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Solving Optimal Unit Commitment Problem Based on Wind Power Effects Using Harmony Search Algorithm

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ABSTRACT

In this paper, Multi Objective Harmony Search Algorithm (MOHSA) is used to solve the Unit Commitment (UC) problem between thermal generating units with wind impact an electricity market to minimize total cost to achieve a real system considered with various generator and wind constraints in power systems. Today the wind power is utilized as energy in power systems to play an important role in remedying the many shortcomings in today's modern energy electricity market. Actually, wind power becomes a far bigger issue when its total contribution in the renewable power system increases. The effectiveness of the proposed technique is applied to 10 thermal and wind units with various conditions. The achieved numerical results demonstrate the superiority of the proposed technique in comparison with SPSO, GA and λ-iteration to understand the wind generator capacity in production cost analysis and to provide valuable information for both operational and planning problems.

KEYWORDS: Wind Energy, Unit Commitment Problem, MOHSA, Electricity Market.

1. Nomenclature
F_T: *Total operation cost over the scheduling horizon.*
i: Index for thermal units.
j: Index for wind units.
N_T: *Number of thermal units in the system.*
N_W: *Number of wind units in the system.*
$P_i(t)$: *Generation of thermal unit i at hour t.*
$P_{i,r}^{max}$: *Upper generation limit of thermal unit i.*
$P_{i(t)}^{max}$: *Maximum generation of thermal unit i at hour t.*
$P_{i,r}^{min}$: *Lower generation limit of thermal unit i.*
$P_{i(t)}^{min}$: *Minimum generation of thermal unit i at hour t.*
$P_L(t)$: *System load demand at hour t.*
ASR_1: *Additional up reserve requirement considering wind power generation.*
ASR_2: *Additional down reserve requirement considering wind power generation.*
Cn: Number of states saved at each hour in the HDP algorithm.
d%: Percentage of maximum unit capacity.
DR_i^{max}: *Maximum ramp-down rate for thermal unit i.*
DS_i^{max}: *Maximum down reserve contribution of thermal unit i.*
$DS_i(t)$: *Down reserve contribution of thermal unit i at hour t.*
P_{Wj}^{max}: *Upper generation limit of wind unit j.*
$P_{Wj}(t)$: *Actual generation of wind unit j at hour t.*
$P^*_{Wj}(t)$: *Available generation of wind unit j at hour t.*
$P_{WT}(t)$: *Total actual wind generation at hour t.*
$P^*_{WT}(t)$: *Total available wind generation at hour t.*
r%: Coefficient of additional up (or down) reserve requirement (linear model).
SR_i: *Startup ramp rate limit of thermal unit i.*
T: Number of time intervals (hours).
TDR(t): System ramping down capacity at hour t.
$t_{i(t)}^{OFF}$: *Time period that thermal unit i had been continuously down till period t.*
T_i^{OFF}: *Minimum down time of thermal unit i.*
T_i^{ON}: *Minimum up time of thermal unit i.*
$t^{ON},i(t)$: *Time period that thermal unit i had been continuously up till period t.*
TUR(t): System ramping up capacity at hour t.
$U_i(t)$: *Scheduled state of thermal unit i for hour t (1: unit i is up, 0: unit i is down).*
UR_i^{max}: *Maximum ramp-up rate for thermal unit i.*
$US_i(t)$: *Up reserve contribution of thermal unit i at hour t.*
US_i^{max}: *Maximum up reserve contribution of thermal unit i.*
USRB: System up spinning reserve requirement not considering wind power generation.

1. INTRODUCTION

Solving unit commitment problem is one of the problems in deciding which electricity generation units should be running in each period so as to satisfy a predictably varying demand for electricity. The proposed problem is

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interesting because in a typical electrical system there are a variety of units available for generating electricity, and each has its own characteristics.

In some of the power generation units, the value of power that can be generated depends upon the time of day, year, etc. The simple and basic example is generation based on the change of water level due to tide at a sea coast. Also the wind generated power where the amount of power available depends upon the amount of wind, a factor that may vary in a predictable way over the period of a day or year. The significant wind generated capacity exists in several states, such as California and Texas [1]. Actually, some hydro power units are placed on rivers, but without a significant storage reservoir. Hence, the power generation capacity is proportional to the current flow in the river. The mentioned unit is called run-of-river hydro. For these types of units, there is not a single capacity that applies to every period, however rather a capacity for each period.

In recent decades, the problem of low cost of energy generation and its environmental characteristics, using wind energy in electric power generation, has been seemed useful. The drastic changes in nature and climate can be avoided by replacing fossil energy sources with clean and fuel free energy generation [1]. The increasing concern for environment has asked for rapid developments in wind power generation technology. On the other hand because of variability and uncertainty of this energy, using it has made some challenges to power-system operators. In order to adjust the unforeseeable nature of the wind power, planned productions and uses in electricity market must be enhanced during the real operation of the power system [2, 3].

Actually, with the increased penetration of the wind energy, there will be huge fluctuation in the power generation. Hence, storage devices such as pumped storage are necessary. The pumped storage is used to level the mismatch between power generation and demand. They store the excess generation from wind farms and the excess generation by the base load generation plants during off-peak periods for later use [4]. This will enable efficient utilization of the base-load generation units and to smooth the peak loads. The pumped storage can also be used to provide reserve during off-peak period so that no other unit is committed just for providing the reserve [5].

In other hand, reduce of production of the air pollutant gases is under consideration as behavioral patterns in countries industries are considered. So the level of produced gases by plants must be minimized in operation planning of them. Also, Unit Commitment (UC) and Energy Dispatch (ED) operations are of great importance because of their strong economic impact and increasing emissions concerns. Commitment of the wind plants in power generation increases the importance of considering the generating pollution of thermal units [5]. Because on one hand these wits are not producers of the air pollutant gases, but on the other hand the generating pollution curve of the thermal units is in a way that by high decrease in their generating power level, their generated pollution level increases. By raising the penetration of wind power generation and providing the load by it, power level of the thermal units decreases [6].

In recent decades, several UC studies analyzing the impact of increasing adoption levels of wind power have been performed. Where, dynamic programming [6], branch-and-bound [7], Lagrangian Relaxation (LR) approach [9], Genetic Algorithm (GA) [10], and Evolutionary Programming (EP) [11], could be used to solve the extended unit commitment problem. In [11], a security-constrained stochastic UC formulation that accounts for wind power volatility is presented together with an efficient Benders decomposition solution technique. But, the issue of constructing probability distributions for the wind power is not addressed. In [9], a detailed closed-loop stochastic UC formulation is reported. The authors' analysis the effect of the frequency of recommitment on the production, startup, and shutdown costs. They find that increasing the recommitment frequency can reduce costs and increase the reliability of the system. However, the authors do not present details on the wind power forecast model and uncertainty information used to support their conclusions. In [7, 9], Artificial Neural Network (ANN) models are used to compute forecasts and confidence intervals for the total aggregated power for a set of distributed wind generators. Such approaches can thus result in inaccurate medium and long-term forecasts and over- or under-estimated uncertainty levels [6, 8], which in turn affect the expected cost and robustness of the UC solution.

This paper presents, a HSA method incorporated with a simplified dispatch method is developed to solve the problem of combining unit commitment of the generating units while minimizing the cost. Actually, the fundamental idea of the proposed technique is based on HSA. Application results of the proposed algorithm to several test systems are presented to illustrate its effectiveness. The results are demonstrated that the proposed technique is superior to the other compared methods.

2. Constrains of Generators

Energy derived from our indigenous renewable sources improves the security of our supply and provides a hedge against volatile imported energy prices. This profits all society through a reduced dependence on fossil fuels and achievement of a cleaner, more appropriate environment where employment and national competitiveness can be strengthened, and our low carbon energy makes us a marvelous place to do business [12]. One of the most important functions of modern energy management system is solving the wind–thermal scheduling problem, which determines the optimal real power settings of generating units for a specific period of operation and in return satisfying the system load demand with minimizing the total fuel cost subjected to the operating constraints of a power system [12].

Accordingly, the wind power energy by the public utility is considered in this paper where minimize the generation cost rate and meet the load demand of a power system over some period based on objective function. The needed constrained for UC in this paper are in literature as:

$$F_T = \sum_{t=1}^{T} \sum_{i=1}^{NT} F_i\,(P_i\,(t)) \tag{1}$$

1) Constrains of optimization problem are:

a) Power balance: This constraint is based on the principle of balance among total system generation and total system loads (PD) and losses (PL),

$$\sum_{i=1}^{NT} U_i\,(t) \times P_i\,(t) + P_{wt}\,(t) = P_L\,(t) \tag{2}$$

b) The requirements of system up/down spinning reserve:

$$\sum_{i=1}^{NT} U_i\,(t) \times US_i\,(t) \geq USR_B + ASR_1(P_{WT}\,(t)) \tag{3}$$

$$\sum_{i=1}^{NT} U_i\,(t) \times DS_i\,(t) \geq ASR_2(P_{WT}\,(t)) \tag{4}$$

c) The constraints of minimum/maximum thermal plant output:

$$\mathrm{P_L(t) - P_{WT}(t) = ASR_2\ (P_{WT}(t))} + \sum_{i=1}^{NT} U_i\,(t) \times P_i^{\min}(t) \tag{5}$$

$$\sum_{i=1}^{NT} U_i\,(t) \times P_i^{\max}(t) + P_L\,(t) + USR_B + ASR_1(P_{WT}\,(t)) \tag{6}$$

2) The constraints of thermal generator:

a) Maximum up/down reserve contribution constraints of unit's:

$$US_i^{max}=d\%\times P_{i,r}^{max} \tag{7}$$

$$DS_i=d\%\times P_{i,r}^{max} \tag{8}$$

b) The up/down spinning reserve contribution constraints of unit's:

$$US_i(t)=min\{\ US_i^{max}\ ,\ P_{i,r}^{max}\_\ P_{i,r}(t)\} \tag{9}$$

$$DS_i(t)=min\{\ DS_i^{max}\ ,\ P_i(t)\_\ P_{i,r}^{min}\} \tag{10}$$

c) The constraints of unit's ramping up/down capacity:

$$UR_i(t)=min\{\ UR_i^{max}\ ,\ P_{i,r}^{max}\_\ P_i(t)\} \tag{11}$$

$$DR_i(t)=min\{\ DR_i^{max}\ ,\ P_i^{max}\_\ P_{i,r}^{min}\} \tag{12}$$

d) Unit generation limits:

$$P_i^{\min}(t) \times U_i\,(t) \leq P_i\,(t) \leq P_i^{\max}(t) \times U_i\,(t) \tag{13}$$

$$P_i^{\max}(t) = \begin{Bmatrix} \min\left\{P_{i,r}^{\max}, P_i\,(t-1) + UR_i^{\max}\right\} \\ \min\left\{P_{i,r}^{\max}, P_i\,(t-1) + SR_i\right\} \end{Bmatrix} \begin{matrix} if\ U_i\,(t) = U_i\,(t-1) = 1 \\ \\ if\ U_i\,(t) = 1, U_i\,(t-1) = 0 \end{matrix}$$

$$P_i^{\min}(t) = \begin{Bmatrix} \min\left\{UR_i^{\max}, P_i\,(t-1) - DR_i^{\max}\right\} \\ P_{i,r}^{\min}\ if \quad U_i\,(t) = 1, U_i\,(t-1) = 0 \end{Bmatrix}$$

$$if \quad U_i\,(t) = U_i\,(t-1) = 1 \tag{14}$$

e) Minimum up/down time constraints:

$$[t_{ON,i}(t\text{-}1)\text{-}T_{ON,i}]\times[U_i(t\text{-}1)U_i(t)]\geq 0 \tag{15}$$

$$[t_{OFF,i}(t\text{-}1)\text{-}T_{OFF,i}]\times[U_i(t\text{-}1)U_i(t)]\geq 0 \tag{16}$$

3) The constrains of wind generator:

a) Wind generation fluctuation constraints:

$$P_{WT}(t)\text{-}P_{WT}(t\text{-}1)\leq TDR(t), if\ P_{WT}(t\text{-}1)\leq P_{WT}(t) \tag{17}$$

$$P_{WT}(t\text{-}1)\text{-}P_{WT}(t)\leq TDR(t), if\ P_{WT}(t\text{-}1)\leq P_{WT}(t) \quad (18)$$

b) Wind power curve constraints:

$$P^{*}_{wi}(t)=\begin{cases} 0 & V(t)\leq V_{Ij}\ or\ V(t)>V_{Oj} \\ \varphi_j(v(t)) & V_{Ij}\leq V(t)\leq V_{Rj} \\ P^{max}_{wj} & V_{Rj}\leq V(t)\leq V_{Oj} \end{cases} \quad (19)$$

c) Total available wind generation:

$$P^{*}_{wi}(t)=\sum_{j=1}^{NW} P^{*}_{wi}(t) \quad (20)$$

d) The limit of total actual wind generation:

$$0\leq P_{WT}(t)\leq P_{WT}^{*} \quad (21)$$

3. Harmony Search Algorithm (HSA)

The brief procedure steps of harmony search for solving optimization problems are described in five steps as shown in following flow chart:

HS procedure can be described as Fig. 1.

Step 1: Identify objective function and Equality & Inequality constraints.

$$\begin{aligned} &Minmize : \{f(x), x\in X\} \\ &s\,t \\ &g(x)\geq 0 \\ &h(x)=0 \end{aligned} \quad (22)$$

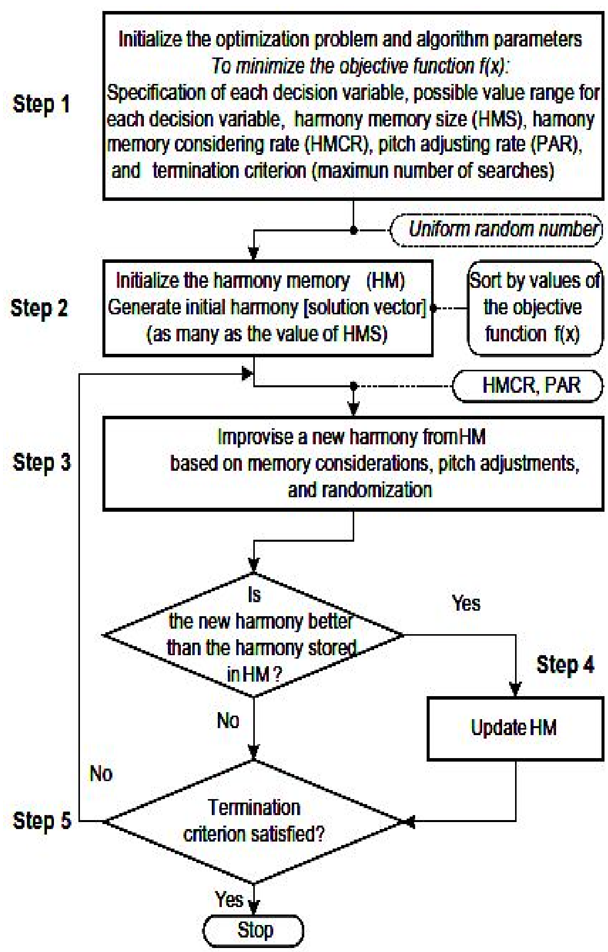

Figure. 1. Flowchart of HSA

Where f (x) is the objective function. Xi is the feasible set. xi is the random choosing parameter. G(x) is the inequality constraint. h (x) is the equality constraint [17-18].

Step 2: Initialize harmony memory (HM) in this step chooses the initial value of xi from Xi parameters and fill them in HM matrix randomly.

$$HM = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_{N-1}^1 & x_N^1 \\ x_1^1 & x_2^2 & \cdots & x_{N-1}^2 & x_N^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_1^{HMS-1} & x_2^{HMS-1} & \cdots & x_{N-1}^{HMS-1} & x_N^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & \cdots & x_{N-1}^{HMS} & x_N^{HMS} \end{bmatrix} \frac{\Delta y}{\Delta x} \tag{23}$$

Step 3: Improvise New Harmony Improvise new xi from harmony memory considers rated (HMCR) and pith adjust rated (PAR).

Step 3.1:.1 Harmony consider rated (HMCR)

$$x_i^{'} \leftarrow \begin{Bmatrix} x_i^{'} \in \left\{ x_i^1, x_i^2, ..., x_i^{HMS} \right\} (HMCR) \\ x_i^{'} \in X_i \, (1 - HMCR) \end{Bmatrix} \tag{24}$$

Where x_i' is new value of xi HMCR is probability of choosing x_i' w.p. means with probability

Step 3.2: pitch adjust rate (PAR)

$$x_i^{'} \leftarrow \begin{Bmatrix} Yes, \Pr(PAR) \\ No, \Pr(1 - PAR) \end{Bmatrix} \tag{25}$$

Where PAR is probability to shift xí

$$x_i^{'} \leftarrow x_i^{'} \pm rand\,() \times bw \tag{26}$$

Where b*w* is range of Xi rand is random number during 0-1. In this step, random choose the value of x_i'. If the value of x_i' is in the range of Xi it has probability HMCR. If out of condition probability of x_i' is 1−HMCR and then will check PAR if PAR of x 'i is carry on the condition eq. (10), shift x_i' by eq [19-20].

Step 4: Update HM and check the stopping criterion Find value of f (x_i') from substitute x_i' in eq. (9) if value of f (x_i') is better than the worst value of f (x) in HM, substitute x_i' instead the worst xi in HM.

Step 5: To check the stopping criterion, set the NI (Number of iteration) before begins to run the simulation; HS can stop calculation instantaneously when NI is reached. The aim of this paper is to apply multi objective harmony search for AGC problem. Results show that harmony search can solve this problem intelligently and find a near optimal solution.

3.1. Benchmark

The proposed technique is tested over a standard benchmark for achieving the robustness of that. For this purpose the rastrigin function is used in this step, which is presented in literature as:

$$\begin{aligned} & f\ (x) = 20 + \sum_{i=1}^{n} (x_i^2 - 10.\cos(2.\pi.x_i)) \\ & -3 \le x_1 \le 12.1 \\ & 4.1 \le x(2) \le 12.8 \end{aligned} \tag{27}$$

The output of the software for objective function's shape is presented in Figure 2. This algorithm is run several times to find the best answer for objective function. Table 1 presents the average results over many runs. And Figure 3 shows the convergence curve of this technique.

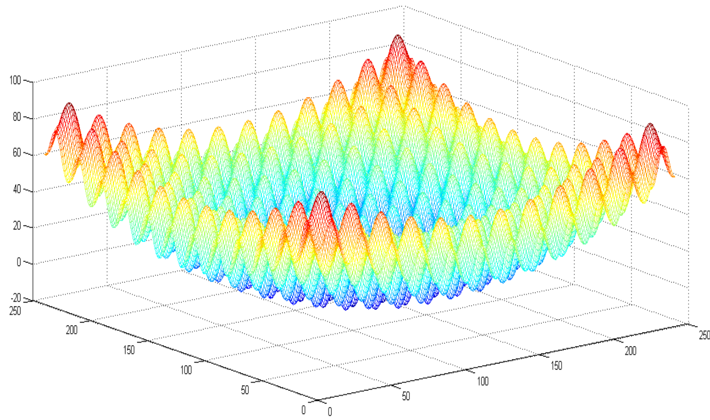

Figure 2. The shape of rastrigin function for testing the algorithm

TABLE 1. THE AVERAGE RESULTS OVER MANY RUNS OF HSA

Run	Max	Ave	Min	X(1)	X(2)
1	22.2624	20.021	19.5142	0.9930	4.1024
2	22.2813	20.020	19.5140	0.9931	4.1022
3	22.2824	20.021	19.5142	0.9930	4.1024
4	22.2878	20.019	19.5143	0.9930	4.1024
5	22.2809	20.015	19.5141	0.9931	4.1024
6	22.2799	20.018	19.5140	0.9931	4.1024
7	22.2834	20.015	19.5142	0.9930	4.1022
8	22.2865	20.013	19.5143	0.9931	4.1024
9	22.2853	20.004	19.5142	0.9931	4.1025
10	22.2832	20.016	19.5141	0.9931	4.1024
SD*e-4	0.4538	0.2336	0.0001	0.00002	0.00008

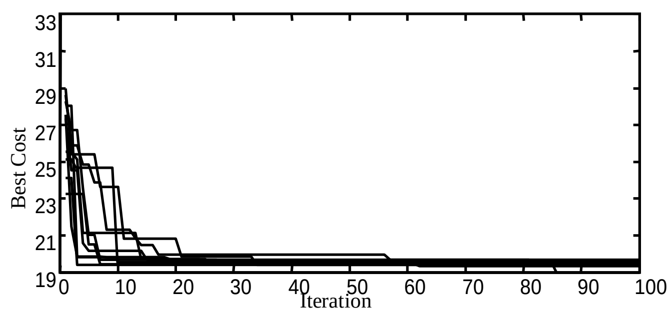

Figure 3. The convergence trend of HSA for several run

4. RESULTS AND DISCUSSION

In order to illustrate the efficiency of the proposed HSA algorithm for the solution of the proposed problems, three power systems, including several test systems. All the computations are calculated by MATLAB 2009a software.

4.1. Case I: 10- Thermal Unit System without wind power

In this test case contains 10 generating units without wind power effect. The require system unit data and the generation requirements for each stage given in [12]. Also, the determined schedule using Genetic Algorithm (GA), Standard Particle Swarm Optimization (SPSO), HSA technique is given in Table 2. The optimal results using the proposed methods in comparison than the other heuristic methods are shown in Table 3 that satisfies the generator constraints. It can be apparent from this Table that the proposed HSA technique provided superior solutions compared with other reported evolutionary algorithm methods. Figure 4 shows the minimum fitness functions evaluating process.

TABLE 2. THE DETERMINED COMMITMENT SCHEDULE

Units	Hour (1→24)
	HSA
1	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
3	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
4	1 1 1 1 1 1 1 1 0 0 0 1 1 1 0 0 0 0 0 0 1 1 1 1
5	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 1 1 1 1 1 1
6	1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1
7	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
8	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
9	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
10	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
	SPSO [23]
1	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
3	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
4	1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1
5	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
6	1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
7	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
8	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
9	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
10	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
	GA [23]
1	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
3	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
4	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1
5	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
6	1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
7	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
8	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
9	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
10	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

TABLE 3. THE COMPUTING TIME AND THE TOTAL COST FOR TEST I

Method	Time (sec)	Min Cost ($)
λ – iteration [23]	10.93	78907
FDP [23]	NA	78895.5
GA [23]	13.92	78896.14
SPSO [23]	8.827	78804.65
HSA	8.161	78714.12

It is clear that the computing time of the proposed technique is 8.161 second with the minimum cost of 78714.12 $. Where this technique could achieve good results in comparison other compared technique.

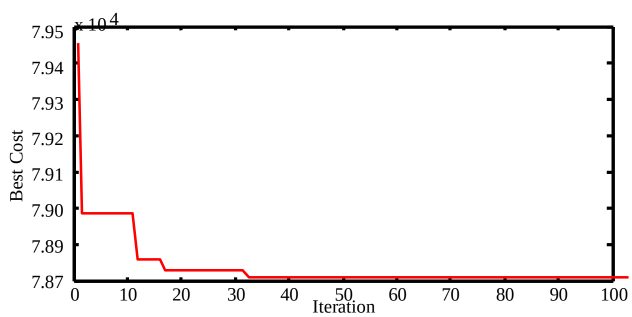

Figure 4. Fitness convergence of proposed HSA technique

4.2. Case II: Test for a Ten-Unit Thermal System with an Equivalent Wind Generator

In this test, the performance of the proposed HSA based UC under practical conditions is verified by applying an equivalent wind generator. For achieved better discussion and analyze of the numerical results considered system with small capacitor. The accessible wind power generation considered 400 MW for all hours. Actually, the adjustments of the power output are instantaneous that it is considered in the studied cases. Accordingly, generators are constrained because of ramp rate limits where, generation may increase or decrease with corresponding upper and downward ramp rate limits. The generator ramp rate and startup ramp rate constraints are set at 60% of its rated capacity. Also, the system up spinning reserve requirement is assumed to be 300 MW for all time periods. The thermal power units is more than 20% of its rated capacity (*d*% = 20%). The best cost solution for different methods with constraint satisfaction is shown in Tables 4.

TABLE 4. THE COMPUTING TIME AND THE TOTAL COST FOR TEST I

Method	Time (sec)	Min Cost ($)
FDP[12]	84.81	58233
HDP[12]	30.87	58233
HDP*[12]	10.71	58233
GA [23]	47.82	58232.87
SPSO [23]	9.716	58232.19
HSA	9.101	58229.96

In this case similar the previous one, it can be considered that the proposed technique is better than other techniques. Where, the convergence time of this technique is 9.101 and its minimum cost is 58229.96 $. These values are better than the compared technique in [12] where the proposed technique is run in ten trials. Also, the results of SPSO and GA are compared with the proposed HSA in this paper. The values of the SPSO and GA are presented in [23]. Also regarding to the results of Table 5 which presents the results of 10 trials, the proposed technique has good Standard Deviation and time and minimum iteration than the other techniques of [23].

Table 5. DIFFERENT METHODS RESULTS FOR 10 TRIALS

Run	**GA [23]**				
	Min	Max	Mean	Time	Iter
1	58232.87	58235.43	58233.86	47.82	97
2	58233.54	58237.67	58233.64	47.85	95
3	58232.99	58235.49	58234.82	47.84	98
4	58233.23	58236.74	58233.89	47.83	89
5	58232.83	58235.92	58234.77	47.85	76
6	58233.07	58238.45	58233.87	47.82	96
7	58232.56	58235.44	58233.10	47.83	90
8	58232.76	58238.23	58235.34	47.82	93
9	58233.25	58236.78	58234.55	47.84	87
10	58232.80	58235.48	58233.76	47.84	88
SD	0.2735	1.1369	0.6445	0.0111	6.2
Run	SPSO [23]				
	Min	Max	Mean	Time	Iter
1	58232.19	58235.32	58233.45	9.716	57
2	58232.34	58235.39	58233.56	9.717	64
3	58232.24	58235.38	58233.78	9.716	54
4	58232.31	58234.67	58233.89	9.718	60
5	58232.27	58235.39	58233.90	9.715	53
6	58232.33	58234.38	58233.12	9.716	49
7	58232.30	58235.56	58233.03	9.716	65
8	58232.42	58235.78	58233.65	9.717	63
9	58232.26	58235.29	58233.33	9.716	58
10	58232.37	58235.56	58233.75	9.717	84
SD	0.0633	0.4030	0.2923	0.0008	9.1
Run	HSA				
	Min	Max	Mean	Time	Iter
1	58231.73	58234.75	58232.14	9.128	25
2	58231.73	58234.75	58232.14	9.128	25
3	58231.78	58234.76	58232.14	9.128	28
4	58231.78	58234.64	58232.16	9.129	31
5	58231.82	58234.37	58232.17	9.130	29
6	58231.83	58234.29	58232.23	9.133	25
7	58231.88	58234.57	58232.20	9.133	27
8	58231.88	58234.40	58232.20	9.133	25
9	58231.90	58234.95	58232.18	9.135	28
10	58231.91	58234.78	58232.21	9.135	25
SD	0.0112	0.2262	0.0345	0.0008	2.08

Also to calculate the efficacy and robustness of the HSA several operation conditions and system configurations, simultaneously are considered. The achieved results are presented in Table 6 which is compared with [23].

Table 6. COMPARISON OF RESULTS FOR FIVE DIFFERENT CASES IN CASE 2

Scenario	I	II	III	IV	V
$P^*_{WT}(t)$ MW	0	400	400	400	400
USR_B MW	300	300	300	300	300
ASR_1	---	LM	LM	LM	SM
ASR_2	---	---	---	LM	LM
WGC [23]	---	without	with	with	with
HDP* [23]	78911	58134	57955	58233	58790
GA [23]	78913	58133	57955	58233	58791
SPSO [23]	78910	58133	57954	58233	58790
HSA	78907	58131	57951	58230	58786

WGC: Wind Generation Curtailment.
LM (Linear Model): $\gamma\%=0.2$.
SM (Second-order Model): $\alpha\%=0.2$, $\beta\%=10^{-4}$.

The determined schedule using GA, SPSO techniques with HSA with contain the system down spinning reserve requirement or not are given in Table 8.

TABLE 8. THE DETERMINED COMMITMENT SCHEDULE

Units	Hour (1→24)
	HSA
1	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
3	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
4	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
5	1 1 1 1 1 1 1 1 0 0 0 1 1 1 0 0 0 0 0 0 0 0 0 0
6	1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1
7	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
8	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
9	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
10	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
	SPSO [23]
1	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
3	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
4	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
5	1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1
6	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
7	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
8	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
9	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
10	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
	GA [23]
1	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
3	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
4	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
5	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
6	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
7	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
8	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
9	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
10	1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

5. Conclusion

In this paper Harmony Search Algorithm (HSA) is proposed to find feasible solution in UC problem with considered wind power energy. The continuous increasing of the global energy demand is a reality. It is well-known that conventional sources of energy are running out rapidly and they cannot cover this tremendous demand. Nowadays the renewable energies have become efficient, reliable and competitive sources of energy, supplemental to conventional sources. They are one of the solutions that will help meeting, the increasing global energy demand, and reducing the greenhouse gases emissions. The problem of find best answer is formulated as an optimization problem according to the time domain-based objective function for a wide range of operating conditions and is solved by the HSA technique which is simple, robust and capable to solve difficult combinatorial optimization problems. The results obtained for three test systems were always comparable or better that the earlier best reported results. From these comparative studies, it is evident that the HSA can be effectively used for the solution of UC problems in the real world power systems.

REFERENCES

[1] C. D. Yue, C.M. Liu, and M. L. L. Eric, “A transition toward a sustainable energy future: Feasibility assessment and development strategies of wind power in Taiwan,” Energy Pol., vol. 29, pp. 951–963, 2001.

[2] T. J. Chang,Y.T.Wu,H.Y.Hsu, C. R. Chu, and C.M. Liao, “Assessment of wind characteristics and wind turbine characteristics in Taiwan,” Renew. Energy, vol. 28, pp. 851–871, 2003.

[3] A. G. Bakirtzis and P. S. Dokopoulos, “Short term generation scheduling in a small autonomous system with unconventional energy sources,” IEEE Trans. Power Syst., vol. 3, no. 3, pp. 1230–1236, Aug. 1988.

[4] C. Brunetto and G. Tina, “Optimal hydrogen storage sizing for wind power plants in day ahead electricity market,” Renewable Power Generation, vol. 1, no. 4, pp. 220–226, Dec. 2007.

[5] S. Chakraborty, M. Weiss, and M. G. Simoes, “Distributed intelligent energy management system for a single-phase high-frequency AC microgrid,” IEEE Trans. Ind. Electron., vol. 54, no. 1, pp. 97–109, Feb. 2007.

[6] J. Juban, L. Fugon, and G. Kariniotakis, “Uncertainty estimation of wind power forecasts”, in Proceedings of the European Wind Energy Conference EWEC08, Brussels, Belgium, 2008.

[7] K. Methaprayoon, W. J. Lee, C. Yingvivatanapong, and J. Liao, “An integration of ANN wind power estimation into uc considering the forecasting uncertainty”, IEEE Trans. Ind. Appl., vol. 43, pp. 116–124, 2007.

[8] T. Palmer, G. Shutts, R. Hagedorn, F. Doblas-Reyes, T. Jung, and M. Leutbecher, “Representing model uncertainty in weather and climate prediction”, Annual Review of Earth and Planetary Sciences, vol. 33, pp. 163–193, 2005.

[9] V. S. Pappala, I. Erlich, K. Rohrig, and J. Dobschinski, “A stochastic model for the optimal operation of a wind-thermal power system”, IEEE Transactions on Power Systems, vol. 24, pp. 940–950, 2009.

[10] A. Tuohy, P. Meibom, E. Denny, and M. O’Malley, “Unit commitment for systems with significant wind penetration”, IEEE Transactions on Power Systems, vol. 24, pp. 592–601, 2009.

[11] J. Wang, M. Shahidehpour, and Z. Li, “Security-constrained unit commitment with volatile wind power generation”, IEEE Transactions on Power Systems, vol. 23, pp. 1319–1327, 2008.

[12] C.L. Chen. “Optimal Wind–Thermal Generating Unit Commitment”, IEEE Transactions on energy conversion, vol. 23, no. 1, pp. 273-280, march 2008.

[13] M. Sailaja Kumari, M. Sydulu, “A Fast Computational Genetic Algorithm for Economic Load Dispatch”, International Journal of Recent Trends in Engineering vol. 1, no. 1, pp. 349-356, May 2009.

[14] A. Konak, D. W. Coit, and A. E. Smith, “Multi-objective optimization using genetic algorithms: A tutorial”, Reliability Engineering and System Safety, vol. 91, pp. 992–1007, 2006.

[15] Z. W. Geem, J. H. Kim, GV. Loganathan, “A new heuristic optimization algorithm: harmony search”. Simulation, vol. 76, no. 2, pp. 60–68, 2001.

[16] MP. Saka, “Optimum design of steel sway frames to BS5950 using harmony search algorithm”, J Constr Steel Res, in press. doi:10.1016/j.jcsr. 2008.

[17] A. Vasebi, M. Fesanghary, SMT. Bathaee, “Combined heat and power economic dispatch by harmony search algorithm”, Electrical Power Energy Syst Vol. 29, no. 10, pp. 713–719, 2007.

[18] ZW. Geem, C. Tseng, Y. Park, “Harmony search for generalized orienteering problem”, best touring in China. Springer Lect Notes Comput Sci, pp. 741–7150, 2005.

[19] JH. Kim, ZW. Geem, ES. Kim, “Parameter estimation of the nonlinear Muskingum model using harmony search”. J Am Water Resour Assoc, vol. 37, no. 5, pp. 1131–1138, 2001.

[20] ZW. Geem, JH. Kim, GV. Loganathan, “Harmony search optimization: application to pipe network design, Int J Model Simulat., vol. 22, no. 2, pp. 125–133, 2002.

[21] H. Shayeghi, A. Ghasemi” Solving Economic Load Dispatch Problems with Valve Point Effects Using Artificial Bee Colony Algorithm” International Review of Electrical Engineering (I.R.E.E.), vol. 6, no. 5, pp. 2569- 2577, September-October 2011.

[22] H. Shayeghi, A. Ghasemi, “Market based LFC design using artificial bee colony”, International Journal on “Technical and Physical Problems of Engineering” (IJTPE), vol. 1, no. 1, pp. 1-10, Mar. 2011.

[23] H. Shayeghi, H. Gholamalitabar, A. Ghasemi, O. Abedinia, R. Bazyar, Optimal Thermal Generating Unit Commitment With Wind Power Impact: A PSO-IIW Procedure, “Technical and Physical Problems of Engineering” (IJTPE), Issue. 11, Vol. 4, No. 2, pp: 90-97, Jun 2012.