Solving Economic Dispatch in Competitive Power Market Using Improved Particle Swarm Optimization Algorithm

Hossein Lotfi[*1], Ali Dadpour[2] , Mahdi Samadi[3]

[1]Department of Electrical Engineering, Islamic Azad University, Neyshabour, Iran,Hossein_lotfi95@yahoo.com
[2]Department of Electrical Engineering, Islamic Azad University, Bojnourd, Iran,a.dadpour105@yahoo.com,
[3]Department of Electrical Engineering, Hakim Sabzevari University, Sabzevar, Iran,ma.samadi@hsu.ac.ir

Abstract

Generally the generation units in the traditional structure of the electricity industry try to minimize their costs. However, in a deregulated environment, generation units are looking to maximize their profits in a competitive power market. Optimum generation planning in such structure is urgent. This paper presents a new method of solving economic dispatch in the competitive electricity market with the aim of maximizing the total contribution profit of power generation. In this regard, with a combination of two intelligent optimizations, a new efficient algorithm which called improved particle swarm optimization algorithm is suggested. The simulation of the new approach and conventional PSO algorithm were performed on two case study systems, 10-units and 15-units. According to the results, the suggested method not only resolves the convergence problem, but it also makes more efficient response

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1. Introduction

Mainly restructuring in the electricity industry has been effective in the abolition of the monopoly generation, and also leads to the competitive environment in generation levels, However, sudden changes in the market caused some problems, such as demand price elasticity and the abusing of market power. That is why the number of generating units in a competitive power market must be high, that outage one or more units could not take advantage of market power. Recently, most of the electrical power industries have changed from a vertically integrated structure to private structure so called restructuring, which means a vertically integrated power system divided into generation, transmission and distribution companies [1].

The main objective of privatization is to create a competition between producers and provide cheaper prices for consumers, which leads to change methods of problem solving in this new condition. Nowadays, there is no guarantee that a company be the only electricity supplier, so the load forecast that must be provided by generation companies is more difficult than in the past [1].

In conventional power system's structure, collaborative planning signifies the optimization of generation units to meet demand with the minimum cost. In minimizing operation costs, usually economic dispatch and unit commitment are used.

In the maximization of total profits in the market, the first priority is to maximize the profits of the units in the market. In economic dispatch, the purpose is, minimization the cost of the units, but the priority in the power market is maximization the total profit. The market price in each hour play key role in generation planning. In economic dispatch model two objectives are: firstly, to maximize total profit in the competitive market secondly, supplying the demand. So if the market price be in the lowest level, some of the units would operate in their minimum capacity, but do not switch-off due to ramp-rate constraints. The following is some examples of the optimization techniques which are used in solving economic dispatch.

In order to solving economic dispatch problem, an adaptive particle swarm algorithm is presented. In the proposed algorithm, to achieve the inertia factor and also, to improve the global search capabilities a new mutation operator by using fuzzy rules is applied [2]. In [3] for solving the economic dispatch, improved particle swarm (PSO) is presented, in this reference a combination of the particle swarm algorithm and the Gaussian probability distribution function is used. In [4] the improved genetic algorithm for solving economic dispatch problem is suggested. To find the best solution the proposed method has been tested on four different systems. In [5], a combination of the PSO algorithm and optimized harmony search is implemented, in the proposed method, constraints are related to the balance between generation and consumption, as well as, limitation of loading units are considered. For solving economic dispatch, the bee colony algorithm is presented [6], In order to solve the economic dispatch, Mac-Lorin series hybrid method based on Lagrange relaxation is proposed [7]. In [8], particle swarm optimization algorithm is suggested. The features of the proposed method are global search and prioritize of areas. In [9] the improved genetic algorithm for solving economic dispatch is applied, the proposed method is the faster and more accurate than conventional genetic algorithm.

Following of this paper: the formulation of the objective function and constraints is described. The third part introduces particle swarm optimization algorithm .The fourth part deals with the introduction of the proposed method. In the fifth and sixth part respectively, simulation results and conclusions are explained.

2. Formulation of the problem

The purpose of optimal planning in the power market is maximizing the total profit of units. In following, the formulations of objectives and constraints are discussed.

A)*Objective function*

The difference between the sales revenue and costs of generation units in the power market is equal to the profit of generation unit which can be obtained from (1).

$$\text{Max (PF)} = \text{RV-TC} \tag{1}$$

The sale revenues of electric power and cost of generation units have been presented by (2) and (3).

$$\text{RV}=\sum_{t=1}^{T}\sum_{i=1}^{N} P_{it}.P_r(t) \tag{2}$$

$$\text{RV}=\sum_{t=1}^{T}\sum_{i=1}^{N} P_{it}.P_r(t) \tag{3}$$

P_{it}: Output power of unit i-th at hour t-th .$P_r(t)$:price market at hour t-th, N: the number of generation units, T: total time that generation units are operation. The cost of generation of the equation (4) is obtained.

$$C_{it}(P_{it}) = a_i.P_{it}^2 + b_i.P_{it} + C_i \tag{4}$$

B)*Problem Constraints*

The constraints related to the power balance, generation limits of units and ramp rate constraint are as follows:

– Real power balance: (5) shows the balance between generated power and load demand:

$$\sum_{i=1}^{N} P_{it} = P_D(t) \tag{5}$$

Where $P_D(t)$ is hourly demand.

– Generation limit: (6) shows the generation limitation of units. generated power of each unit is between their minimum and maximum:

$$P_i^{min} \le P_{it} \le P_i^{max} \tag{6}$$

– Ramp-rate limit constraints: ramp of output power in thermal units must be within the acceptable range, as avoid mechanical stress to some parts like the boiler and combustion equipment [10]. Ramp up and down limits of generator are represented by (7),(8).

$$P_{it} - P_{it-1} \le UR_i \tag{7}$$

$$P_{it-1} - P_{it} \le DR_i \tag{8}$$

UR_i and DR_i are the ramp rate limits of the ith generator, respectively. However, by considering the ramp rates of generation units and taking into account the equation (6), the generation limit of units can be obtained in (9).

$$\text{Max}\,(P_i^{min}, P_{it-1} - DR_i) \le P_{it} \le \text{Min}\,(P_i^{max}, P_{it-1} + UR_i) \tag{9}$$

3. Particle Swarm Optimization (PSO)

Particle swarm algorithm is one of the evolutionary population-based methods, which is used for optimization problems. This algorithm is inspired by the social behavior of some animals such as categories of fish and birds. In this algorithm, each particle is a possible answer for optimization problem, the particles in the search space reach the best position, by two factors:

previous best position and best position among particles group.

This algorithm has high ability to solve problems such as, multidimensional, complex constrained and nonlinear [11].The position of each particle in the search space is defined by two vector, position vector X= $[X_1, X_2, \ldots, X_d]$ and the velocity vector V= $[V_1, V_2, \ldots, V_d]$. In this way, each particle improves its position by current velocity, previous best position and the best position of its neighbor. PB=$[pb_1, pb_2, \ldots, pb_n]$: Best position of i-th particle have ever found. GB= $[gb_1, gb_2, \ldots gb_n]$: best position among the particles. Velocity and position of sample particle i-th by using (10) and (11) are updated.

$$v_i^{k+1} = \omega v_i^k + c_1 r_1 (pb_i^k - x_i^k) + c_2 r_2 (gb_i^k - x_i^k) \quad (10)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (11)$$

where C1 and C2 are Acceleration factors and r1 , r2 are normally distributed random values in the range (0, 1) [12]. Also ω is inertia weight[12].Usually the inertia factor in the implementation of the algorithm is set during learning and usually is reduced linearly from one to values close to zero, according to (12) [13] .

$$W = Wmax - \frac{Wmax - Wmin}{iter_{max}} \times iter \quad (12)$$

i_{ter} is the current iteration number and $iter_{max}$ is the maximum iteration number. Amount of velocity V_i (Velocity vector) in each dimension between [-Vmax +Vmax] [14]. In this paper, PSO algorithm is done for the Maximization of the total profit units in the competitive power market in the following steps:

Step 1: Importing required data and parameters of PSO algorithm. Generate initial population randomly. Initial population (X) has n particles, and also each particle consisted of 24 × a matrix, a is the total number of variables that affect the optimization function. This variable is the amount of generation units.

$$X = \begin{bmatrix} x_1 \\ x_2 \\ . \\ x_n \end{bmatrix} \quad (13)$$

In which the matrix elements are as follows:

$$X_n = \begin{bmatrix} P_{1,1} & . & . & P_{1,a} \\ P_{2,1} & . & . & P_{2,a} \\ . & . & . & . \\ P_{24,1} & . & . & P_{24,a} \end{bmatrix} \quad (14)$$

Step 2: By creating the initial population, all values of the matrix in each particle with initial velocity and position are selected randomly.

Step 3: By calculating the objective function for the initial population, particle fitness is determined. The objective function of maximizing total profit of generation units can be obtained from (1).

Step 4: In each iteration, evaluate the fitness value of the particle and compare with previous particle best (pbest) value. If the current fitness value is greater than its pbest value, then would assign the pbest value to the current value (This problem is Maximization), and in each iteration the value is updated.

Step 5: determine the current global best (gbest) maximum value among the particles individual best (pbest) values, and in each iteration the value is updated.

Step 6: Current position is updated by using (10) and (11).

Step 7: If the stop criteria are achieved (maximum iteration), the algorithm terminates.

Finally, when the algorithm is completed, the optimal (best position particle) represents the optimal generation planning of units, and the corresponding fitness value indicates the maximum total profit of units.

4. The Proposed Approach

In this section, the proposed optimization algorithm is introduced and how to maximize the total profit of the units in the competitive power market is described.

Although in the PSO all particles move toward the best position, but the position may be a local optimum. In fact, in some issues, a general search of all space particles do not reach the optimal point beyond local or close to it, but all the particles are concentrated in a small area and do not have the ability to global exploration. One approach to meet this challenge is, using an improved particle swarm algorithm (IPSO) which is a combination of shuffled leaping frog (SFLA) [15] and PSO algorithm. In following, optimization problem subject to this algorithm is described.

First, an initial population of particles is randomly produced with primary velocities and positions. By calculating the objective function for the initial population, the fitness of each particle is determined. Then, selected particles in various set are classified according to decreasing fitness. In each set, the best fitness of each particle (pbest) and the best fitness among the particles of each set (gbest) selected. And similar particle swarm algorithm velocities and Positions of each set are updated. Finally, the best position and the fitness associated with it in the sets are selected. Then information exchange between all sets until finding the best solution.

5. Result of Simulation

In this section, case study network, hourly price and hourly market demand are introduced. Moreover, the simulation results for both conventional PSO algorithm and proposed Improved PSO algorithm for ten and fifteen generator test network are applied. The data for this two test network can be found in reference [3].

A) *Case study*

In this paper, the ten and fifteen power generation units [16] are being used for solving the problem; the data are given in the table 1 and table 3 respectively. In addition, power demand and market price data [1] are provided in Table 2.

B)*Test result of PSO algorithm*

The conventional PSO algorithm is applied on the ten units system in order to maximize total profit in the competitive market and the results are as follows. Fig.1. shows the convergence curve of PSO algorithm. Additionally, table 4 shows the optimal generation of each unit in order to maximize the total profit in the competitive market in 24-hours. The maximum total profit of units in this case is 293704.8639 $ in competitive market.

C)*Test Result of IPSO algorithm*

Improved particle swarm algorithm for the optimal generation of units to find maximum total profit is implemented in a competitive market model. The results are investigated in following. In Figure 2, the convergence curve of particle swarm algorithm is illustrated. Moreover, table 5 shows the optimal 24-hours generation planning of each unit to maximize the total profit in the competitive market. The maximum total profit of units in this case is 295045.4361 $ in competitive market. Comparison of both algorithms results, indicate that improved PSO algorithm can provide better solution than conventional PSO algorithm. (Increasing the total profit of generation units from 293704.8639 $ to 295045.4361 $). By comparison between the results of both algorithms it is clear that the total profits of generation units by implementing improved PSO algorithm is more than conventional PSO algorithm. Consequently, generation planning of units in this metaheuristic algorithm is more efficient than conventional PSO algorithm. In the next section for testing the proposed method, a fifteen units system [3] is used. The data of this test system are given in Table 3. As well as, load demand and market price [1], are presented in Table 2. Fig.3. shows the convergence curve of conventional PSO algorithm. The maximum total profit of units in this case is 234572.3006$ in competitive market.

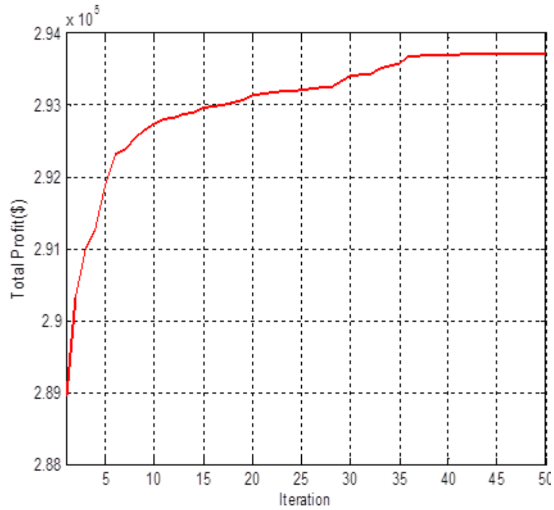

Fig. 1. The convergence characteristics of conventional PSO(293704.8639 $ in competitive market)

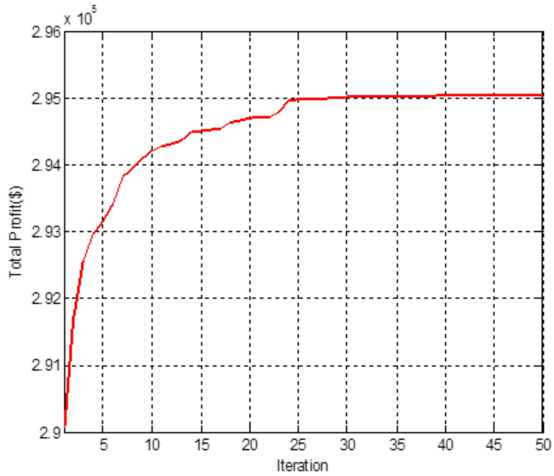

Fig. 2. The Convergence characteristics of Improved PSO(295045.4361 $ in competitive market)

Fig.4. shows the convergence curve of particle swarm algorithm. In addition, the maximum total profit of units in this case is 235752.3954$ in competitive market.

Comparison of both algorithms results, indicate that improved PSO algorithm can provide better results than conventional PSO algorithm. (Increasing the total profit of generation units from 234572.3006 $ to 235752.3954 $).

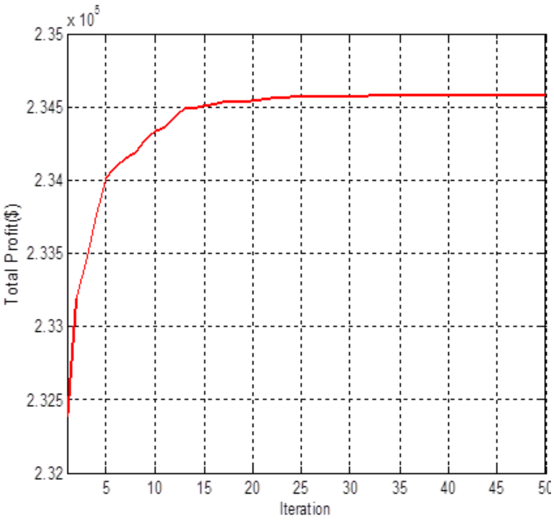

Fig. 3. The convergence characteristics of conventional PSO(234572.3006$ in competitive market)

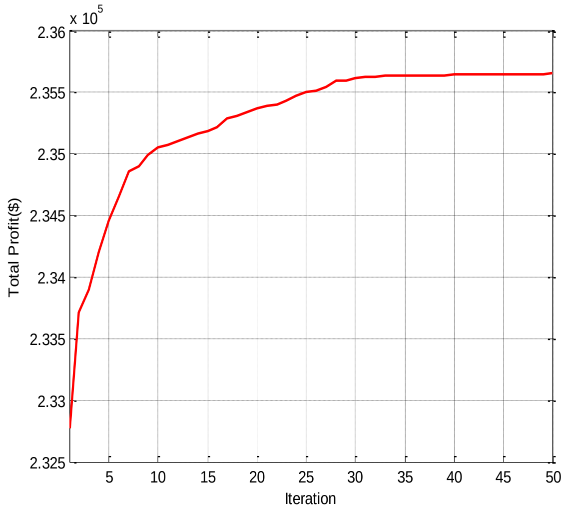

Fig. 4. The convergence characteristics of Improved PSO235752.3954$ in competitive market)

Table.1.
Data of the ten power generation units [3]

Units	$DR_i(^{Mw}/_{h})$	$UR_i(^{Mw}/_{h})$	$c_i(^{\$}/_{(Mwh)^2})$	$b_i(^{\$}/_{Mwh})$		l	$p_{min}(MW)$
1	120	80	671	10.1	0.000299	455	150
2	120	80	574	10.2	0.000183	455	150
3	130	130	374	8.8	0.001126	130	20
4	130	130	374	8.8	0.001126	130	20
5	100	60	173	11.2	0.000807	162	25
6	80	80	186	10.2	0.003586	80	20
7	80	80	230	9.9	0.005513	80	20
8	80	80	225	13.1	0.000371	85	25
9	55	55	309	12.1	0.001929	55	15
10	55	55	323	12.4	0.004447	55	15

Table.2.
24-hour power demand and market price data [1]

Hour	***Demand(MW)***	***Price($)***	***Hour***	***Demand(MW)***	***Price($)***
1	1400	24.60	13	700	22.15
2	1300	24.5	14	750	22
3	1200	22.50	15	850	23.10
4	1050	22.30	16	950	23.65
5	1000	22.25	17	1000	23.25
6	1100	22.05	18	1100	22.95
7	1200	22.20	19	1150	22.5
8	1400	22.65	20	1200	22.15
9	1300	23.10	21	1300	22.8
10	1100	22.95	22	1400	29.35
11	900	22.75	23	1450	30.15
12	800	22.55	24	1500	31.65

Table.3.
Data of the fifteen power generation units [3]

Units	$DR_i(^{Mw}/_h)$	$UR_i(^{Mw}/_h)$	$c_i(^{\$}/_{(Mwh)^2})$	$b_i(^{\$}/_{Mwh})$		l	$p_{min}(MW)$
1	120	80	671	10.1	0.000299	455	150
2	120	80	574	10.2	0.000183	455	150
3	130	130	374	8.8	0.001126	130	20
4	130	130	374	8.8	0.001126	130	20
5	100	60	173	11.2	0.000807	162	25
6	80	80	186	10.2	0.003586	80	20
7	80	80	230	9.9	0.005513	80	20
8	80	80	225	13.1	0.000371	85	25
9	55	55	309	12.1	0.001929	55	15
10	55	55	323	12.4	0.004447	55	15
11	120	80	461	10.4	0.000205	470	150
12	120	80	630	10.1	0.000301	460	135
13	120	80	548	9.8	0.000364	465	135
14	100	65	227	11.2	0.000338	300	60
15	100	60	175	10.7	0.001203	160	25

Table.4.
Optimal 24-hours generation planning of units in competitive market by using conventional PSO algorithm

hour	***P10(Mw)***	***P9(Mw)***	***P8(Mw)***	***P7(Mw)***	***P6(Mw)***	***P5(Mw)***	***P4(Mw)***	***P3(Mw)***	***P2(Mw)***	***P1(Mw)***
1	15.00	15.00	25.00	20.00	20.00	25.00	130.00	20.00	150.00	280.00
2	15.00	15.00	25.00	20.00	20.00	25.00	20.00	20.00	440.00	150.00
3	15.00	15.00	25.00	20.00	20.00	25.00	130.00	20.00	430.00	150.00
4	15.00	15.00	25.00	80.00	80.00	25.00	130.00	130.00	300.00	150.00
5	15.00	15.00	25.00	24.57	20.00	25.00	129.96	129.96	273.15	342.36
6	15.00	15.00	25.00	20.00	20.00	25.00	130.00	20.00	375.00	455.00
7	15.00	15.00	25.00	80.00	20.00	25.00	130.00	130.00	255.00	455.00
8	55.00	15.00	25.00	80.00	80.00	25.00	130.00	130.00	455.00	205.00
9	15.00	55.00	25.00	80.00	80.00	162.00	130.00	130.00	455.00	168.00
10	15.00	15.00	25.30	80.00	80.00	25.00	130.00	130.00	444.70	455.00
11	15.00	55.00	25.00	80.00	80.00	25.00	130.00	130.00	455.00	455.00
12	55.00	55.00	85.00	80.00	80.00	162.00	130.00	130.00	455.00	268.00
13	15.00	15.00	25.00	79.55	80.00	25.00	130.00	130.00	448.25	452.20
14	15.00	15.00	25.00	30.38	20.00	25.00	129.91	130.00	454.91	454.80
15	15.00	15.00	25.00	20.00	20.00	25.00	130.00	130.00	365.00	455.00
16	15.00	15.00	25.00	20.00	80.00	25.00	130.00	130.00	455.00	155.00
17	15.00	15.00	25.00	79.91	79.96	25.00	129.93	20.00	454.95	155.25
18	15.00	15.00	25.00	30.50	20.00	25.00	129.41	129.49	259.20	451.40
19	15.00	15.00	25.00	20.00	20.00	25.00	130.00	130.00	455.00	365.00
20	15.00	15.00	25.00	70.50	80.00	25.00	130.00	130.00	454.50	455.00
21	15.00	15.00	25.00	80.00	80.00	25.00	130.00	20.00	455.00	455.00
22	55.00	55.00	25.00	20.00	20.00	25.00	130.00	130.00	455.00	185.00
23	55.00	55.00	25.00	20.00	20.00	25.00	20.00	20.00	285.00	455.00
24	15.00	15.00	25.00	20.00	20.00	25.00	130.00	20.00	380.00	150.00

Table.5.
Optimal 24-hours generation planning of units in competitive market by using IPSO algorithm

hour	***P10(Mw)***	***P9(Mw)***	***P8(Mw)***	***P7(Mw)***	***P6(Mw)***	***P5(Mw)***	***P4(Mw)***	***P3(Mw)***	***P2(Mw)***	***P1(Mw)***
1	15.00	15.00	25.00	20.00	20.00	25.00	130.00	130.00	169.15	150.85
2	15.00	15.00	25.21	20.10	20.00	25.26	130.00	130.00	211.98	157.45
3	15.00	15.00	25.00	20.00	20.00	25.00	20.00	129.85	150.00	430.15
4	55.00	15.00	25.00	20.00	20.00	25.00	130.00	130.00	150.00	380.00
5	15.00	15.00	25.00	20.19	20.42	25.00	129.90	129.96	454.88	164.65
6	15.00	15.10	25.00	20.00	20.00	25.00	20.00	130.00	374.90	455.00
7	15.00	15.00	25.00	20.00	20.00	25.00	130.00	130.00	455.00	315.00
8	15.00	15.00	25.00	20.00	43.17	25.00	129.82	20.00	454.28	452.73
9	15.00	15.00	25.10	30.32	20.00	25.00	129.68	129.95	455.00	454.95
10	15.00	15.10	25.00	80.00	79.70	25.00	130.00	130.00	453.00	447.30
11	55.00	15.00	25.00	80.00	80.00	25.00	130.00	130.00	455.00	455.00

12	15.00	15.20	85.00	80.00	80.00	54.80	130.00	130.00	455.00	455.00
13	15.00	15.00	25.00	20.00	20.00	162.00	130.00	130.00	455.00	428.00
14	15.00	15.00	25.00	39.25	20.00	25.00	130.00	130.00	445.75	455.00
15	15.00	15.00	25.00	20.00	20.00	25.00	130.00	130.00	365.00	455.00
16	55.00	15.00	25.00	20.00	79.90	25.10	130.00	130.00	455.00	155.00
17	15.00	15.00	25.00	20.00	20.00	25.00	20.00	130.00	455.00	275.00
18	15.00	15.10	25.10	76.92	77.10	25.10	130.00	130.00	150.73	454.95
19	15.00	15.00	25.00	20.00	20.00	25.00	130.00	130.00	455.00	365.00
20	15.00	15.00	25.00	79.81	79.76	25.00	129.73	130	451.35	449.35
21	15.00	15.00	25.00	43.74	20.00	25.00	129.83	129.83	444.80	451.80
22	15.00	15.00	25.00	20.00	80.00	25.00	130.00	130.00	455.00	205.00
23	15.00	15.00	25.00	20.00	20.00	25.00	130.00	130.00	150.00	370.00
24	15.00	15.00	85.00	80.00	20.00	25.00	130.00	130.00	150.00	150.00

6. Conclusion

The purpose of this article is solving economic dispatch in the electricity market with the aim of maximizing the total profit of cooperative generation units in a competitive electricity market. According to some limitations of the classic methods and also, in order to increase speed and flexibility of resolving the problem, in this paper, a new metaheuristic optimization method is applied. The suggested approach that combines shuffled Frog-leaping algorithm and particle swarm algorithm is called improved particle swarm algorithm. The proposed algorithm was implemented in two case study systems, 10-units and 15-units, and the results were compared with a conventional PSO algorithm. According to the simulation results, the total profit of generating units that are using an improved PSO algorithm is higher than a conventional PSO algorithm. As a consequence, the corresponding generation planning is more efficient, which leads to a less operating cost.

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