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Unit Commitment Problem of the Algerian Network using Particle swarm optimization under a deregulated market

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Abstract- The present work was conducted with the aim of finding a general method for solving the Unit Commitment (UC) problem with Particle Swarm Optimization (PSO) that is suitable for the deregulated electricity market. The traditional UC problem determines the optimal set of generating units within a power system to be used during the next one to many days. The Problem formulation of the UC takes into consideration the minimum up and down time constraints, start-up cost, and spinning reserve and is defined as the minimization of the total objective function while satisfying all the associated constraints. UC problem under deregulated environment is more complex and more competitive than traditional problem. Generation Companies (GENCO's) solves Unit Commitment problem not for minimizing total production cost as before but for maximizing their own profit. This paper will present the implementation of PSO algorithm and the results for 10-generators for 24-hour commitment schedule of the Algerian network. Simulation results on the 10 units system show that by this method, an optimum solution can be given quickly in vertically integrated system case and in a competitive market case.

Keywords: Unit Commitment, Power Systems, deregulated market, Optimization techniques.

1. Introduction

With regard to electricity, the total demand of energy will be generally higher, during the day and at the beginning of evening when the industrial loads are strong and lit lighting and, lower during the night and this until the morning. Moreover, the demand for electricity follows a weekly cycle since the load is weaker the weekend than the week [1].

The traditional Unit Commitment (UC) Problem in vertically integrated system consist to determine a minimal cost turn-on and turn-off schedule of a set of electrical power generating units to meet a load demand while satisfying a set of operational constraints[2]. The units must satisfy the load as well as the reserve. Moreover, each unit has its own limits of production. However UC problem under deregulated environment is more complex and more competitive than traditional problem. Generation Companies (GENCO's) solves Unit Commitment problem not for minimizing total production cost as before but for maximizing their own profit [3][4]. It is thus about a problem of optimization on a large scale under constraints. Many successful and powerful optimization methods and algorithms have been employed in formulating and solving the UC problem. The most typical approaches for its solutions are Priority-list Schemes [5], Dynamic programming (DP) [6] and Lagrange Relaxation (LR) [7][8].

This paper proposes a Particle Swarm Optimization (PSO) method to solve the Unit commitment problem. The (PSO) is a population based stochastic optimization technology developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking and fish schooling. It is used for optimization of continuous non linear functions [9], [10] [11], [12].

PSO has been very successfully developed in solving problems in power systems. For example in [13] PSO applied to the reactive power and voltage control problem that also considers voltage security assessments. In [14], [15] also applied PSO to the economic dispatch problem that considers nonlinear characteristics of power systems. Ref. [16] solved a practical distribution state estimation problem with PSO, and identification of dynamic security border [17]. Transmission network optimal planning using PSO [18], a novel approach for unit commitment problem [19], contingency constrained OPF in [20]. Other problems where the PSO was used are the OPF in [21], [22], [23], [24] and [25]

2 Problem Formulation

The objective of unit commitment in a power system is to minimize total generation cost, while observing a large set of operating constraints. The total generation cost includes the production cost of the scheduled combination units and the transition cost. The transition cost is the sum of the start-up cost and shut-down cost, which is the cost associated with changing from one combination of power-producing units to another combination. Problem formulation of the unit commitment must consider the system constraints and the generating unit constraints. It is a complex mathematical optimization problem with both integer and continuous variables. Mathematical formulations of UC problem are discussed as follows;

2 1 Objective Function

The objective function of the UC problem to minimize the production cost is mathematically formulated as [6]

$$\min\left(fuel\ \cos t + Transition\ \cos t\right)(\$) \tag{1}$$

$$Transition\cos t = startup\ \cos t + shut\,down\cos t \tag{2}$$

Fuel Cost

For a given set of *N* committed units at hour *t*, the total fuel cost is minimized by economically dispatching the units. This is a nonlinear programming sub-problem of the UC problem, commonly referred as economic dispatch problem, and it can be classically stated as:

$$F_t = \sum_{t=1}^{T}\sum_{i=1}^{N} FC_i\left(P_{it}\right)X_{it} \tag{3}$$

$$FC_i\left(P_{it}\right) = a_i + b_i P_{it} + c_i P_{it}^2 \ \left(\$/hr\right) \tag{4}$$

where

FC_i : is fuel cost function of generator *i*.

a_i , b_i and c_i are the cost coefficients of generator at bus *i*.

X_{it} : is the on (1)/off (0) status of generator *i* at hour *t*.

N: number of units.

T: scheduling period in hours.

P_{it} : is a real power output of generator *i* at hour *t*.

Subject to

$$P_{i\min} \le P_{it} \le P_{i\max} \tag{5}$$

where

$P_{i\min}$, $P_{i\max}$: the minimum and maximum power of generator *i*.

$$\sum_{i=1}^{N} P_{it} X_{it} = D_t \qquad (6)$$

where

D_t : is load demand at hour *t*.

$$\sum_{i=1}^{N} X_{it} P_{i\max} \geq D_t + SR_t \qquad (7)$$

where

SR_t : is spinning reserve at hour *t*.

Start-up Cost

$$ST_{it} = \sum_{t=1}^{T} \sum_{i=1}^{N} S_{it} X_{it} \left(1 - X_{i(t-1)}\right) \qquad (8)$$

$$S_{it} = \sigma_i + \delta_i \left(1 - \exp\left(-\frac{T_{it}^{off}}{\tau_i}\right)\right) \qquad (9)$$

where

S_{it} $(\$)$: Start-up cost of unit *i* at time *t*.

σ_i $(\$)$, δ_i $(\$)$ and τ_i (hr) are start-up cost coefficients of unit *i*.

T_{it}^{off} (hr): Off period of unit *i* at time *t*.

Subject to

$$T_{it}^{on} > MUT_i \qquad (10)$$

$$T_{it}^{off} > MDT_i \qquad (11)$$

where

T_{it}^{on} : On period of unit *i* at time *t*.

MUT_i : Minimum up time of unit *i*.

MDT_i : Minimum down time of unit *i*.

Shut-down Cost

$$SD_{it} = \sum_{t=1}^{T} \sum_{i=1}^{N} D_{it} X_{i(t-1)} \left(1 - X_{it}\right) \qquad (12)$$

where

D_{it} : Shut down cost of unit *i* at time *t*.

Subject to (10) and (11).

Total objective function

The total objective function considers at the same time the cost of the generation (fuel cost) and the cost of transition (start-up cost and shut down cost). This objective function is described by [6]:

$$TC = F_t + ST_{it} + SD_{it} \tag{13}$$

where

TC: Total production cost.

According to equation (l3), when solving the UC problem, it is first necessary to determine the start-up, shut-down, and generation levels of all units over a specified period. In addition, the scheduled units (combinations) must provide proper power for system demand, subject to power balance, spinning reserve requirement and individual unit constraints in the given interval. Thus, this is a non-linear programming problem that can be solved by numerical methods.

3 Particle Swarm Optimization in Unit commitment Problem

Particle swarm optimization was introduced in 1995 [9]. The method has been developed through a simulation of simplified social models. The method is based on researches on swarms such as fish schooling and bird flocking. According to the research results for bird flocking, birds are finding food by flocking (not by each individual). It leaded the assumption that information is owned jointly in flocking. The PSO algorithm can start with a population of particles with random positions. In PSO, a single particle is a solution in the search space. All particles have fitness values, which are evaluated by the fitness function to be optimized, and velocities, which direct the flying of the particles. Each individual knows its best value so far (pbest) and its position. Moreover, each individual knows the best value so far in the group (gbest) among pbests. Modification of an individual position is carried out by the position and velocity information.

3.1 Description of Particle Swarm Optimization method

Particle-swarm optimization (PSO), a population-based search algorithm, is initialized with a population of random solutions within the feasible range, called particles. Each particle moves (potential solution) based on its previous velocity, the particle's location at which the best fitness so far has been achieved, and the population global (or local neighborhood, in the local version of the algorithm) location at which the best fit so far has been achieved [9]. The particles have a tendency to move toward better search areas over the course of a search process [24]. Two commonly used PSOs are the global version and the local version. This is achieved by dynamically adjusting an inertia weight over the course of a PSO run. It has been reported that the global version of PSO converges fast, but with the potential to converge to a local minimum, while the local version of PSO might have more chances to find better solutions slowly. The pseudo code of the PSO technique is as follows [9]:

Step (i): initial searching points and velocities of each particle are generated randomly within the allowable range;

Step (ii): evaluate the fitness function value for each particle. The current searching point is set to local best for each particle. The best-evaluated value of local best is set to global best;

Step (iii): modify the searching point of each particle, update the inertia weight and increment the iteration count;

Step (iv): evaluate the fitness function value for each particle. If the current value is better than the previous local best of the particle, the previous best is replaced by the current value. If the best value of all current local bests is better than the previous global best, the former is replaced with the latter;

Step (v): if the termination criterion is satisfied, exit. Otherwise, go to step (iii).

From the above discussion, PSO does not depend on the nature of the function it minimizes; rather it uses the information of the evaluation function to explore the search space. Thus approximations made in traditional methods can be avoided [24].
The particles are manipulated according to the following equations.

$$v_i^{(t+1)} = w.v_i^{(t)} + c_1 * r_1 * \left(x_{gbest}^{(t)} - x_i^{(t)}\right) + c_2 * r_2 * \left(x_{ipbest}^{(t)} - x_i^{(t)}\right) \quad (14)$$

$$x_i^{(t+1)} = x_i^{(t)} + v_i^{(t+1)} \quad (15)$$

where

t : pointer of iterations (generations).
w : inertia weight factor.
c_1, c_2 : acceleration constant.
r_1, r_2 : uniform random value in the range [0,1].
$v_i^{(t)}$: velocity of particle *i* at iteration *t*.
$x_i^{(t)}$: current position of particle *i* at iteration *t*.
$x_{ipbest}^{(t)}$: the previous best position of particle *i* at iteration *t*.
$x_{gbest}^{(t)}$: the best position among all individuals in the population at iteration *t*.
$v_i^{(t+1)}$: new velocity of particle *i*.
$x_i^{(t+1)}$: new position of particle *i*.

3.2 PSO applied to unit commitment problem

Our objective is to minimize the objective function of the UC defined by (13), taking into account constraints.
The cost function implemented in PSO is defined as:

$$TC = \sum_{i=1}^{N}\sum_{t=1}^{T}\left(\left(F_i(P_{it}) + ST_i\left(1 - X_{i(t-1)}\right)\right)X_{it} + SD_i\left(1 - X_{it}\right)X_{i(t-1)}\right) \quad (16)$$

To minimize *TC* is equivalent to getting a maximum fitness value in the searching process. The particle that has lower cost function should be assigned a larger fitness value. The objective of OPF has to be changed to the maximization of fitness to be used as follows:

$$fitness = {f_{\max}}/{F} \quad (17)$$

where:

$f_{\max}$: the maximum of *F* ($p_{gi} = p_{gi\max}$).

The PSO algorithm applied to UC problem can be described in the following steps.

Step 1: Input parameters of system, and specify the lower and upper boundaries of each control variable.

Step 2: Generate randomly many individuals defined each generator's status (ON "1"; OFF "0"), each individual is a matrix with the dimension equal to *N*T*. *N* is the number of generators (units), *T* is the number of scheduling period. Figure (1) shows a matrix representation of a particle in the swarm.

Step 3: Compare maximum power generation with total load demand and spinning reserve using (7). If the constraint is satisfied then go to step 4. otherwise go to step 2.

Step 4: The particles are randomly generated between the maximum and minimum operating limits of the generators with the status of generators.

Step 5: Compare power generation with total load demand using (6). If the constraint is satisfied then go to step 5; otherwise go to step 4.

Step 6: Calculate the evaluation value of each particle using the objective function.

Step 6: Calculate the fitness value of objective function of each particle using (17). x_{ibest} is set as the *i th* particle's initial position; x_{gbest} is set as the best one of x_{ibest}. The current evolution is $t = 1$.

Step 7: Initialize learning factors c_1, c_2, inertia weight w and the initial velocity v_1.

Step 8: Modify the velocity v of each particle according to (14).

Step 9: Modify the position of each particle according to (15). If a particle violates its position limits in any dimension, set its position at the proper limits. Calculate each particle's new fitness, if it is better than the previous x_{gbest}, the current value is set to be x_{gbest}.

Step 10: Update the time counter $t=t+1$.

Step 11: If one of the stopping criteria is satisfied then go to step 12, otherwise go to step 8.

Step 12: The particle that generates the last est p_{gbest} is the global optimum.

4 Profit Based on Unit Commitment (PBUC) problem

The traditional Unit Commitment (UC) is defined as scheduling generating units in order to minimize the total production cost under constraints such as power demand and spinning reserve. This problem under deregulated environment is more complex and more competitive than traditional problem. Generation Companies (GENCO's) solves Unit Commitment problem not for minimizing total production cost as before but for maximizing their own profit. Hence, power prices become an important factor in decision making process. This type of UC is known as : Profit Based on Unit Commitment (PBUC).

4.1 Equations of PBUC problem

This problem is to find the maximum profit and therefore maximizing the objective following equation:

$$\max \quad PF = RV - TC \tag{18}$$

Demand and reserve constraints are defined as follows:

$$\sum_{j=1}^{N} P_{it} X_{it} \le D_t^{'} \qquad \forall t = 1,...,T \tag{19}$$

$$\sum_{i=1}^{N} R_{it} X_{it} \le SR_t^{'} \qquad \forall t = 1,...,T \tag{20}$$

Two additional constraints are added, which are:

$$0 \le R_i \le (P_{i\max} - P_{i\min}), \qquad \forall i = 1,.....,N \tag{21}$$

$$(R_i + P_i) \le P_{i\max}, \qquad \forall i = 1,......,N \tag{22}$$

Wherein the variables are defined below:

PF : The total profit of GENCO,

RV : Total revenue for the GENCO,

R_{it} : The reserve power generated by the generator *i* at time *t*,

$D_t^{'}$: The estimate of the power required at time *t*,

$SR_t^{'}$: The estimate of the reserve power required at time *t*,

The demanded power, reserve power, the spot price (equilibrium price), the cost of reserves, Sales Strategy power and reserves are important parameters for solving the problem of PBUC in a deregulated market for 'electricity. These are used to determine income, which directly affects the profit.

In the system structure, GENCO will sell the active power in energy market and sell the reserve in reserve market. The exact plan programmed to power and reserve depend on the reserve payment way.

4.2 The types of reserve market

4.2.1 Reserve market 1

In this type reserve power is paid only when it is actually used. So the reserve price is higher than the spot price. For this payment method revenue and the cost of GENCO can be calculated from these formulations:

$$RV = \sum_{i=1}^{N}\sum_{t=1}^{T}(P_{it}SP_t)X_{it} + r\sum_{i=1}^{N}\sum_{t=1}^{T}(R_{it}RP_t)X_{it} \quad (23)$$

$$TC = (1-r)\sum_{i=1}^{N}\sum_{t=1}^{T}F_i(P_{it}) + r\sum_{i=1}^{N}\sum_{t=1}^{T}F_i(P_{it}+R_{it}) + \sum_{i=1}^{N}\sum_{t=1}^{T}\left(ST_i(1-X_{i(t-1)})X_{it} + SD_i(1-X_{it})X_{i(t-1)}\right) \quad (24)$$

Where:

SP_t : The spot price (equilibrium price) at time t,

RP_t : The price of the power reserve at time t,

r : The probability of use of the reserve power,

4.2.2 Reserve market 2

For this type of reserve market, GENCO receives the reserve price per unit of power reserves in every period that reserve capacity is allocated but not used. If the reservation is used, GENCO will receive the spot price for power developed reserves. For this method of payment, the price of the power reserve is lower than the spot price. The GENCO revenue is calculated from the following equation:

$$RV = \sum_{i=1}^{N}\sum_{t=1}^{T}(P_{it}SP_t)X_{it} + \sum_{i=1}^{N}\sum_{t=1}^{T}\left((1-r)RP_t + r.SP_t\right)R_{it}X_{it} \quad (25)$$

4.3. Steps in solving the PBUC problem by PSO Method

PBUC problem of variables can be classified into two categories. The first category contains binary variables that describe the articles of engagement (or rest generator on) as well as historic operating (number of successive periods of stop and frequency of stop / start (A / D)) that specify transitions generators of the stop state to the operating state and vice versa, and the second category includes the continuous variable of the optimum power (output of each generator). So this type of problem has mixed variables. The model of PSO to solve the problem PBUC shown here is designed to meet the need above. The problem is

composed of three sub problems, the first problem in trying to optimize the statements of generators (transition costs), the second problem in what is present to optimize the supply of power reserve after results in the first problem (the power delivery and the reserve each generator), and finally in the last problem which is the maximum profit by type of reserve market. This problem can be solved following these steps:
Step 1: Same as **step 1** of the problem of traditional UC.
Step 2: Check the constraints of demand and reserve following equations (19 and 20).
Step 3: Checking the time constraints following equations (10 and 11).
Step 4: The application of PSO to optimize the cost of restarting.
After these four steps, one obtains the best particle which translates the best states of the generators (the minimum restart cost) and performs all the constraints.
Step 5: The creation of the initial random swarm concerning the powers delivered by each generator using the following formula:

$$P_{it} = \left(P_{i\min} + rand\left(P_{i\max} - P_{i\min}\right)X_{it}^{best}\right) \tag{26}$$

X_{it}^{best} : The state of generator i at time t that gives the best cost of transition.

$rand$ **:** A real number randomly generated between 0 and 1.
***Step 6*:** The application of PSO at this swarm of which fitness function is:

$$\max \ PF_1^k = RV_1^k - \left(C_F^k + C_T^k\right) \tag{27}$$

where:

$$RV_1^k = \sum_{i=1}^{N}\sum_{t=1}^{T}\left(P_{it}^k SP_t\right) \tag{28}$$

$$C_F^k = \sum_{i=1}^{N}\sum_{t=1}^{T} F_i\left(P_{it}^k\right) \tag{29}$$

$$C_T^k = \sum_{i=1}^{N}\sum_{t=1}^{T}\left[ST_i\left(1 - X_{i(t-1)}^k\right)X_{it}^k + SD_i\left(1 - X_{it}^k\right)X_{i(t-1)}^k\right] \tag{30}$$

The variables are defined as follows:

PF_1^k : The profit of the first sub GENCO problem.

RV_1^k : The Revenue of the first sub-problem.

C_F^k : The total cost of producing the first sub problem.

C_T^k : The total cost of transition of the first sub-problem.

After this last step we obtain the best particle which translates the optimal power delivered by each generator P_{gi}^{best}; RV_1^{best} the best Revenue; C_T^{best} the best cost of transition and C_F^{best} the best production cost.

Step 7: The creation of the initial random swarm concerning the reservation using the following equation:

$$R_{it}^k = \begin{cases} rand.\min\left\{\left(P_{i\max} - P_{it}^{best}\right), SR_t^{'}\right\} & if \ P_{it}^{best} \neq 0 \\ 0 & Autrement \end{cases} \tag{31}$$

Step 8: The application of PSO on all particles of the swarm of the reserve of which fitness function is as follows:

$$RV^k = \begin{cases} RV_1^{best} + r\sum_{i=1}^{N}\sum_{t=1}^{T}\left(R_{it}^k . RP_t\right) & if\ S=1 \\ RV_1^{best} + \sum_{i=1}^{N}\sum_{t=1}^{T}\left[(1-r)RP_t + rSP_t\right]R_{it}^k & if\ S=2 \end{cases} \quad (32)$$

$$TC = (1-r)C_F^{best} + C_T^{best} + r\sum_{i=1}^{N}\sum_{t=1}^{T} F_i\left(P_{it}^{best} + R_{it}^k\right) \quad (33)$$

S: indicates the type of reserve market.
At each step, the operating condition of each generator is checked for assure within its operating range. In particular you must check the constraints of requests and stock as well as time constraints.
Step 9: The best particle is the image of the best profit and consequently the optimal power supplied by each generator.

5 Application Study

The UC problem using particle swarm optimization method (PSO) has been developed by the use of C++. Consistently acceptable results were observed. The spinning reserve was assumed to be greater than 5% of the load demand in the study system and the shut down cost D_{it} has been taken to be equal to 0 for every unit. The PSO-UC is tested using the 10 units system of the Algerian Network [26]. The system is optimized using the PSO algorithm developed. The parameter settings to execute PSO-UC are w=0.9, c_1=0.5, c_2=0.5, $Vinc$=1.98, nmb_particles=20, max_generation=20. The generators data for this problem are shown in Table (1).

Table 1. Power generation limits and cost coefficients for 10 units system of the Algerian Netwotk.

Bus N°	P_{imin} (MW)	P_{imax} (MW)	α_i ($/h)	β_i ($/MWh)	γ_i ($/MWh^2)	σ_i ($)	δ_i ($)	MUT (h)	MDT (h)	τ_i (h)
1	8	72	0	1.50	0.0085	26	26	1	1	2
2	10	70	0	2.50	0.0170	17	17	2	2	2
3	30	510	0	1.50	0.0085	500	500	5	5	4
4	20	400	0	1.50	0.0085	500	500	5	5	4
13	15	150	0	2.50	0.0170	90	90	2	2	2
27	10	100	0	2.50	0.0170	55	55	2	2	2
37	10	100	0	2.00	0.0030	55	55	2	2	2
41	15	140	0	2.00	0.0030	90	90	2	2	2
42	18	175	0	2.00	0.0030	90	90	2	2	2
53	30	450	0	1.50	0.0085	500	500	5	5	4

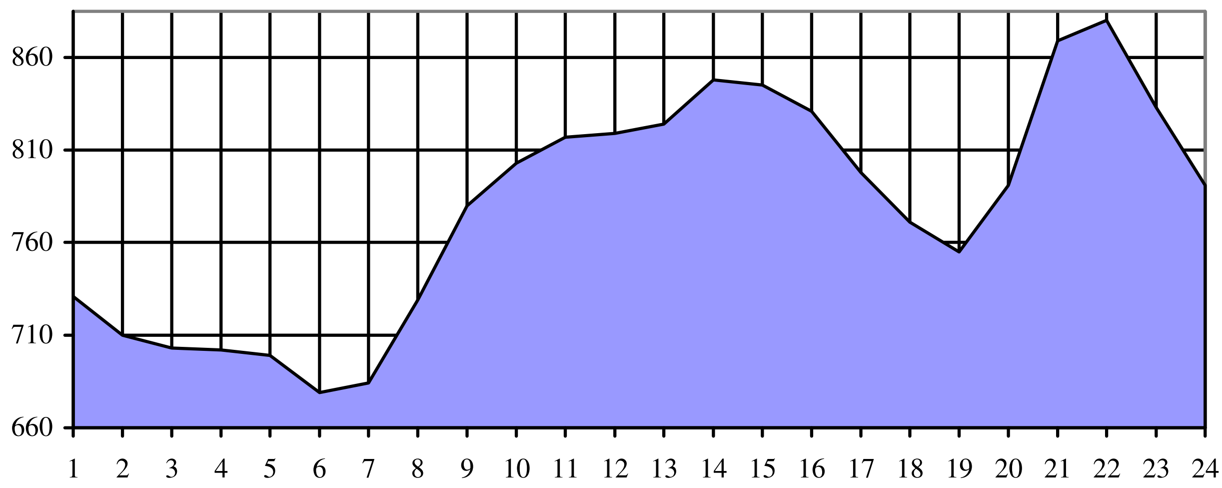

Figure 1 Load Profile of the Algerian network on an interval of 24 hours

Table 2: Best result by the proposed method

		Active power delivered by each unit (MW)									
hour	Unit Schedule	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10
1	0010011010	0	0	430.0617	0	0	87.9347	83.1817	0	129.822	0
2	0010011010	0	0	419.8291	0	0	15.1709	100.0000	0	175.0000	0
3	1010001010	66.23	0	439.6323	0	0	0	93.5506	0	103.5821	0
4	0010101000	0	0	510.0000	0	99.3485	0	92.6515	0	0	0
5	0010101000	0	0	461.6804	0	137.3196	0	100.0000	0	0	0
6	1010111010	72.00	0	326.6651	0	28.8731	86.8927	89.5588	0	75.0104	0
7	0010111110	0	0	106.2769	0	150.0000	43.3364	69.4867	140.0000	175.0000	0
8	0110110100	0	70	347.8288	0	125.5119	82.9703	0	102.6890	0	0
9	1111110000	72.00	70	438.3270	52.4093	53.0080	94.2557	0	0	0	0
10	1011001010	72.00	0	319.7798	247.5675	0	0	48.1790	0	115.4737	0
11	1011001110	72.00	0	101.1290	281.4432	0	0	47.9597	139.4681	175.0000	0
12	1111010100	72.00	70	316.7039	233.6876	0	87.8248	0	38.7837	0	0
13	1111010000	72.00	70	312.6196	310.4291	0	58.9514	0	0	0	0
14	1011000010	72.00	0	225.3018	375.6982	0	0	0	0	175.0000	0
15	1011000110	72.00	0	331.3072	126.6928	0	0	0	140.0000	175.0000	0
16	1011101100	72.00	0	351.1404	143.9553	41.4238	0	100.0000	122.48	0	0
17	1111111100	66.37	42.1	199.6991	245.2875	70.2100	15.4919	62.9873	95.8501	0	0
18	1111110000	72.00	70	318.2560	274.5987	25.2128	10.9325	0	0	0	0
19	1111110000	72.00	69.85	239.5656	236.6970	77.9558	58.9293	0	0	0	0
20	1001111110	72.00	0	0	271.7034	85.3865	74.4638	49.5020	74.6918	163.2526	0
21	1001101110	72.00	0	0	400.0000	150.0000	0	71.3553	114.1131	61.5315	0
22	1001101111	72.00	0	0	308.4651	33.5092	0	71.1403	91.8245	56.8521	246.21
23	1001111011	72.00	0	0	208.0580	15.0000	22.2782	88.2173	0	47.3188	380.13
24	1001010001	72.00	0	0	400.0000	0	100.0000	0	0	0	219

The best simulation result of PSO is shown in table (2), with figure (2) shows the curve of the scheduling generation and load demand. Table (2) shows the simulation results including the production cost, load demand and spinning reserve of each scheduling time interval, unit scheduled for 24 hours duration and the total generation cost. Table (3) shows the transition cost of each unit. The total generation cost of the best combination of scheduled units is 559684$.
For this simulation, the size of each particle and the swarm are (10 * 24) and (10 * 24 * 20) respectively (10: The number of network test generator, 24: number of times, 20: the number of particles). The table (3.10) shows the best result for the operative state using the OEPD and the power generated by these generators to each time and the cost of production and the spinning reserve of all generators. The requested power is shown in (Figure 2). The total cost of production is 69536.054 $. The spinning reserve is 9208.9 MW. Note that the spinning reserve is sufficient every hour (Figure 2).

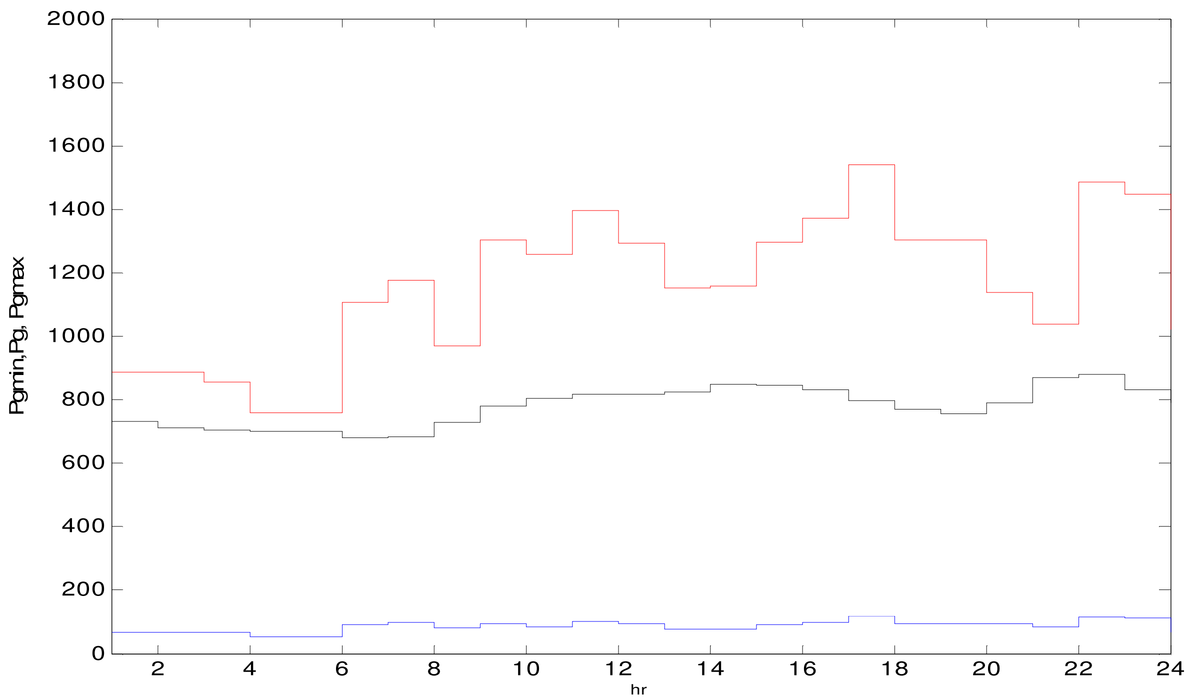

Figure (02): Scheduling generation of the Algerian Network for 24 h

The studied method is tested on the Algerian network with ten generators to determine the maximum advantage of the power company in a free electricity market, to satisfy the required electrical power for 24 hours and calculate the optimal value of the power delivered by each generator. The technical and economic data generators, the power demand, power reserve and spot prices and reserves for the two types the market are given in the tables (3) and (4) respectively. Probability, which reserve power is used, is equal to 0.005 in all cases.

Table (3): Best result by the proposed method

hour	**Unit Schedule**	**Production Cost ($)**	**Spinning Reserve (MW)**
1	0010011010	3065.81	153.9990
2	0010011010	2841.64	175.0000
3	1010001010	2891.65	154.0000
4	0010101000	3603.07	58.0000
5	0010101000	3398.15	61.0000
6	1010111010	2351.12	428.0000
7	0010111110	2087.32	490.9000
8	0110110100	2951.47	241.0000
9	1111110000	3369.88	522.0000
10	1011001010	2767.52	453.9990
11	1011001110	2368.12	580.0010
12	1111010100	2985.46	473.0000
13	1111010000	3201.22	328.0000
14	1011000010	3126.67	309.0000
15	1011000110	2689.17	452.0000
16	1011101100	2771.59	540.9990
17	1111111100	2449.54	744.0000
18	1111110000	2904.72	531.0000
19	1111110000	2592.64	547.0000
20	1001111110	2483.88	346.0000
21	1001101110	3429.26	168.0000
22	1001101111	2900.78	606.9990
23	1001111011	3037.11	614.0000
24	1001010001	3268.23	231.0000
		Total generation cost =69536.054$	Total reserve=9208.9 MW
	Transition cost	4345.637586$	
	Total cost	73881.691699$	

Table 4 Spot price and reserve price for 24 hours

hour	Estimated spot price	Estimated reserve price (Reserve Market of type 1)	Estimated reserve price (Reserve Market of type 21)
1	6.2286	9.3428	0.6229
2	6.1108	9.1663	0.6111
3	6.0352	9.0527	0.6035
4	5.9552	8.9329	0.5955
5	5.9174	8.8762	0.5917
6	5.9174	8.8762	0.5917
7	5.9552	8.9329	0.5955
8	6.0730	9.1094	0.6073
9	6.2664	9.3995	0.6266
10	6.4176	9.6264	0.6418
11	6.4554	9.6831	0.6455
12	6.4764	9.7146	0.6476
13	6.4554	9.6831	0.6455
14	6.4176	9.6264	0.6418
15	6.4008	9.6012	0.6401
16	6.4008	9.6012	0.6401
17	6.4764	9.7146	0.6476
18	6.6488	9.9731	0.6649
19	6.8208	10.2312	0.6821
20	6.5898	9.8848	0.6590
21	6.5352	9.8029	0.6535
22	6.4932	9.7399	0.6493
23	6.4008	9.6012	0.6401
24	6.2832	9.4247	0.6283

Discussion of the results

The proposed method is applied to solve the problem PBUC for types 1 and 2. reserve market the produced optimum powers are deferent from those found in traditional CPU since this time the objective function optimizes simultaneously powers generated and the reserve according to the two cases. The optimal allocation of power for each hour for a period of 24 hr for two cases the market are given in the figure (3). The contribution of production units in the available reserve in both cases the market are given in the figures (4 and 5). Note that the active power generated for the two types are identical. This is the distribution of reserves that differ according to the type of market.

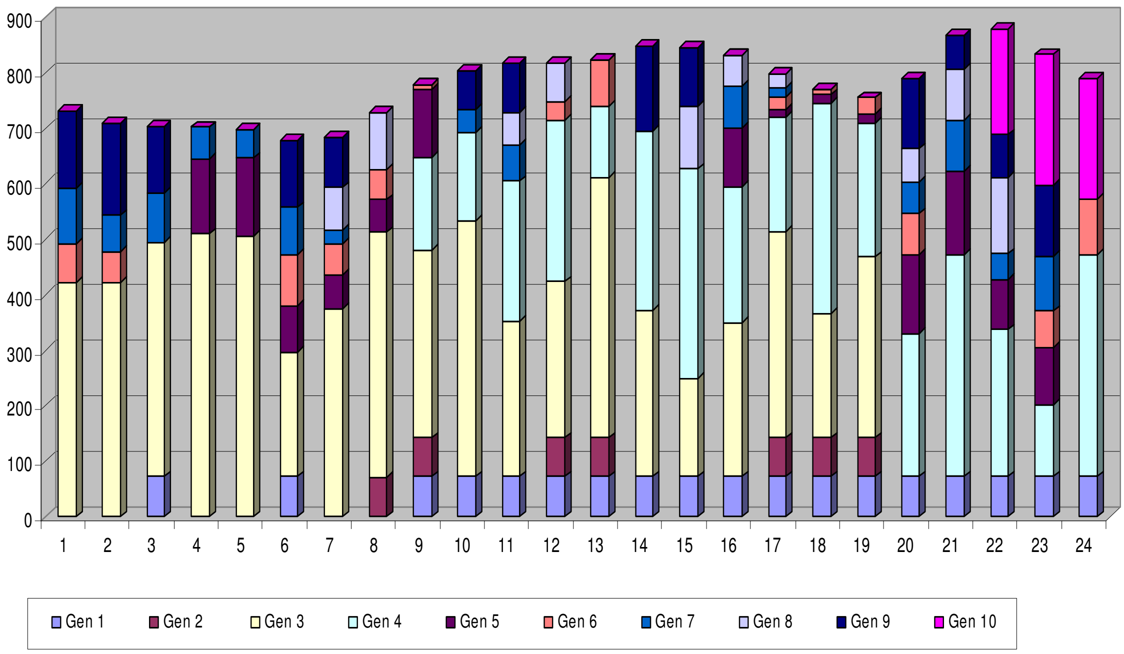

Figure 3 Optimal values of power generated for the type 1 and type 2 of reserve market

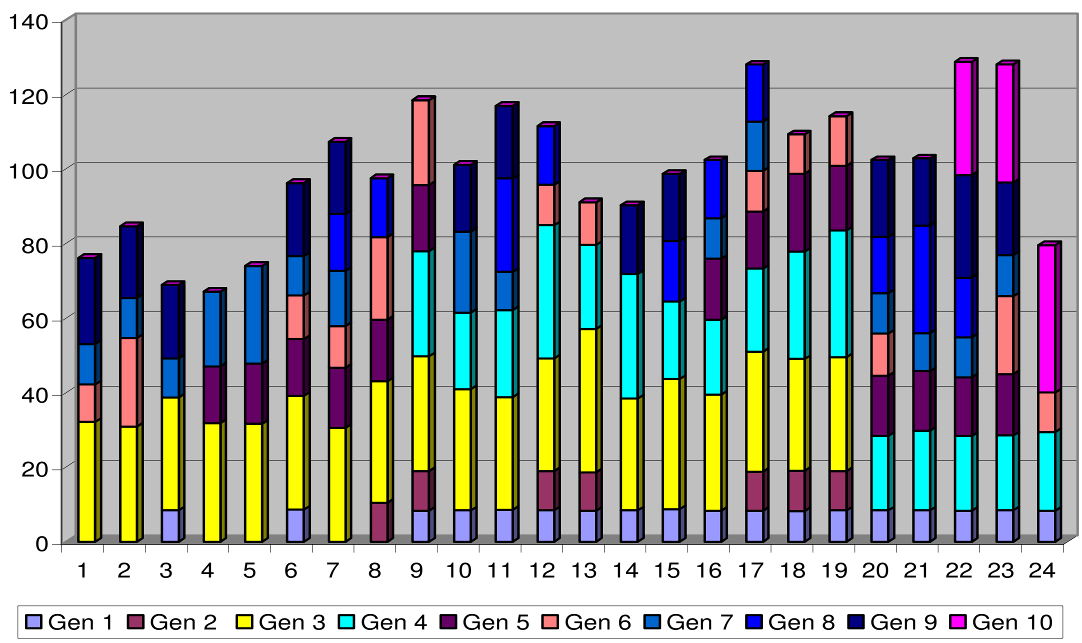

Figure 4 The optimal values of the reserve powers for the type 1 of the reserve market

The results of comparison between the two types of market reserve viewpoint fuel costs and transition as well as the revenue and profit are shown in Table 5. Because the two cases consider differently reserve price, the reserve price of type 2 market is different and it is lower than the price for type1, and fitness functions both cases are also different. Although the available reserve in the case of type 2 market that is 2336.74619 MW is less than that found in the case of 1 type of market (2394.7789 MW), but the PBUC for type 2 gives market \$ 1437.9 (= 45588.768585-44150.828883) more profit for type1 3.25%. What pushes producers to favorite type 2 of reserve market.

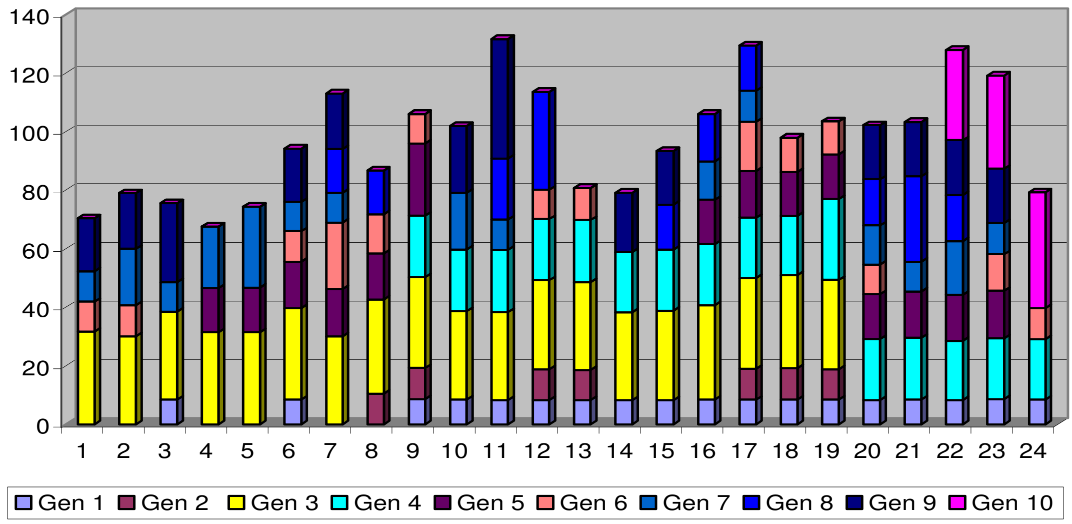

Figure 5 The optimal values of the reserve powers for the type 2 of the reserve market

Table 5 Economic Results of the two types of reserve market

	Type 1	**Type 2**
Fuel cost (\$)	84371.444	83845.516
Transition cost (\$)	2414.000	2414.000
Revenue (\$)	118544.510	119913.103
Profit (\$)	44150.829	45588.768

Conclusion

In this paper, a PSO method has been presented and applied to unit commitment problem. UC in the electricity market considering the power demand reserve and has been tested on the Algerian network. Since the problem of PBUC is solved under the condition of competition, the spot price and the reserve price are important parameters. According to the power and the reserve price on the market, the producer can choose to sell the power and /

or more lower than the estimated level of reserves to maximize its own profit. Two reserve payment methods are simulated using the Algerian network. From the simulation results, we can conclude that the new problem of PBUC provides a better profit than traditional CPUs.

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