International Journal of Technical Research and Applications e-ISSN: 2320-8163,
www.ijtra.com Volume 4, Issue 1 (January-February, 2016), PP. 107-113

SOLVING CONSTRAINED UNIT COMMITMENT PROBLEM CONSIDERING VALVE POINT EFFECT

K.M. Abo-Al-Ez, M. M. El-Saadawi [1], A. Fathy[2]
[1]Dept. of Electrical Engineering, Faculty of Engineering
[1]University of Mansoura, 35516, Egypt
[2]Talkha Power Station,
[2]Middle Delta Electricity Production Company,
Talkha, Egypt
[1]ezzkhalid@mans.edu.eg, m_saadawi@ mans.edu.eg
[2]mba_fa2012@yahoo.com

Abstract— **Optimization of the power system plays a major role in power system planning. Unit Commitment and Economic Dispatching are the most important part of every plant-planning project. Unit Commitment is the problem that searches the economical way for power generation, when the power consumption and altered constraints of the power plants are considered. Recently, the attention of the environmental pollution problem is increasing around the world. The Emission Constrained Unit commitment (ECUC) problem is a very important issue to minimize the production of electrical power side by side with reducing the emissions of power plants while meeting different system constraints. This paper formulates a multi objective Unit Commitment problem with valve point effect considered in both fuel cost and emission function using the Particle Swarm Optimization (PSO) technique. A new approach is proposed to simplify valve point loading effect. The proposed algorithm is applied to a 10 generating units test system in one-day scheduling period at different types of price penalty factor (PPF). The power balance, generation limit, and UC constraints (such as minimum up/down time, spinning reserve, and initial state for each unit) are included in the problems formulation. The simulation is implemented in Matlab environment. The results show that there is an increase in the total operational cost when taking valve point loading effect into account.**

Index terms- **Unit Commitment, Emission Minimization, Price Penalty Factor, Particle Swarm optimization (PSO).**

I. INTRODUCTION

The solution of the problem of Economic Dispatch (ED) indicates that for a certain load demand, all generation units are required to operate together to satisfy the demand under the required constraints. Therefore, the economical and reliable scheduling is intended to reduce the working hours of participation of generating units during long periods of operation (24 hours or more). This means that there are operating units (committed) and other non operating units (uncommitted) for each hour. This is achieved by Unit Commitment (UC), which is a short term operation planning method for generation units to minimize the total production cost (fuel cost, startup cost, and shut down cost) using ON/OFF schedule over a given time horizon for generating units, while satisfying hourly load and system constraints [1]. For many years the environmental impacts were ignored in solving the conventional UC problem [2-4]. However, the current standards for smart and green electrical grids require the reduction of harmful emissions such as nitrogen oxides (NOx), sulphur dioxide (SO2), and carbon dioxide (CO2). The cost of reducing emissions must be added to the main fuel cost of the power generating units. Recent UC problem solutions have considered the environmental impacts without considering steam valve loading of the units such as in [5-6].

The steam generators usually have a number of steam admission valves that are opened or closed sequentially during operation of the thermal power station to control the steam flow, in order to respond to changing system load demands. However, the change in the amount of steam flow to the turbine will not change turbine speed; it will produce more/less power depending on the rate of flow change. A valve point loading effect is the loading output levels at which a new steam admission valve is opened. As a result of the sharp increases in throttle losses due to throttling of the steam that passes through the admission valve, a discontinuously in both the cost curves and the incremental rate curves occurs. This makes the fuel cost curve of such a thermal generator to be high nonlinearity and non–convexity. Accordingly there will be an increase in the number of local minima for solving the Emission Constrained Unit Commitment (ECUC) problem. As a result the ECUC problem become more complex, non-convex, and multi-objective optimization one [7]. Therefore, the valve point loading effect must be considered for accurate calculations.

II. LITERATURE SURVEY

With the increased complexity of the UC problem in terms of environmental impacts and operational requirements, there is a great need for intelligent optimization techniques. The widely used optimization methods for solving UC problem are Dynamic Programming (DP), and Lagrange Relaxation (LR) methods [8-9]. Although, DP is characterized by the simplicity of adding constraints, it is mathematically complex and time consuming method. Because priority ordering is not imposed, the LR method is more flexible than DP. The disadvantages of LR are dual solution which may be infeasible, and the small duality gap [10]. With the advances in computer engineering, and the need for real time operation, and fast data computation and exchange, Artificial Intelligence (AI) optimization methods were replacing conventional optimization methods. Among that AI method there are Simulated Annealing (SA) [11], Genetic Algorithm (GA) [12], Artificial Neural Networks (ANN) [13], and Particle Swarm Optimization (PSO) [14]. The SA is a power optimization technique, which can theoretically converge to a global optimum solution. But, it is consumes a large time to reach the near-global minimum [15]. Sometimes GA does not have a strong ability to the best production of the offspring and because slow convergence close to the global optimum it is may be trapped at a local optimum [16]. The ANN has a good solution quality and rapid convergence, and this method can take into account more complicated constraints [17]. However, the ANN optimization method it is not flexible in terms of moving between different tasks, in other word it is hard to extend for another task without retrain of the neural network .The most drawbacks that can be mentioned for the current AI techniques are local convergence and curse of dimensionality. This paper proposed PSO for solving the unit commitment problem due to its simplicity, less modification of the parameter, and short time solution compared to other methods [1].

III. PROBLEM FORMULATION

Unit commitment is a constrained optimization problem used to find the optimal schedule of committed/ uncommitted units and generated power for each generating unit over a study period of time in order to meet the load demand and spinning reserve at minimum total production cost (total fuel cost, start up cost shut down cost), while satisfying all unit, and system constraints. By adding the emission impact, the ECUC problem turns into a multi objective optimization one. Using a price penalty factor (h_i) the emission rate is converted to an emission cost, so that the unit commitment problem can be formulated as [18]:

$$Min\ (F_T) = FP_T + h_i \,.\, E_T \qquad (1)$$

Where, F_T is the total system cost in \$/hr, FP_T is the total production cost and E_T is the total emission, and h_i is the price penalty factor (PPF).

A. Total Production Cost Objective Function

The total production cost is the sum of the fuel cost, start up cost and shut down cost for all the units [19]. Each of these items will be explained in the following subsection.

1) Start up cost

The startup cost occurs when a unit is turned on; it depends on how long the unit has been off. If the unit has been off for a long time, a cold start up cost is applied. If the unit has been off for a short time, a hot start up cost

i) Step function [20]:

$$SUC = \begin{cases} \sigma_i & \text{if} \quad T_{i,t}^{off} \le MDT_i \\ \delta_i & \text{otherwise} \end{cases} \qquad (2)$$

ii) Exponential function [21]:

$$SUC = \sigma_i + \delta_i * \left[1 - e^{(T_{off}/\tau_i)}\right] \qquad (3)$$

where,

$SUC_{i,t}$: start up cost of the ith generating unit in (\$)

σ_i : Hot start up cost in (\$)

δ_i : Cold start up cost in (\$)

MDT_i : Minimum down time of the ith generating unit (hr)

τ_i : Unit cooling time constant in (hr)

In this paper the used form will be as given in (2).

2) Shut down cost

Shut down cost is usually a constant value for each unit. The typical value of the shut down cost is zero in the standard systems.

3) Fuel cost function

In case of neglecting the valve point effects; the fuel cost of a thermal power generation unit can be expressed as [2]:

$$f_{i,t} = a_i . P_{i,t}^2 + b_i * P_{i,t} + c_i$$

$$i = 1, 2, 3\ldots\ldots, N, \quad t = 1, 2, 3\ldots\ldots, T \qquad (4)$$

Where a_i, b_i, and c_i are the coefficients of the ith generating unit, and N is the total number of generating units committed to the system, in [\$/MW^{2}h], [\$/MWh] and [\$/h] respectively.

However, due to valve-point loading effect, the real fuel cost function appears to be higher-order in nonlinearity and discontinuity as explained by Figure 1. In this case the fuel cost of thermal units is expressed as the sum of quadratic and sinusoidal functions [22]:

$$f_i = a_i . P_i^2 + b_i * P_i + c_i + \left| d_i * \sin(e_i * (P_i^{min} - P_i)) \right| \qquad (5)$$

Where: d_i, and e_i are valve point effect coefficients.

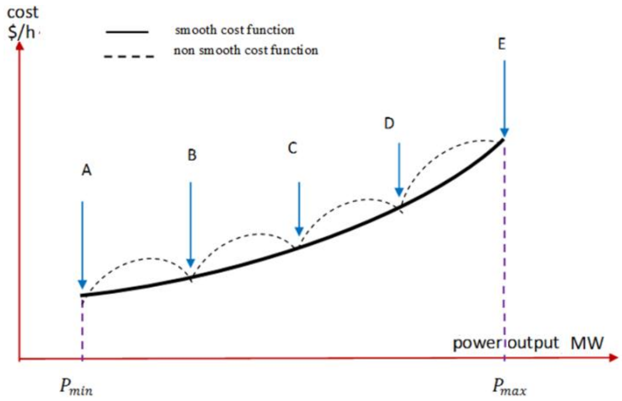


Figure 1: Fuel cost curve considering valve-point effect

B. Environmental Objective Function

The following mathematical formula can be used to express the amount of pollutants [5]:

$$E_i\ (P_i) = \alpha_i * P_i^2 + \beta_i * P_i + \gamma_i \qquad (6)$$

Where; α_i, β_i, and γ_i are the emission coefficients of the ith generator in [kg/MW^{2}h], [kg/MWh] and [kg/h] respectively.

The total emission of generation can be expressed by a quadratic function as follows:

$$E_T = \sum_{i=1}^{N} E_i(P_i), \; i = 1,2,3,\ldots\ldots\ldots,N \qquad (7)$$

The conventional unit commitment aims to minimize the total production cost of the generation power system (FP_t), for N generation system units over a time horizon T. In this case the total production cost is the sum of the fuel cost, start up cost and shut down cost for all the units. By using equations (2, 5, and 6), the UC problem turns into the following formula:

$$Min(F_T) = \sum_{t=1}^{T}\sum_{i=1}^{N} f_i \cdot U_{i,t} + SUC_{i,t}\cdot(1 - U_{i,t-1})\cdot U_{i,t} + SD.U_{i,t} + h_i \cdot E_T.U_{i,t} \qquad (8)$$

Where $U_{i,t}$ =1 if unit i is committed at time t, otherwise $U_{i,t} = 0$.

$$Min(F_T) = \sum_{t=1}^{T}\sum_{i=1}^{N} [a_i.P_i^2 + b_i * P_i + c_i + \left|d_i * \sin(e_i * (P_i^{min} - P_i)).\ U_{i,t} + SUC_{i,t}.(1 - U_{i,t-1}).U_{i,t} + SD.U_{i,t}\right| + h_i.(\alpha_i * P_i^2 + \beta_i * P_i + \gamma_i).U_{i,t} \qquad (9)$$

In this paper a new method is proposed to solve ECUC problem based on converting valve point effect part to a second order equation using curve fitting technique.

$$\left|d_i * \sin(e_i * (P_i^{min} - P_i))\right| = r_i * P_i^2 + s_i * P_i + u_i \qquad (10)$$

According to (10), the total production cost equation can be represented as:

$$F_T = \sum_{t=1}^{T}\sum_{i=1}^{N}\left[(A_i.P_i^2 + B_i * P_i + C_i).U_{i,t} + SUC_{i,t}.(1 - U_{i,t-1}).U_{i,t}\right] + h_i.(\alpha_i * P_i^2 + \beta_i * P_i + \gamma_i).U_{i,t} \qquad (11)$$

Where, $A_i = (a_i + r)$, $B_i = (b_i + s_i)$, $C_i = (c_i + u_i)$

C. System Constraints

The objective function of the studied problem is to minimize the total system cost FT (explained by (11)) subject to a number of system constraints. These constraints include power balance constraint, Spinning reserve constraint, generation limit constraint, minimum up/down time constraints, and initial unit status.

1) Power balance constraint

The total generation must supply the demand at each hour [23]:

$$\sum_{i=1}^{N} P_{i,t} * U_{i,t} = Pd_t \qquad t = 1,2\ldots T \qquad (12)$$

Where T is the scheduling period, equals to 24 hour (i.e. one day ahead)

2) Spinning reserve constraint

Spinning reserve is the on-line reserve capacity that is synchronized to the grid system and ready to meet electric demand during any sudden changes (trip) of dispatch. Spinning Reserve is needed to maintain system frequency stability during emergency operating conditions and unforeseen load swings. However, hourly spinning reserve requirements (R_t) must be satisfy the following equation:

$$\sum_{i=1}^{N} P_i^{max} * U_{i,t} \geq Pd_t + R_t \qquad (13)$$

3) Generation limit constraint

The generated power for each generating units must be within a certain range of operation between a minimum and a maximum value, this is mathematically represented as:

$$P_i^{min} \leq P_{i,t} \leq P_i^{max} \qquad (14)$$

4) Minimum up/down time constraints

Minimum up/down (MUT/MDT) time limits indicate that a unit must be on/off for a certain number of hours before it can be shut off or brought online. This is expressed in (15), (16) respectively [23]:

$$T_{i,t}^{on} \geq MUT_i \qquad if \; T_{i,t}^{on} \geq 0 \qquad (15)$$

$$T_{i,t}^{off} \geq MDT_i \qquad if \; T_{i,t}^{off} \geq 0 \qquad (16)$$

Where,

MUT_i : Minimum up time for i^th generating unit (hr)

MDT_i : Minimum down time for i^th generating unit (hr)

$T_{i,t}^{on}$: Number of consecutive uptime periods until time period t (hr)

$T_{i,t}^{off}$: Number of consecutive downtime periods until time period t(hr)

5) Initial unit status

The initial unit status at the start of the scheduling period must be taken into account, if the initial status equal to negative value, that is main $U_{i,0} = 0$, if the initial state equal to positive value then $U_{i,0} = 1$

IV. PROPOSED ALGORITHM

Many methods are used to combine between several objectives in the multi-objective optimization problem. The most common methods are the weight factor and price penalty factor methods. Weighted sum method is the simplest approach to solve multi-criteria optimization problem, but it is visible only when all the data have the same units, and it depends on the suitable choice of the weights. The price penalty factor approach gives a better value to the objective function and has a faster solution time for combined economic emission dispatch problem compared to the weighted sum approach. There are many formulas used for calculating the price penalty factors. Comparison between the impacts of the each one of price penalty factors in the dual-objective optimization problem solution is done during application of the PSO method to solve the ECUC problem.

A. Price Penalty Factor (PPF)

Price penalty factor (PPF) is the ratio of fuel cost to emission for each generating unit, and used to transfer the physical meaning of the emission from rate (kg/hr) of the emission to the emission cost ($/hr). PPF is calculated using one of the following equations:

$$max/\max PPF = \frac{f_i(p_i^{max})}{E_i(p_i^{max})} \qquad (17)$$

$$min/\min PPF = \frac{f_i(p_i^{min})}{E_i(p_i^{min})} \qquad (18)$$

$$min/\max PPF = \frac{f_i(p_i^{min})}{E_i(p_i^{max})} \qquad (19)$$

$$max/\min PPF = \frac{f_i\,(p_i^{max})}{E_i\,(p_i^{min})} \quad (20)$$

$$average\ PPF = \frac{(max/max\ PPF + min/min\ PPF + min/max\ PPF + max/min\ PPF)}{4} \quad (21)$$

$$common\ PPF = \sum_{i=1}^{N}(\ average\ PPF)\ /N \quad (22)$$

B. Particle Swarm Optimization Technique

In this paper the PSO technique is used for solving the ECUC problem with valve point effect. The problem is solved with different types of PPF over scheduling period (24 hour). The PSO algorithm mimics of social behavior to the movement of organisms such as a bird flock [24-26]. Like the other evolutionary techniques, PSO is a population based searching algorithm, it is able to find the optimal solution for non-linear optimization problems in a shortest time. The PSO algorithm consists of a group of particles (swarm or population) moving towards optimal solution in a given multi-dimensional search space, by using position, velocity for each particle. Each particle represents a feasible solution to an optimization problem, if P_{best} is the previous best position, and G_{best} is the best among all the other particles. The movement of each particle towards the optimal solution is based on P_{best}, position of other particles and G_{best} [27-28]. The search does not stop until obtaining a globally best solution or reach to a prescribed maximum number of iteration, assuming a population of N particles are moving in a space with D dimension, where X_i is the position of ith particle and V_i is its velocity. During the movement, the velocity of the particle is updated using the following equation [23]:

$$V_i\ (k+1) = \omega\, V_i\ (k) + c_1 * Rand(\,) * (P_{i\,best}(k) - X_i(k)) + c_2 * Rand(\,) * (G_{best}(k) - X_i\ (k)) \quad (23)$$

Where: k is the iteration number, c_1, c_2 are cognitive and social acceleration coefficients, Rand( ) is random number between (0,1), and ω is inertia weight and it can be calculated as:

$$\omega = \omega_{max} - \left(\frac{\omega_{max} - \omega_{min}}{k_{max}}\right) * k \quad (24)$$

Where: ω_{min} is the final inertia weight, ω_{max} is initial inertia weight.

The particle position is computed by the following equation [23]:

$$X_i\ (k+1) = X_i\ (k) + V_i\ (k) \quad (25)$$

C. PSO steps for Solving ECUC Problem

The procedure of applying the PSO technique to solve the emission constrained unit commitment problem can be summarized in the following steps:

a. Read all implementation data such as population size, initial and final inertia weight, acceleration constant, the maximum, minimum generation limits, emission coefficients, cost coefficients, valve point effect coefficients, startup cost coefficients.
b. Random initialize the swarm position (p_i) to each particle in multidimensional space of the problem using maximum and minimum operating limits of j^{th} unit in the power system.
c. Use (11) to calculate the fitness function by means of current location of each particle then find P_{best}. The different constraints are considered while meet the demand load.
d. Compare the values of fitness function for each individual particle with its P_{best} value. Set the current value as the P_{bes}, if the current value is better than the P_{bes} value, then the best value among all P_{best} values is set as G_{best}.
e. For each particle update the velocity using (23), and position using (25).
f. Repeat steps from (b to e) using the new position value for each particle. If the stopping criterion is achieved (a good enough value for the fitness function or maximum number of iterations achieved), then the position of each particle is denoted as the optimal solution.

V. SIMULATION AND RESULTS

The proposed algorithm has been tested on a system with 10 generating units. The unit data and load demand data for 24 hours are taken from [20] and are given in Appendix. The valve point effect coefficients are taken from [29]. The population size is chosen as 10 and the maximum number of iterations is taken as 1000. The dimension of problem=10; $c_1 = c_2 = 2$, $\omega_{max}= 0.9$, $\omega_{min}= 0.4$

The simulation is implemented in Matlab environment. The problem is solved for different types of PPF over 24 hour scheduling period. The simulation results are given in Tables 1-4.

Table 1 shows the total cost (fuel cost + start up cost + shut down cost), total emission, and solution time for PSO method at different PPF types.

TABLE 1. ECUC SIMULATION RESULTS USING PSO METHODS AT DIFFERENT PPF

PPF	Total cost $/hr	Total emission kg/hr	Solution time sec
max/max	$1.1943*10^6$	$2.5056*10^4$	**32.8752**
min/min	$2.0349*10^6$	**$2.0112*10^4$**	39.4137
min/max	$8.8248*10^5$	$2.5082*10^4$	33.9697
max/min	$3.8699*10^6$	$2.0701*10^4$	39.3064
average	$2.0284*10^6$	$2.0623*10^4$	38.7174
common	**$8.1507*10^5$**	$2.3245*10^4$	40.1842

The analysis of this table indicates that:

i. For 24 hour scheduling period, the minimum total costs are obtained at common PPF.
ii. The minimum total emission values are obtained at min/min PPF.
iii. Minimum solution time is obtained at ma/max PPF

Table 2 illustrates the effect of including valve point loading effect into ECUC problem. From this table; it is clear that when taking into account valve point loading effect there is a considerable increase in both total cost and emission. Therefore, the valve point loading effect must be taken into consideration for accurate calculations.

TABLE 2 EFFECT OF INCLUDING VPE EFFECT INTO ECUC PROBLEM

	Obj. Func.	**Min/Min PPF**		**Common PPF**	
		Without VPE	**With VPE**	**Without VPE**	**With VPE**
ECEU	F_T	$1.7377*10^6$	$2.0349*10^6$	$7.2526*10^5$	$8.1507*10^5$
	E_T	$2.0683*10^4$	$2.0112*10^4$	$2.3028*10^4$	$2.3245*10^4$

Table 3 and 4, show the generating power from the 10 unit test system during the scheduled 24 hour period with Min/Min PPF and Common PPF respectively. The tables explain that the PPF type affects the unit commitment of the units. For example unit 10 will be committed for 6 hours with Min/Min PPF, whereas the same unit will be committed for only one hour with Common PPF.

VI. CONCLUSION

This paper presents a proposed algorithm to solve the emission constrained unit commitment problem with valve Point Effect using PSO Algorithm. A new approach is proposed to simplify valve point loading effect. The proposed algorithm is applied to a 10 generating units test system in one-day scheduling period at different types of price penalty factor (PPF). The ten generator multi-objective unit commitment problem is solved separately with and without valve point effect for various price penalty factors.

The proposed algorithm has many advantages compared to other UC solution methods. The power balance, generation limit, and UC constraints (such as minimum up/down time, spinning reserve, and initial state for each unit) are included in the problems formulation. The simulation is implemented in Matlab environment. The results prove that when taking into account valve point loading effect there is a considerable increase in both total cost and emission. Therefore, the valve point loading effect must be taken into consideration for accurate calculations.

TABLE 3 POWER GENERATION OF THE TEST SYSTEM WITH MIN/MIN PPF

Hour	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10
1	150	150	108	130	162	0	0	0	0	0
2	178	150	130	130	162	0	0	0	0	0
3	150	168	130	130	162	0	0	55	55	0
4	188	150	130	130	162	80	0	55	55	0
5	150	153	130	130	162	80	85	55	55	0
6	363	150	130	130	162	80	85	0	0	0
7	413	150	130	130	162	80	85	55	55	55
8	214.77	233.23	130	130	162	80	85	0	0	0
9	455	258	130	130	162	80	85	0	0	0
10	303	455	130	130	162	80	85	55	0	0
11	298	455	130	130	162	80	85	0	55	55
12	357.88	390.16	130	130	162	80	85	55	55	55
13	303	455	130	130	162	80	85	55	0	0
14	455	258	130	130	162	80	85	0	0	0
15	150	433	130	130	162	0	85	0	55	55
16	368	150	130	130	162	0	0	55	55	0
17	373	150	130	130	162	0	0	55	0	0
18	455	168	130	130	162	0	0	55	0	0
19	150	353	130	130	162	80	85	0	55	55
20	303	455	130	130	162	80	85	55	0	0
21	455	258	130	130	162	80	85	0	0	0
22	455	320	130	0	0	0	85	55	0	55
23	455	315	130	0	0	0	0	0	0	0
24	455	345	0	0	0	0	0	0	0	0

TABLE 4 POWER GENERATION OF 10 UNIT 24 HOUR SYSTEM FOR PSO WITH COMMON PPF

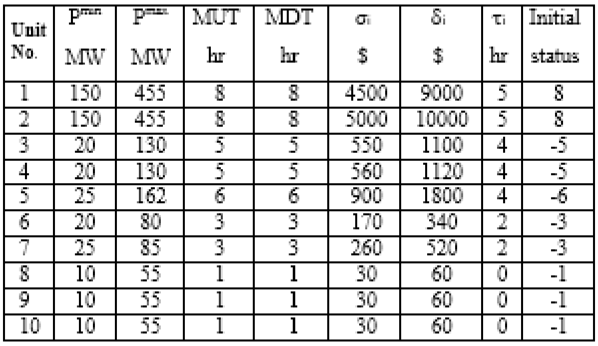
Hour	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10
1	150	233	0	130	162	0	25	0	0	0
2	150	283	0	130	162	0	25	0	0	0
3	383	150	0	130	162	0	25	0	0	0
4	455	203	0	130	162	0	0	0	0	0
5	455	253	0	130	162	0	0	0	55	0
6	168	455	130	130	162	0	0	0	0	0
7	188	455	130	130	162	0	0	0	0	0
8	238	455	130	130	162	0	85	0	0	0
9	258	455	130	130	162	80	85	55	0	0
10	455	303	130	130	162	80	85	55	55	0
11	455	298	130	130	162	80	85	55	55	55
12	394.56	353.44	130	130	162	80	85	0	55	0
13	455	303	130	130	162	80	85	55	0	0
14	283	455	130	130	162	0	85	0	0	0
15	455	323	130	130	162	0	0	0	0	0
16	455	173	130	130	162	0	0	55	0	0
17	373	150	130	130	162	0	0	0	0	0
18	150	448	130	130	162	80	0	0	0	0
19	158	455	130	130	162	80	85	55	0	0
20	455	303	130	130	162	80	85	0	55	0
21	283	455	130	130	162	0	85	0	0	0
22	455	223	130	130	162	0	0	0	0	0
23	315	455	130	0	0	0	0	0	0	0
24	345	455	0	0	0	0	0	0	0	0

APPENDIX

TABLE A.1: COST DATA FOR GENERATING UNITS

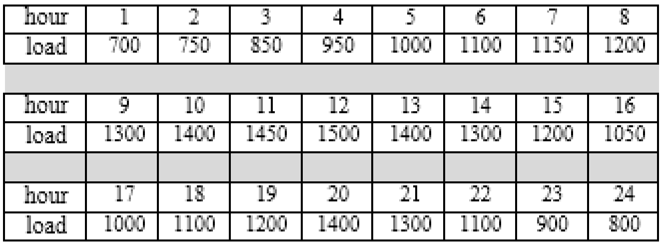
Unit No.	fuel cost coefficients			Valve point loading effect coefficients		Emission coefficients		
	A **\$/hr**	**b** **\$/MW.hr**	**c** **\$/MW².h**	**d** **\$/h**	**e** **rad/MW**	**α** **ton/MW2.h**	**B** **ton/MW.hr**	**γ** **ton/h**
1	1000	16.19	0.00048	450	0.041	10.33908	-0.24444	0.00312
2	970	17.26	0.00031	600	0.036	10.33908	-0.24444	0.00312
3	700	16.60	0.00200	320	0.028	30.03910	-0.40695	0.00509
4	680	16.5	0.00211	260	0.052	30.03910	-0.40695	0.00509
5	450	19.70	0.00398	280	0.063	32.00006	-0.38132	0.00344
6	370	22.26	0.00712	310	0.048	32.00006	-0.38132	0.00344
7	480	27.74	0.00079	300	0.086	33.00056	-0.39023	0.00465
8	660	25.92	0.00413	340	0.082	33.00056	-0.39023	0.00465
9	665	27.27	0.00220	270	0.098	33.00056	-0.39524	0.00465
10	670	27.79	0.00173	380	0.094	36.00012	-0.39864	0.00470

TABLE A.2 OPERATIONAL DATA FOR GENERATING UNITS



Unit No.	P^{min} MW	P^{max} MW	MUT hr	MDT hr	σ_i $	δ_i $	τ_i hr	Initial status
1	150	455	8	8	4500	9000	5	8
2	150	455	8	8	5000	10000	5	8
3	20	130	5	5	550	1100	4	-5
4	20	130	5	5	560	1120	4	-5
5	25	162	6	6	900	1800	4	-6
6	20	80	3	3	170	340	2	-3
7	25	85	3	3	260	520	2	-3
8	10	55	1	1	30	60	0	-1
9	10	55	1	1	30	60	0	-1
10	10	55	1	1	30	60	0	-1

TABLE A.3 LOAD DEMANDS DATA IN MW



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

REFERENCES

[1] T. Logenthiran,; D. Srinivasan, "Particle Swarm Optimization for unit commitment problem", IEEE 11th International Conference Probabilistic Methods Applied to Power Systems (PMAPS), 2010, pp. 642-647.

[2] W. Ongsakul, N. Petcharaks "Unit Commitment by Enhanced Adaptive Lagrangian Relaxation", IEEE Transactions on Power Systems, 2004, 19 (1), pp. 620-628.

[3] P.V. Krishna, G. P. Rao, S. Sao, "Particle Swarm Optimization Technique to Solve Unit Commitment Problem", International Journal of Advanced Computer Research (ISSN (print): 2249-7277, Volume-2 Number-4 Issue-7 December-2012.

[4] W. J. Hobbs, G. Hermon, S. Warner, and G. B. Sheblé, “An Enhanced Dynamic Programming Approach for Unit Commitment", IEEE Trans. Power Syst., Vol. 3, No. 3, Aug. 1988, pp. 1201–1205.

[5] B. Saravanan, E. R. Vasudevan, "Emission Constrained Unit Commitment Problem Solution Using Invasive Weed Optimization Algorithm", IEEE International Conference on Advances in Electrical Engineering (ICAEE), 9-11 Jan. 2014, pp.1-6.

[6] K. Asokan and R. Ashokkumar," Emission Controlled Profit based Unit commitment for GENCOs using MPPD Table with ABC Algorithm under Competitive Environment", WSEAS TRANSACTIONS on SYSTEMS, Volume 13, 2014.

[7] L Gerald, and D. Aaron, "Valve Point Loading Of Turbines", Proceeding of IEEE on Power Apparatus and Systems Part III., Volume 77, Issue 3, 07 May 2008, pp.481-484.

[8] X. Guan et al., "Optimization Based Methods for Unit Commitment: Lagrangian Relaxation versus General Mixed Integer Programming." IEEE Power Engineering Society General Meeting, Vol. 2, 2003.

[9] C. K. Pang, G. B. Sheble and F. Albuyeh, “Evaluation of Dynamic Programming Based Methods and Multiple Area Representation for Thermal Unit Commitments”, IEEE Transactions on Power Apparatus and Systems, Vol., PAS-100, No 3, Mar 1981, pp 1212-1218.

[10] A. Bhardwaj, et al., "Unit Commitment in Electrical Power System: A Literature Review", IEEE International Power Engineering and Optimization Conference (PEDCO) Melaka, Malaysia, 2012, pp. 275-280.

[11] D. Simopoulos, S. Kavatza, "Consideration of Ramp Rate Constraints in Unit Commitment using Simulated Annealing", Power Tech, 2005 IEEE Russia, 27-30 June 2005, pp. 1-7.

[12] V. Shanthi, A. E. Jeyakumar, " Unit Commitment by Genetic Algorithms’’, Power Systems Conference and Exposition, IEEE PES, Vol.3. , 2004, pp.1329-1334.

[13] M. Kurban, U. B. Filik, “Unit Commitment Scheduling by using the Autoregressive and Artificial Neural Network Models Based Short-Term Load Forecasting”, Proc., International Conference on Probabilistic Methods Applied to Power Systems, May2008, pp 1-5.

[14] K. Chandrasekaran, S. P. Simon, “Binary/Real Coded Particle Swarm Optimization for Unit Commitment Problem”, International Conference on Power, Signals, Controls and Computation (EPSCICON), Thrissur, Kerala, 3-6 Jan. 2012, pp. 1-6.

[15] G. Dudek, "Adaptive Simulated Annealing Schedule to the Unit Commitment Problem", Electric Power Systems Research, 2010, 80(4), pp. 465-472.

[16] L. A. Koridak, M. Rahli, M. Younes, "Hybrid Optimization of the Emission and Economic Dispatch by the Genetic Algorithm", Leonardo Journal of Sciences, Issue 14, January-June 2008, pp. 193-203.

[17] T. Saksornchai, W. J. Lee, K. Methaprayoon, J.R. Liao, R.J. Ross, "Improve the Unit Commitment Scheduling by using the Neural-network-based Short-term Load Forecasting", IEEE Transactions on Industry Applications, Vol. 41, No. 1, 2005, pp. 169-179.

[18] J. M. Anita, I. J. Raglend, "Solution of Emission Constrained Unit Commitment Problem using Shuffled Frog Leaping Algorithm", IEEE International Conference on Circuits, Power and Computing Technologies (ICCPCT 2013), 20-21 March 2013, pp.93-98.

[19] X. Guan et al., "An Optimization-Based Method for Unit Commitment." Electric Power and Energy Systems 14, No. 1 (February 1992): 9-17.

[20] R. K. Santhi, S. Subramanian, "Adaptive Binary PSO based Unit Commitment", International Journal of Computer Applications (0975 – 8887) Volume 15– No.4, February 2011.

[21] A. Ahmadian, M. Sedghi, and M. Golkar," Solving Multiobjective Unit Commitment Problem to Minimize Operation Cost and Emissions Using HBMO Algorithm", International Conference on Machine Learning, Electrical and Mechanical Engineering (ICMLEME'2014) Jan. 8-9, 2014 Dubai (UAE).

[22] S. Hemamalini, S. P. Simon, "Emission Constrained Economic Dispatch with Valve-Point Effect Using Particle Swarm Optimization", IEEE Region 10 Conference TENCON 2008, pp.1-6.

[23] R. K. Santhi, S. Subramanian, "Adaptive Binary PSO based Unit Commitment", International Journal of Computer Applications (0975 – 8887) Volume 15– No.4, February 2011.

[24] J. Kennedy and R.l C. Eberhart "Swarm Intelligence", Morgan Kaufmann, USA, 2001.

[25] M. Clerc and J. Kennedy, "The Particle Swarm: Explosion Stability and Convergence in a Multi-Dimensional Complex Space," IEEE Trans. on Evolutionary Computer, 2002, pp.58-73.

[26] J. Kennedy and R. C, Eberhart, "A Discrete Binary Version of the Particle Swarm Algorithm," Proceedings of the Conference on Systems, Man, and Cybernetics, Piscataway, 1997, pp.4104-4108.

[27] Y. Valle, G. Kumar, S. Mohagheghi, J. Carlos and R. G. Harley "Particle Swarm Optimization: Basic Concepts, Variants and Applications in Power Systems", IEEE transactions on Evolutionary Computation, Vol. 12, No.2, April 2008.

[28] V. S. Pappala and I. Erlich "Power System Optimization under Uncertainties: A PSO Approach”, IEEE Swarm Intelligence Symposium, September 21-23, 2008, USA.

[29] P. Attaviriyanupap, H. Kita, E. Tanaka, J. Hasegawa, "A Hybrid EP and SQP for Dynamic Economic Dispatch with No Smooth Fuel Cost Function", IEEE Transactions on Power Systems Vol. 17, No. 2, June 2002, pp. 411-416**.**