo-rithm while $W \leq 24$.

Table 2 demonstrates the scheduling of generation power for the 4-unit system with 10% spinning reserve with proposed solu-tion which is calculated in 2.12 seconds.

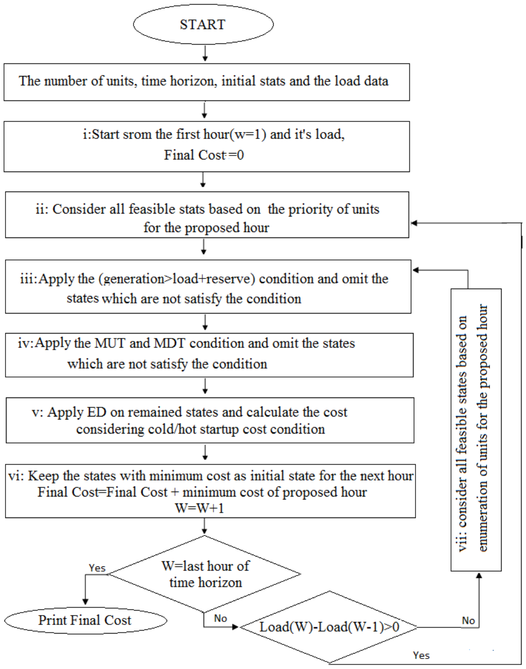

Fig. 4. Steps of the proposed method

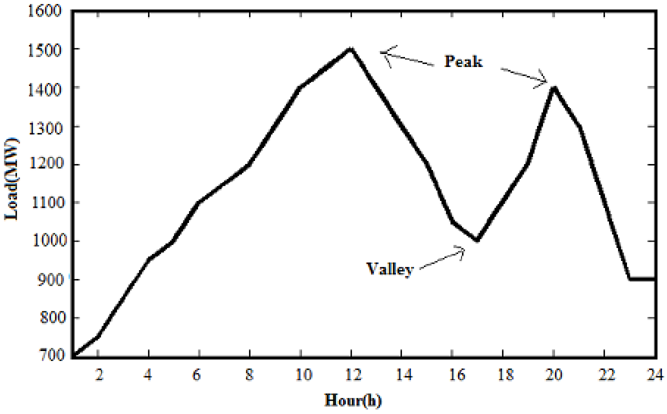

Fig. 5. The daily load curve of 10 units test system

4. RESULTS AND DISCUSSION

A 10-unit system with the daily 24-hour demand is studied as an earlier case study and the obtained results are considered to verify the effectiveness of the proposed method. The units' specification and load profile are extracted from [33].

Fig.5 depicts the daily load demand curve of the proposed case study and demonstrates that the 12^{th} and 20^{th} hours are the peak hours and the 17^{th} hour is the valley in this system.

Two following scenarios are taken into ac-count which are considered in the numerical studies [33]. In the first scenario, 5% of the hourly load demand is considered as SRRs and in the second one SRRs is assumed to be equal to 10%. The optimization results of two scenarios are shown in the Tables 3 and 4, respectively.

Each line illustrates the output power of unit, fuel, startup, and total cost for each hour. Considering the priority order of the units which is obtained by (9-10), the units scheduling is extracted at each time, accordingly. The last columns of these Tables demonstrate the available hourly SRRs which are may be more than the determined percentage of the hourly load demand.

Table 3. Generation schedule of the 10-unit test system with the 5% reserve

Hour	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	Total Cost	FC	STC	Reserve
1	455	245	0	0	0	0	0	0	0	0	13683.1298	13683.1298	0	210
2	455	295	0	0	0	0	0	0	0	0	14554.4998	14554.4998	0	160
3	455	395	0	0	0	0	0	0	0	0	16301.8898	16301.8898	0	60
4	455	455	0	0	40	0	0	0	0	0	19497.6678	18597.6678	900	122
5	455	455	0	0	90	0	0	0	0	0	19608.5378	19608.5378	0	152
6	455	455	0	130	60	0	0	0	0	0	22980.2868	21860.2868	1120	137
7	455	410	130	130	25	0	0	0	0	0	24361.9795	23261.9795	1100	142
8	455	455	130	130	30	0	0	0	0	0	24150.3408	24150.3408	0	167
9	455	455	130	130	110	20	0	0	0	0	26928.9648	26588.9648	340	197
10	455	455	130	130	162	43	25	0	0	0	29890.3923	29370.3923	520	152
11	455	455	130	130	162	80	25	13	0	0	31284.0733	31224.0733	60	157
12	455	455	130	130	162	80	25	53	10	0	33269.6985	33209.6985	60	162
13	455	455	130	130	162	43	25	0	0	0	29370.3923	29370.3923	0	152
14	455	455	130	130	110	20	0	0	0	0	26588.9648	26588.9648	0	197
15	455	455	130	130	30	0	0	0	0	0	24150.3408	24150.3408	0	132
16	455	310	130	130	25	0	0	0	0	0	21513.6595	21513.6595	0	282
17	455	260	130	130	25	0	0	0	0	0	20641.8245	20641.8245	0	332
18	455	360	130	130	25	0	0	0	0	0	22387.0445	22387.0445	0	232
19	455	455	130	130	30	0	0	0	0	0	24150.3408	24150.3408	0	132
20	455	455	130	130	162	43	25	0	0	0	30060.3923	29370.3923	690	152
21	455	455	0	130	162	73	25	0	0	0	27171.1699	27171.1699	0	197
22	455	455	0	130	0	35	25	0	0	0	22550.2183	22550.2183	0	312
23	455	425	0	0	0	20	0	0	0	0	17645.3638	17645.3638	0	172
24	455	345	0	0	0	0	0	0	0	0	15427.4198	15427.4198	0	110
Total											558168.591	553378.591	4790	

The results of applying 30 different methods to the ten-unit test system, com-paring with our results both in the cost and execution time, are given in the Table 5 Obviously, the execution time which depends on the system specification and algorithm accuracy is acceptable in seconds compared to the other methods. As it is shown in the Table 5, the proposed method is implemented efficiently in MATLAB software and run on the Intel Core 2Duo 2.5 GHz, 2 GB RAM PC.

Choosing one situation among many possible situations may challenge the cost-effectiveness, but these kinds of problem may have some optimum solutions with the equal costs. In cases with the equal total cost, the computation time and accuracy must be checked, simultaneously. For ex-ample, the references [13,22,23] have the acceptable final costs, but their methods are time consuming in contrast. So, the optimum cost is obtained versus loosing time. In addition, some researchers have reported the same hourly generation scheduling as our method, with less reported total cost. It seems their reported results should be corrected based on more accurate analysis. So, some of them are selected randomly and the cost is calculated with the reported generating powers, accessible in the related text. Table 6 compares the reported and calculated value for some references and illustrates that the difference between them is undeniable.

To verify the proposed method, a new case as a standard UCP with the 20 units is created by duplicating the amounts of ten generating units' data and multiply-ing the load data by 2. The comparison with the other different methods are shown in the Table 6. The obtained cost is 1126697$ for the mentioned 20 units test system. Table 7 clarifies that our hierarchical method can improve the reported cost which is obtained by some previous techniques and surmount on the others such as DP [7], ACSA [15], BSFL [17], TLBO [20], and TSGB [34], which cannot handle 20 unit test system.

Table 4. Generation schedule of the 10-unit test system with the 10% reserve

Hour	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	Total Cost	FC	STC	Reserve
1	455	245	0	0	0	0	0	0	0	0	13683.1297	13683.12975	0	210
2	455	295	0	0	0	0	0	0	0	0	14554.4997	14554.49975	0	160
3	455	370	0	0	25	0	0	0	0	0	17709.4485	16809.4485	900	222
4	455	455	0	0	40	0	0	0	0	0	18597.6677	18597.66775	0	122
5	455	390	0	130	25	0	0	0	0	0	20580.0195	20020.0195	560	202
6	455	360	130	130	25	0	0	0	0	0	23487.0445	22387.0445	1100	232
7	455	410	130	130	25	0	0	0	0	0	23261.9795	23261.9795	0	182
8	455	455	130	130	30	0	0	0	0	0	24150.3407	24150.34075	0	132
9	455	455	130	130	85	20	25	0	0	0	28115.4997	27255.49975	860	197
10	455	455	130	130	162	33	25	10	0	0	30121.9940	30061.99405	60	152
11	455	455	130	130	162	73	25	10	10	0	31980.5048	31920.50485	60	157
12	455	455	130	130	162	80	25	43	10	10	33955.9067	33895.90674	60	162
13	455	455	130	130	162	33	25	10	0	0	30061.9940	30061.99405	0	150
14	455	455	130	130	85	20	25	0	0	0	27255.4997	27255.49975	0	197
15	455	455	130	130	30	0	0	0	0	0	24150.3407	24150.34075	0	132
16	455	310	130	130	25	0	0	0	0	0	21513.6595	21513.6595	0	282
17	455	260	130	130	25	0	0	0	0	0	20641.8245	20641.8245	0	332
18	455	360	130	130	25	0	0	0	0	0	22387.0445	22387.0445	0	232
19	455	455	130	130	30	0	0	0	0	0	24150.3407	24150.34075	0	132
20	455	455	130	130	162	33	25	10	0	0	30551.9940	30061.99405	490	152
21	455	455	130	130	85	20	25	0	0	0	27255.4997	27255.49975	0	197
22	455	455	0	0	145	20	25	0	0	0	22739.9647	22739.96475	0	137
23	455	425	0	0	0	20	0	0	0	0	17645.3637	17645.36375	0	90
24	455	345	0	0	0	0	0	0	0	0	15427.4197	15427.41975	0	110
Total											563978.9812	559888.9812	4090	

Table 5. Comparison with other methods for the 10 units test system and the 10% spinning reserve ("-" means no value was reported in the related paper)

Reference Number	Method	Best Cost($)	Mean Cost($)	Worst Cost($)	Ave CT(s)	System Specification
[12]	SPL	564950	-	-	7.2	Pentium IV, 1.5 GHz, 128 MB
[5]	ALR	565508	-	-	3.2	Pentium IV, 1.6 GHz
[5]	DP-LR	564049	-	-	108	Pentium IV, 1.6 GHz
[6]	GA	565825	567928	570032	221	HP Apollo 720 workstation
[6]	DP	565825	-	-	-	HP Apollo 720 workstation
[6]	LR	565825	-	-		HP Apollo 720 workstation
[8]	SA	565828	565988	566260	3.35	Pentium IV
[9]	PSO	564212	565103	565783	150	Pentium IV, 2 GHz
[9]	IPSO	563954	564162	564579	122	Pentium IV, 2 GHz
[11]	DBDE	563977	564028	564241	3.6	Pentium IV , 2.4 GHz, 256 MB
[13]	GSA	563938	564008	564241	2.89	Core 2 duo processor, 2 GHz, 1 GB
[14]	ACSA	564049	-	-	-	-
[15]	SFLA	564769	-	-	35	Pentium IV, 2 GHz, 512 MB
[16]	BSFL	569678	-	-	-	-
[17]	BRCFF	563937	564743	565597	-	-
[18]	HSA	565827	-	-	6.9	Sony VAIO FW57, 2.8 MHz, 2 GB
[19]	TLBO	564018.8	-	-	171	Intel Core 2 Duo processor, 2.93 GHz
[20]	BF	565872	-	-	80	Intel Pentium IV, 2.0 GHz, 512 MB
[22]	CR-GA	563977	-	-	46	AMD Opteron 2.0 GHz
[23]	FPGA	564094	566675	569237	-	Intel Pentium IV, 1.60 GHz, 512 MB
[25]	PSO-LR	565869	566331	566793	4.2	Dell Dim 4100
[28]	MRCGA	564244	564467	565756	3.6	Intel Pentium 4, 1.4 GHz, 256 MB
[31]	SOCP	564531	-	-	0.78	Intel Duo processor, 2.50 GHz, 4 GB
[32]	TSGB	568315	-	-	-	-
[33]	S- PL	564950	-	-	7.24	Intel Pentium IV, 1.50 GHz, 120 MB
[34]	LS	564970	-	-	2.8	-
[35]	IPPD	563977			0.516	-
[36]	MA	565827	566453	566861	84	Sun Ultra 2 dual, 200 MHz
[36]	LRMA	566686	566787	567022	61	Sun Ultra 2 dual, 200 MHz
[37]	MICP	564178	-	-	6	PC Duo processor, 2.40 GHz, 2 GB
	Proposed	563978.9812	-	-	13	Intel Pentium IV of 2.40 GHz, 2 GB

Table 6. Cost calculation with the reported generation power values ("-" means no value was reported in the related reference)

	Reported value ($)			Calculated value ($)		
Reference number	Fuel Cost	STC	Total Cost	Fuel Cost	STC	Total Cost
[3]	559,887.10	4090	563977.1	559888.9812	4090	563978.9812
[7]	559848	4090	563938	559888.9812	4090	563978.9812
[10]	-	-	565325.94	561373.8051	4440	565813.8051
[14]	559848.0729	4090	563938.0729	559888.0528	4090	563978.0528
[19]	-	-	564018.8	559958.152	4100	564058.152
[21]	-	-	564703.15	560257.4987	4650	564907.4987
[24]	559852.3	4090	563942.3	559918.4727	4090	564008.4727

Table 7. Comparison with other methods for the 20 unit test system

Reference Number	Method	Average Cost($)
[5]	ALR	1,126,720
[5]	DP-LR	1,128,089
[6]	LR	1,130,660
[6]	DP	-
[8]	SA	1,127,955
[9]	PSO	1,128,518
[14]	ACSA	-
[16]	BSFL	-
[18]	HSA	1,127,177
[19]	TLBO	-
[20]	BF	1,128,112
[23]	FPGA	1,128,311
[25]	PSO-LR	1,128,072
[25]	LR	1,128,360
[32]	TSGB	-
[36]	MA	1,128,824
[36]	LRMA	1,128,213
	Proposed	1,126,697

5. CONCLUSIONS

Unit commitment plays an undeniable role in optimal generation of power system as it tries to minimize the total generation cost which leads to the most money saving. In this paper, a hierarchical combination solution method has been proposed to solve UCP. The presented solution method namely the hierarchical method, schedules the generating units in each hour to obtain the feasible states, while the specified limitations are met. The proposed method decreases the solution space by prechecking the constraints before the power dispatch and cost calculations. It is tested on benchmark system and the calculated cost is 563,978.9$ and 1,126,697$ for 10 and 20 unit systems, respectively. Also the calculation time is as comparable as other mentioned methods. As it is drown from Table 4, some other related papers have a near value to the proposed method but the computing time is not comparable. The simulation results confirm that the proposed method is suitable to be applied to microgrid and active power distribution grids. Furthermore it is efficiently compatible with the other complex, intelligent, and deterministic methods. This point plays a crucial role when analyze microgrid with renewable penetration. Generally, the proposed method confirms that proper and efficient constraint handling techniques can make up a successful non-iterative approach for small scale power systems.

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