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A New Heuristic Algorithm for Unit Commitment Problem

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Abstract

Large scale power systems Unit Commitment (UC) is a complicated, hard limit, mixed integer combinatorial and nonlinear optimization problem with many constraints. This paper presents an innovative and effective solution based on modification of the Harmony Search (HS) Algorithm to solve the strategic planning of Generating unit's commitment. The proposed algorithm is easy in application compared to the other Evolutionary Methods (EM) and has a high capability in reaching to optimal solution with reasonable time. The proposed method is tested using the reported problem data sets. Simulations were down for daily unit commitment. The results are compared with previous reported articles results. Numerical results show the efficiency and improvement of the solution in cost and execution time compared to the results of the other powerful heuristic optimization algorithms.

Keywords: Unit Commitment, Evolutionary Algorithm, Harmony Search (HS), Economic Dispatch

1. Introduction

Unit commitment problem is one of the most difficult hard limit optimization problems which are affected by some especial constraints that are imposed from system and physical conditions. Solving the UC problem is important from both the execution time and the correct lay out of plants with minimum cost aspects. To Many text resources have been published in the field of UC problem. Below there is a brief look at the UC problem solution methods in the recent literatures. The priority list (PL) [1]–[2] commits in ascending order of units with full-load cost so that the most economic base load units are committed first in order to meet the load demand. The PL method is very fast but highly heuristic and gives schedules with a relatively higher operation cost. The branch-and-bound (BB) method [3]–[4] has the danger of a deficiency in storage capacity and increasing the calculation time enormously encountering with large-scale problem. The Lagrangian Relaxation (LR) method [5]–[7] concentrates on finding an appropriate coordination technique for generating a feasible primal solution while minimizing the duality gap. The main problem with the LR method is the difficulty encountered in obtaining feasible solutions. The meta-heuristic methods are iterative search techniques that can search not only local optimal solutions but also a global optimal solution. In the meta-heuristic methods, the GA, TS, EP, SA and etc are used for UC [8]–[11]. These methods have the advantage of searching the solution space more thoroughly and avoiding premature convergence to local minima. The main difficulty is their sensitivity to the choice of parameters. However, in case of a large-scale problem, they consume a lot of time and space due to their iterative nature.

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Reference [12] presents a new approach to solve the short-term unit commitment problem using an evolutionary programming-based tabu search (TS) method. In [13] the ant colony search algorithm (ACSA) is proposed to solve the thermal unit commitment problem in [14]. Authors in [15] propose a new method based on SA for the incorporation of the unit unavailability and the uncertainty of the load forecast in the solution of the short-term UC. In [16] a model is presented for calculating the cost of power system reliability based on the stochastic optimization of long-term security-constrained unit commitment. Article [17-18] compares stochastic and reserve methods and evaluates the benefits of a combined approach for the efficient management of uncertainty in the unit commitment problem. Paper [19] provides a model of dynamic ramping in unit commitment. The dynamic ramping limit is modelled as mixed integer linear constraints, and unit commitment is solved by a mixed integer programming (MIP) solver. In this paper the UC problem has been solved based on the application of Harmony Search (HS) algorithm [20].

2. Harmony Search Algorithm (HSA)

Harmony search algorithm is based on natural musical performance processes that occur when a musician searches for a better state of harmony [20]. The engineers seek for a global solution as determined by an objective function, just like the musicians seek to find musically pleasing harmony as determined by an aesthetic [21]. HS algorithm includes a number of optimization operators, such as the harmony memory (HM) which stores the feasible vectors, the harmony memory size (HMS) which is the number of solution vectors in harmony memory, the harmony memory considering rate (HMCR), and the pitch adjusting rate (PAR). A new vector is generated by selecting the components of different vectors randomly in the harmony memory. HS algorithm is effectively directed using two parameters, i.e., HMCR and PAR. The HS algorithm formulation procedure has been explained at next section [21].

3. UC constraints

The constraints that must be satisfied during the UC optimization process are as follows [22-23]:

1. The generated power by all the committed and ON units must satisfy the load demand plus the system losses, which is defined as,

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

2. To maintain system reliability, adequate spinning reserves are required which obtains from (6),

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

3. Each unit has generation range, which is given by (7),

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

4. Once a unit is committed or de-committed, there is a predefined minimum time (Minimum up and down time) after it can be de-committed or committed again. These constraints are defined by the following equations,

$$\begin{cases} (1 - u_i(t+1)).MU_i \le X_i^{on}(t) & if \quad u_i(t) = 1 \\ u_i(t+1).MD_i \le X_i^{off}(t) & if \quad u_i(t) = 0 \end{cases} \tag{8}$$

5. For each unit, output is limited by ramp up/down rate at each hour as follows,

$$P_i^{\min}(t) \le P_i(t) \le P_i^{\max}(t) \tag{9}$$

where,

$$P_i^{\min}(t) = \max(P_i(t-1) - RD_i, P_i^{\min})$$
$$P_i^{\max}(t) = \min(P_i(t-1) - RU_i, P_i^{\max}) \qquad (10)$$

6. Must run and must out units include prescheduled units which must be online, due to operating reliability and/or economic considerations, and units which are on forced outages and maintenance are unavailable for commitment. At the beginning of scheduling, the units' initial status must be taken into account also.

4. UC objective function

The objective of the UC problem is minimizing the total cost which includes fuel cost; start up cost, shot down cost. The fuel cost $FC_i(t)$ unit *i* at hour *t* is expressed as a second order polynomial as equation (11); [24].

$$FC_i(P_i(t)) = A_i + B_i P_i(t) + C_i P_i^2(t) \qquad (11)$$

where, $P_i(t)$ is the power generation of unit *i* at hour *t*, and A_i, B_i, C_i are the cost coefficients of unit *i*.

The start-up cost (SU) for restarting a de-committed thermal unit, which is related to the temperature of the boiler, is included in the model. If the unit is cold which means that it has been shut down for a long time, it is necessary to consume more fuel to warm up the boiler. If the unit is de-committed for a short time satisfying the minimum down time, less energy will be needed to restart the unit.

If $u_i(t) = 1$, the start up costs is calculated as follows,

$$SU_i(t) = \begin{cases} 0 & if\ \ u_i(t-1) = u_i(t) \\ H\cos t_i & if\ \ X_i^{OFF}(t-1) \le Chour_i \\ C\cos t_i & if\ \ X_i^{OFF}(t-1) > Chour_i \end{cases} \qquad (12)$$

Beside, from (8) having,

$$X_i^{OFF}(t-1) \ge MD_i \qquad (13)$$

and if $u_i(t) = 0$, the i^{th} unit start up cost is equal with zero.

Shut-down cost (SD) is constant and the typical value is zero in standard systems.

Therefore, the objective function of UC is:

$$TC = \sum_{t=1}^{H} \sum_{i=1}^{N} \{FC_i(P_i(t)) + SD_i(t) + SU_i(t)\} \qquad (14)$$

Any new type of cost may be included or any existing type of cost may be excluded from the objective function according to the system operators' demand with different weights [11].

5. Test results

In the following section the results of application of the HS to the UC problem are presented. By integer coding of the UC problem the minimum up and down time constraints of units could be satisfied without any penalty factor. In Table I the results of implementation of the HS to 10-units system UC is presented. According to this table scheduling of the units satisfying all of the constraints and without any violations is obtained at each time. In this table the ON/OFF time of the units, output power of units, the fuel cost for each hour, the start up cost with initial state, the start up cost without initial state, hourly load demand of the system and the total cost of the system for 24 hours are indicated. In HS there are two parameters that can affect the time and cost values of the fitness function. When harmony search algorithm is applied to an optimization problem it is necessary that the obtained results be confirmed by either an increase in harmony memory or by an increase in iteration counter. A three-dimension illustration of the fitness function for 10-units system with respect to the increase of the mentioned parameters is shown in Fig. 1. This figure shows that after a given number of harmony memory sizes and iteration number the algorithm reaches to its global optima and isn't improved further. In this paper the best obtained value for harmony memory size and the number of iteration for ten units system is 10 and 15 respectively. Any point in this figure is the minimum value of total cost for a given number of (*HM Size*, *Iteration Counter*). Table II has summarized and compared the costs and times results of the application of the HS to the 10-units UC. From this table it is deduced that the global minimum of the 10-units system is about \$565825 reported in [8].

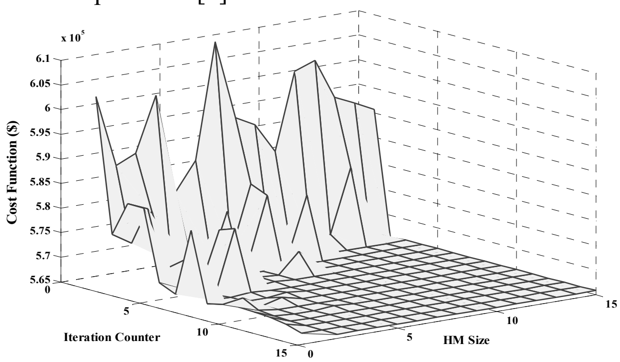

Fig. 1. Cost function with respect to HM size and Iteration Counter

In Table II, the results of the implementation of the proposed method for 20-100 units systems are given and compared to the previously reported results both in cost function and execution time. This table indicates that the harmony search algorithm has an appropriate capability in UC problem solution especially in larger real systems. Comparing the costs and the spent times of the previous works on the same system listed in this table clearly proves the effectiveness and capability of the novel proposed optimization method. The results implies that the proposed algorithm can solve the hard satisfactory optimization problems and reach the global optimal in a reasonable time. The costs calculated by the HS indicate this algorithm is more efficient in large scale UC problems.

6. Conclusion

In this paper, a novel optimization algorithm based on Harmony Search (HS) is adapted and applied to UC problem. The proposed method is first implemented in ten units system and the obtained results are compared with the results given in the references. At the second step of the study, the test system is modified and duplicated for 20-100 units system. The obtained results show that the proposed method can solve both small scale and either the large scale UC problems effectively. The calculated cost and execution time is compared to the other well known optimization methods. Based on the obtained results, the algorithm is an effective method to solve the complex, nonlinear and hard satisfactory optimization problems.

Table I :results of implementation of the hs to uc for 10 units system (detailed power and cost analysis)

Hours (h)	Units										Fuel Cost for per Hour ($)	Start up Costs with Initial State ($)	Start up Costs without Initial State ($)	Load Demands (MW)
	1	2	3	4	5	6	7	8	9	10				
1	455	245	0	0	0	0	0	0	0	0	13683.13	0	0	**700**
2	455	295	0	0	0	0	0	0	0	0	14554.5	0	0	**750**
3	455	370	0	0	25	0	0	0	0	0	16809.45	1800	900	**850**
4	455	455	0	0	40	0	0	0	0	0	18597.67	0	0	**950**
5	455	390	0	130	25	0	0	0	0	0	20020.02	1120	560	**1000**
6	455	360	130	130	25	0	0	0	0	0	22387.04	1100	1100	**1100**
7	455	410	130	130	25	0	0	0	0	0	23261.98	0	0	**1150**
8	455	455	130	130	30	0	0	0	0	0	24150.34	0	0	**1200**
9	455	455	130	130	85	20	25	0	0	0	27251.06	860	860	**1300**
10	455	455	130	130	162	33	25	10	0	0	30057.55	60	60	**1400**
11	455	455	130	130	162	73	25	10	10	0	31916.06	60	60	**1450**
12	455	455	130	130	162	80	25	43	10	10	33890.16	60	60	**1500**
13	455	455	130	130	162	33	25	10	0	0	30057.55	0	0	**1400**
14	455	455	130	130	85	20	25	0	0	0	27251.06	0	0	**1300**
15	455	455	130	130	30	0	0	0	0	0	24150.34	0	0	**1200**
16	455	310	130	130	25	0	0	0	0	0	21513.66	0	0	**1050**
17	455	260	130	130	25	0	0	0	0	0	20641.82	0	0	**1000**
18	455	360	130	130	25	0	0	0	0	0	22387.04	0	0	**1100**
19	455	455	130	130	30	0	0	0	0	0	24150.34	0	0	**1200**
20	455	455	130	130	162	33	25	10	0	0	30057.55	920	920	**1400**
21	455	455	130	130	85	20	25	0	0	0	27251.06	0	0	**1300**
22	455	455	0	0	145	20	25	0	0	0	22735.52	0	0	**1100**
23	455	425	0	0	0	20	0	0	0	0	17645.36	0	0	**900**
24	455	345	0	0	0	0	0	0	0	0	15427.42	0	0	**800**
Sum of Costs											559847.69	5980	4520	
Total Costs Sum						With Initial State					**565827.69**			
						Without Initial State					**564367.69**			

Table II: comparision of costs for 20, 40, 60, 80, 100-units

Method	Operating cost($)	Execution Time (s)	Method	Operating cost($)	Execution Time (s)
20-units			**80-units**		
LR [8]	1130660	-	LR [8]	4526022	-
PSO-LR[26]	1128072	91	PSO-LR[26]	4496717	543
GA [8]	1126243	1000	GA [8]	4504933	4000
BCGA[27]	1130291	15.9	BCGA[27]	4511438	257
ICGA[27]	1127244	22.4	ICGA[27]	4498943	176
BF[25]	1128112	210	BF[25]	4508762	2600
HS (Proposed)	**1127377**	**92**	**HS (Proposed)**	**4500745**	**2157**
40-units			**100-units**		
LR [8]	2258503	-	LR [8]	5657277	-
PSO-LR[26]	2251116	213	PSO-LR[26]	5623607	730
GA [8]	2251911	2000	GA [8]	5627437	5000
BCGA[27]	2256590	63.1	BCGA[27]	5637930	397
ICGA[27]	2254123	58.3	ICGA[27]	5630838	242.5
BF[25]	2255112	510	BF[25]	5632491	4700
HS (Proposed)	**2250968**	**467**	**HS (Proposed)**	**5622350**	**3710**
60-units					
LR [8]	3394066	-			
PSO-LR[26]	3376407	360			
GA [8]	3376625	3000			
BCGA[27]	3382913	137			
ICGA[27]	3378108	117.3			
BF[25]	3379120	1100			
HS (Proposed)	**3375138**	**1021**			

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