Integer Coded Radial Movement Optimization Technique for Solving the Economic Dispatch Problem with Multiple Fuel Options

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Abstract- *The aim of the economic dispatch (ED) problem is the allocation of generation to the power generators in such a way that the total fuel cost is minimized by satisfying all the operating constraints. For the ED problem in power systems, it is difficult to obtain the global optimal solution using mathematical approaches. In this paper, a novel method called integer coded radial movement optimization (ICRMO), is developed to solve the optimal generation dispatch problem with multiple fuel options in a power system. Generally, for this type of economic dispatch (ED) problem, the cost function for each generator in fossil fuel thermal power plant is approximately given by a single quadratic function. Hence the generation cost is expressed by a segmented piecewise quadratic functions. The proposed ICRMO technique with Lagrangian method is implemented to a ten unit ED problem with piecewise objective functions. The results obtained were compared in terms of cost and computational time, with various reported methods. The results show that the proposed method yields quality solution with lesser computation time.*

Keywords- Optimization, multi fuel option, economic dispatch, radial movement optimization

I. INTRODUCTION

One of the important optimization problems in the economic operation of power systems is economic dispatch (ED) problem.The objective of economic dispatch is to find the optimum number of units to meet the power demand in most economical way by satisfying the physical and operational constraints. In fossil fuel plants, the cost of power generation isvery high and economic dispatch helps in saving a significant amount of cost. The multiple fuel generation units consist of various fuels like gas,oil, coal, etc. are facing with the problem of determining the most economical fuel to burn. Since the cost of fossil fuel increases, it becomes even more important to have a good model for the production cost of each generation unit. The segmented-piecewise quadratic function is used to represent the cost function of power generation using these fossil thermal units.Conventional method yields good results, but they are complicated and its convergence ratio is slow. Alsothey always givethe optimal solution when the search space is non-linear and has discontinuities. Hence it is necessary to adopt artificial intelligence to overcome these difficulties, especiallythose with high-speed search to the optimal and not beingtrapped in local minima[1].

During the past decades, many techniques have been employed to solve the economic dispatch problem with multiple fuel options. Lin and Viviani (1984) [2] used the numerical approach of the Lagrangian function for solving the economic dispatch problem with segmented piecewise quadratic cost functions. Park et al., (1993) [3] presented a solution to the economic dispatch problem with a piecewise-quadratic cost function by using traditional the Hopfield neural network (HNN). Lee et al., (1998) [4]proposed solutions to the economic dispatch problem using adaptive hopfield neural networks (AHNN) and Jayabarathi and Sadasivam (2000) [5] employed an evolutionary programming approach to do the same work.Economic load dispatch (ELD) problems with piecewise quadratic cost functions and nonlinear constraints are solved by Enhanced Lagrangian Neural Network (ELNN) [6] and Improved Genetic Algorithm (IGA) [7]. Various evolutionary programming techniques [8], Taguchi method [9], Particle swam optimization [10]were employed to solve the ED problem with multiple fuel options.

Parket al., [11]executed improved particle swam optimization (IPSO) to solve the economic dispatch problem with multi-fuel option.An adaptive-improved genetic algorithm for the economic dispatch of units with multiple fuel options has been done by Chiang and Su (2005) [12]. Manoharan and Kannan (2008) [13] implemented the evolutionary programming with Levenberg- Marquards optimization (EPLMO) for solving the multi fuel option problem. In the past few years, few works has been carried out to solve the multiple fuel option using various stochastic methods like Evolutionary Programming with Levenberg-Marquardt Optimization (EPLMO) [14], Composite cost function(CCF) [15], Hopfield Lagrange network [16], firefly algorithm[17], ISPO [18], Flower Pollination Algorithm[19].

An efficient tool, for global optimization of multivariable complex system, called Radial Movement Optimization (RMO) was developed by Rasoul Rahmani and RubiyahYusof (2014) [20]. RMO has an edge over other search techniques as it requires a smaller memory and due to its ability to carry out better and denser search around the target [20].

In this paper, an integer coded radial movement optimization algorithm is proposed for solving an economic dispatch problem i.e. multi fuel option in thermal power plants and the results are compared with other stochastic methods. This algorithm requires small memory storage for the data saved and transferred between the iterations.

II. PROBLEM FORMULATION

The main objective of ED problem is to evaluate the combination of power generation that will minimize the total generation by satisfying all the constraints. The input – output curve of a generator with multiple fuel option can be represented by piecewise quadratic function. The cost curve is divided into k discrete regions for a generator with k fuel options between lower and upper levels. The economic dispatch problem is written in terms of piecewise quadratic function as

Minimize $\sum_{i=1}^{n} F_i(P_i)$

$$F_i(P_i) = \begin{cases} a_{i1}P_i^2 + b_{i1}P_i + c_{i1}, & \text{fuel 1}, \quad P_i^{min} \le P_i \le P_{i1} \\ a_{i2}P_i^2 + b_{i2}P_i + c_{i2}, & \text{fuel 2}, \quad P_{i1} < P_i \le P_{i2} \\ \vdots \\ a_{ik}P_i^2 + b_{ik}P_i + c_{ik}, & \text{fuel k}, \quad P_{ik-1} < P_i \le P_i^{max} \end{cases} \quad (1)$$

Where $F_i(P_i)$ - Fuel cost function

P_i – Power output of the ith unit

N – Number of generating units in the system

a_{ik}, b_{ik} and c_{ik} – Cost coefficients of the ithunit using fuel type k

Minimization of the generation cost is subjected to the following constraints

Power balance constraints

$$\sum_{i=1}^{n} P_i = P_D \quad (2)$$

Where P is the total system demand in MW

Generating capacity constraints

$$P_i^{min} \le P_i \le P_i^{max} \quad (3)$$

Where P_i^{min} and P_i^{max} – Minimum and maximum power outputs of the ith unit

III. ECONOMIC DISPATCH PROBLEM – LAGRANGIAN MULTIPLIER APPROACH

The power generation from each unit must be allocated optimally with the given choice of fuel options to minimize the total operating cost of the various power generating unit. It is given by:

$$Min\ F = \sum_{i=1}^{n} F_i(P_i) = \sum_{i=1}^{n} a_i^e P_i^2 + b_i^e P_i + c_i^e \quad (4)$$

subject to the equality and inequality constraint

$$\sum_{i=1}^{n} P_i = P_D\ MW \quad (5)$$

$$P_{ik}^{min} \le P_i \le P_{ik}^{max} \quad (6)$$

Where $a_i^e = a_{ik}$, $b_i^e = b_{ik} and\ c_i^e = c_{ik}$, $i = 1, 2, \ldots, n, k = 1, 2, \ldots, l$ are the possible fuel options for the ithgenerating unit, $P_{ik}^{min}\ and\ P_{ik}^{max}$ are the minimum and maximum power output ofithunit using*k* the fuel type.

Minimization of total operating cost can be achieved by satisfying the condition

$$\frac{dF_i}{dP_i} = \lambda, i = 1,2, \ldots \ldots n \quad (7)$$

Where λ is the incremental fuel cost of the *i*th generating unit in $/MWh. The coordination equation is

$$\frac{dF_1}{dP_2} = \frac{dF_2}{dP_2} = \cdots = \frac{dF_n}{dP_n} = \lambda \quad (8)$$

Equation (8) is written as

$$2(a_i^e P_i) + b_i^e = \lambda, i = 1,2, \ldots, n \quad (9)$$

Therefore, the individual unit generation is written as

$$P_i = \frac{\lambda}{2a_i^e} - \frac{b_i^e}{2a_i^e}\ MW \quad (10)$$

The total generation of the units should satisfy the total load demand, that is,

$$P_1 + P_2 + \cdots + P_n = P_D \quad (11)$$

$$\frac{\lambda - b_1^e}{2a_1^e} + \frac{\lambda - b_2^e}{2a_2^e} + \cdots + \frac{\lambda - b_n^e}{2a_n^e} = P_D \quad (12)$$

λ value is calculated using (9)

$$\lambda = \frac{2P_D + K_1}{K_2} \quad (13)$$

Where $K_1 = \sum_{i=1}^{n} \frac{b_i^e}{a_i^e}$ and $K_2 = \sum_{i=1}^{n} \frac{1}{a_i^e}$. For the given load demand and fuel type for each unit, the optimal generation schedule can be obtained from eq .(10).

IV. INTEGER CODED RADIAL MOVEMENT OPTIMIZATION (ICRMO) BASED ECONOMIC DISPATCH WITH MULTIPLE FUEL OPTION

The proposed hybrid ICRMO algorithm (Fig.1) is a combination of integer coded radial movement optimization and Lagrangian multiplier approach for solving the economic load dispatch problem with multiple fuel options. It is desired to operate all the committed units to meet the total demand P_D at minimum cost with the optimal choice of fuel for each unit. In order to minimize the search region, the fuel options of each unit are taken as the control variable and the fitness function of the agents are calculated by the Lagrangian multiplier algorithm.

Step – I: Initialization

The initial particles in the search space are randomly generated within their limits. The control variables are fuel options and the size of initial population is n x m matrix. Here n is the number of particles and m is the number of control variable. The initial population is represented as

$$X_{ij} = \begin{bmatrix} X_{1,1} & X_{1,2} & \cdots & X_{1,n} \\ X_{2,1} & \ddots & \cdots & \vdots \\ \vdots & \cdots & \ddots & \vdots \\ X_{m,1} & X_{m,2} & \cdots & X_{m,n} \end{bmatrix} \quad (14)$$

Where i = 1, 2, 3….. m and j = 1, 2, 3….n. The initial population vector consists of various possible combinations of fuel options. The population vector consists of integer variables

Step – 2 : Generate the initial velocity vector

The velocity vector v_{ij} is randomly generated using the following equation

$$V_{ij} = rand\,(0,1) \times V_{\max(j)} \quad (15)$$

$$V_{max}(j) = \frac{X_{\max(j)} - X_{\min(j)}}{K} \quad (16)$$

K is an integer number which is choosen judiciously. X_{max}(j) and X $_{min}$ (j) are the minimum and maximum limits of j^{th} control variable respectively.

Step – 3: Locate the center point

The optimal generation schedule for each vector is calculated using equ (10). The fitness of each particle in the population vector is estimated using the following equation

$$F_t = \sum_{i=1}^{n} F_i\,(P_i) + W(\sum_{i=1}^{n} P_i - P_D)^2 \quad (17)$$

Where w is the penalty factor

The population vector which gives the minimum fitness value is chosen as the initial center point (C_p) and it is the gbest vector in the initial population.

Step – 4: To find the radial movement

The radial movement of the particles from the center point Cp is given by

$$U_{ij} = round\,(W \times V_{ij} + center\,(j)) \quad (18)$$

W is the inertial weight which is calculated in each iteration using

$$W = W_{max} - \left(\frac{W_{max} - W_{min}}{Generation_{max}}\right) \times Generation \quad (19)$$

W_{max} is fixed as 1 and W_{min} is fixed as 0

Here the particles are sprinkled. If any control variable in the population in the population vector V_{ij}violates their maximum or minimum limits then that variable is fixed at their violated limit.

The fitness of each vector in the population U_{ij} is evaluated. The particle which gives the minimum error is selected as radial best (Rbest)vector. The new center location (center 1) is updated using the following equation

$$Center^{K+1} = round\,(Center^K + (C_1[G_{best} - Center^K]) + +(C_2[R_{best} - Center^K])) \quad (20)$$

where K is the iteration number.

The fitness of radial best vector is compared with the fitness of global best (Gbest) vector. If R best is better than Gbest, Gbest is replaced by Rbest.

The convergence of radial movement optimization is improved by generating number of trial vectors around the Gbest using

$$V_{ij} = round\,(G_{best} + unifrnd(0,1) * (U_{r1j} - U_{r2j})) \quad (21)$$

i = 1, 2,….m; j = 1, 2, ….n

where r_1 and r_2 are randomly selected vector which are mutually different from each other.

The fitness of each vector in V_{ij} is evaluated and are compared with Gbest. If the fitness of trial vector is better than Gbest, trial vector replaced the Gbest vector. This step is repeated for Nt times for each vector in every iteration.

The iteration is incremented by 1. The steps 2 – 4 is repeated for predefined iterations.

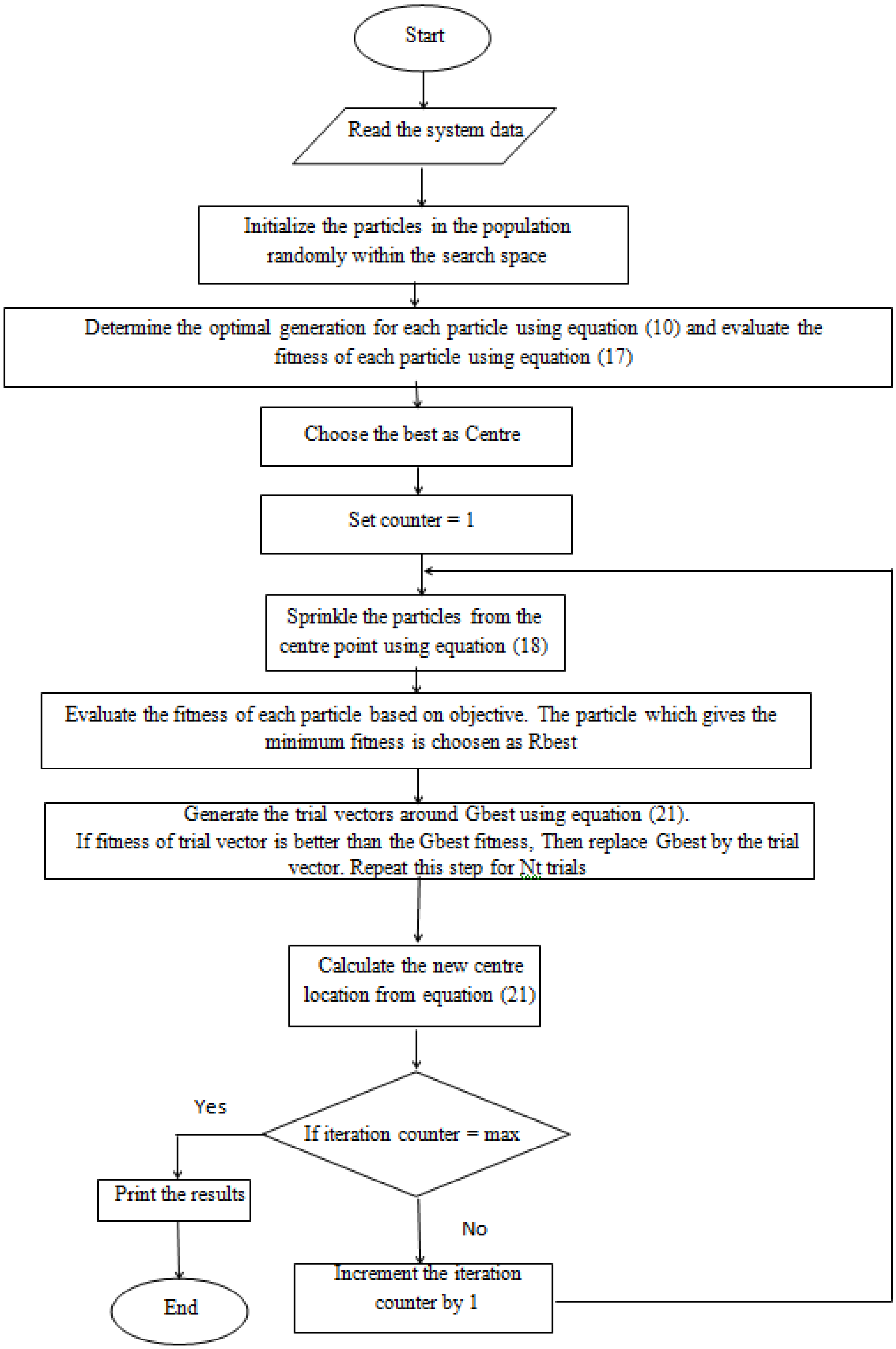

Fig. 1.Flowchart for fuel cost parameter estimation using ICRMO

V. RESULTS AND DISCUSSION

In this work, to evaluate the efficiency of the proposed ICRMO technique, ten various fuel generating units with multiple fuel option were considered. There are three different types of fuels: Type 1, 2, and 3. Total power demands were varied as 2400 MW,2500 MW, 2600 MW and 2700 MW. This ED problem includes one objective function with ten variable parameters (P1,P2, …, P10), one equality and twenty inequality constraints i.e. power balance constraint, maximum and minimum limits of each generating unit. The system data and related constraints are collected from ref. [21]. The initial population of the ICRMO contains random choice of generation between minimum and maximum generation limits of each unit. The following control parameter has been chosen after the number of trials: population size – 20; C_1 – 0.8; C_2 – 0.9. Integer coded radial movement optimization technique is employed to test different types of thermal generating units for finding the best solution. The ED problem is solved in MATLAB 2011 in a CPU with Intel Core i3 PU with 2 GB RAM and the simulation results were presented in Table 1- 5. The ICRMO is applied to the multiple fuel option described in equation (19) and the results are analyzed. The data collected from the literature [2-5, 22, 23] were used to compare with the obtained results.

The optimal fuel combination generation schedule, total costs (TC) and computational times (CT) results obtained for various fuel generating units using ICRMO are tabulated in Table 2-5. The results obtained in this study were compared with various techniques like HM [2], HNN [3], Adoptive hopfield neural network [4], hybrid real coded genetic algorithm (HGA) [5] and hybrid integer coded differential evolution (HICDE) [23] and the results were also given in Table 2-5. From the tables it was found that the proposed technique outperformed other techniques except HGA and HICDE.The best, average and worst operating costs determined from the trials using the ICRMO method are almost same. They are \$/h 481.7226, \$/h 526.2388, \$/h 574.3808 and \$/h 623.8093 respectively for 2400, 2500, 2600 and 2700 MW. From the results, it is clear that the total cost by ICRMO equals Hybrid ICDE for all cases. But, ICRMO has shorter computation time than HICDE, RGA and hybrid RGA for all cases. The proposed ICRMO method gives solution almost equal quality solution when compared to HM [2], HNN [3], AHNN [4], HGA [5]at 2,400, 2500 and 2600 MW case. The proposed method also obtains better solution than others vizHM, HNN, AHNN, HGA at 2700 MW case. Also at 2700 MW load case, ICRMO get the lower total cost than other methods. Furthermore, the computation time by ICRMO is less than all other methods. ICRMO seems to be a good method for solving ELD problem. In fact, it gets good solution and takes short computation time. The convergence is shown in Fig. 2. From the figure it is inferred that the proposed technique converged to a better solution within the first 35 iterations.

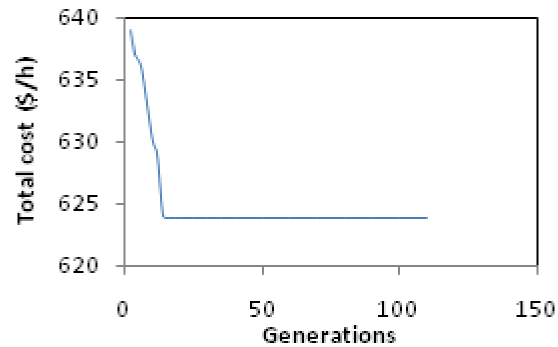

Fig. 2.Convergence characteristics of ICRMO for load demand of 2700 MW

VI. CONCLUSIONS

In this work, an improved radial movement optimization technique is employed for solving the ED problem with non-smooth cost functions considering multiple fuels option. The feasibility of the proposed method for solving ED problem was presented by considering nonlinearities due to multiple fuel options. The ICRMO algorithm efficiently searches and actively explores the solution, and efficaciously handles constraints of the system. The proposed ICRMO algorithms have been successfully applied to economic dispatch problems of 10 Unit generating system. The proposed ICRMO has found better solutions with lesser computation time than the other existing methods so far. The results clearly show that the proposed ICRMO framework can be used as an efficient optimizer providing satisfactory solutions for general non convex economic dispatch problems. Also the results show its potential for solving different types of economic dispatch problems in a power system.

Table 1 Simulation results and its comparison with other methods

Demand (MW)	Solution	Real coded GA	Hybrid real coded GA	Hybrid ICDEDP	Proposed method
2400	Best	481.7233	481.7266	481.7226	481.7226
	Average	481.7234	481.7227	481.7226	481.7226
	Worst	481.7235	481.7230	481.7226	481.7226
	Function eval.	19704	4616	984	780
	Time(s)	-	-	0.490	0.381
2500	Best	526.2393	526.2388	526.2388	526.2388
	Average	526.2396	526.2390	526.2388	526.2388
	Worst	526.2407	526.2404	526.2388	526.2388
	Function eval.	19824	4615	1195	962
	Time(s)	-	-	0.593	0.412
2600	Best	574.3966	574.3808	574.3808	574.3808
	Average	574.4010	574.3808	574.3808	574.3808
	Worst	574.4050	574.3808	574.3808	574.3808
	Function eval.	13313	3954	1178	996
	Time(s)	-	-	0.573	0.428
2700	Best	623.8094	623.8092	623.8092	623.8092
	Average	623.8099	623.8093	623.8092	623.8092
	Worst	623.8106	623.8096	623.8092	623.8092
	Function eval.	18565	4321	1013	985
	Time(s)	-	-	0.513	0.418

Table 2 Simulation results and its comparison with other methods 2400 MW power demand

	HM		HNN		AHNN		HGA		ICRMO	
Methods Unit	Fuel type	Gen	Fuel type	Gen	Fuel type	Gen	Fuel type	Gen	Fuel type	Gen
1	1	193.2	1	192.7	1	189.1	1	181.7551	1	189.7405
2	1	204.1	1	203.8	1	202.0	1	202.3514	1	202.3427
3	1	259.1	1	259.1	1	254.0	1	253.8796	1	253.8953
4	3	234.3	2	195.1	3	233.0	3	233.0430	3	233.0456
5	1	249.0	1	248.7	1	241.7	1	241.8098	1	241.8297
6	1	195.5	3	234.2	3	233.0	3	233.0517	3	233.0456
7	1	260.1	1	260.3	1	254.1	1	253.2890	1	253.2750
8	3	234.3	3	234.2	3	232.9	3	233.0521	3	233.0456
9	1	325.3	1	324.7	1	320.0	1	320.3754	1	320.3832
10	1	246.3	1	246.8	1	240.3	1	239.3929	1	239.3969
TP (MW)		2401.2		2399.8		2400.0		2400.0		2400.0
TC ($/h)		488.500		487.870		481.700		481.7226		481.7226

Table 3 Simulation results and its comparison with other methods for 2500 MW power demand

Methods	HM		HNN		AHNN		HGA		ICRMO	
Unit	Fuel type	Gen	Fuel type	Gen	Fuel type	Gen	Fuel type	Gen	Fuel type	Gen
1	2	206.6	2	206.1	2	206.0	2	206.5422	2	206.5190
2	1	206.5	1	206.3	1	206.3	1	206.4582	1	206.4573
3	1	265.9	1	265.7	1	265.7	1	265.7636	1	265.7391
4	3	236.0	3	235.7	3	235.9	3	235.9436	3	235.9531
5	1	258.2	1	258.2	1	257.9	1	257.9942	1	258.0177
6	3	236.0	3	235.9	3	235.9	3	235.9546	3	235.9531
7	1	269.0	1	269.1	1	269.6	1	268.8709	1	268.8635
8	3	236.0	3	235.9	3	235.9	3	235.9425	3	235.9531.
9	1	331.6	1	331.2	1	331.4	1	331.4712	1	331.4877
10	1	255.2	1	255.7	1	255.4	1	255.0589	1	255.0562
TP (MW)		2501.1		2499.8		2500.0		2500.0		2500.0
TC ($/h)		526.700		526.13		526.230		526.2388		526.2388

Table 4 Simulation results and its comparison with other methods for 2600 MW power demand

Methods	HM		HNN		AHNN		HGA		ICRMO	
Unit	Fuel type	Gen	Fuel type	Gen	Fuel type	Gen	Fuel type	Gen	Fuel type	Gen
1	2	216.4	2	215.3	2	215.8	2	216.5442	2	216.5442
2	1	210.9	1	210.6	1	210.7	1	210.9058	1	210.9058
3	1	278.5	1	278.9	1	279.1	1	278.5441	1	278.5441
4	3	239.1	3	238.9	3	239.1	3	239.0967	3	239.0967
5	1	275.4	1	275.7	1	276.3	1	275.5194	1	275.5194
6	3	239.1	3	239.1	3	239.1	3	239.0967	3	239.0967
7	1	285.6	1	286.2	1	286.0	1	285.7170	1	285.7170
8	3	239.1	3	239.1	3	239.1	3	239.0967	3	239.0967
9	1	343.3	1	343.5	1	342.8	1	343.4934	1	343.4934
10	1	271.9	1	272.6	1	271.9	1	271.9861	1	271.9861
TP(MW)		2599.3		2599.8		2599.9		2600.0		2600.0
TC($/h)		574.030		574.26		574.370		574.3808		574.3808

Table 5 Simulation results and its comparison with other methods for 2700 MW power demand

Methods	HM		HNN		AHNN		HGA		ICRMO	
Unit	Fuel type	Gen	Fuel type	Gen	Fuel type	Gen	Fuel type	Gen	Fuel type	Gen
1	2	218.4	2	224.5	2	225.7	2	218.2559	2	218.2499
2	1	211.8	1	215.0	1	215.2	1	211.6816	1	211.6626
3	1	281.0	1	291.8	1	291.8	1	280.7359	1	280.7228
4	3	239.7	3	242.2	3	242.3	3	239.6298	3	239.6315
5	1	279.0	1	293.3	1	293.7	1	278.4819	1	278.4973
6	3	239.7	3	242.2	3	242.3	3	239.6508	3	239.6315
7	1	289.0	1	303.1	1	302.8	1	288.5721	1	288.5845
8	3	239.7	3	242.2	3	242.3	3	239.6280	3	239.6315
9	1	429.2	1	355.7	1	355.1	1	428.5175	1	428.5216
10	1	275.2	1	289.5	1	288.8	1	274.8466	1	274.8667
TP(MW)		2702.2		2599.8		2700.0				2700.0
TC($/h)		625.180				626.240				623.8092

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