SERBIAN JOURNAL OF ELECTRICAL ENGINEERING
Vol. 13, No. 3, October 2016, 347-360

UDC: 621.311.24:004.414.23]:33 **DOI: 10.2298/SJEE1603347S**

Artificial Bee Colony Algorithm for Economic Load Dispatch with Wind Power Energy

Amin Safari[1], Davoud Moghaddam Sheibai[2]

Abstract: This paper presents an efficient Artificial Bee Colony (ABC) algorithm for solving large scale economic load dispatch (ELD) problems in power networks. To realize the ELD, the valve-point loading effect, system load demand, power losses, ramp rate limits and prohibited operation zones are considered here. Simulations were performed on four different power systems with 3, 6, 15 and 40 generating units and the results are compared with two forms of power systems, one power system is with a wind power generator and other power system is without a wind power generator. The results of this study reveal that the proposed approach is able to find appreciable ELD solutions than those of previous algorithms.

Keywords: Artificial Bee Colony, Economic Load Dispatch, Wind Power Generator, Valve Point Loading Effect.

1 Introduction

Wind energy has become an increasing source of electrical energy generation in recent years. For this reason, it is important to study the possible impact a wind power generation on the power network where it is connected. Therefore, economic load dispatch (ELD) with wind power generation is one of the important optimization problems in the operation of modern power system. For this reason, that is used to determine the optimal combination of electrical power outputs of all generating units to minimize the total fuel cost while satisfying various constraints over the entire dispatch periods.

Over the last few years, various solutions have applied to solve ELD problems by different classic programming methods and optimization techniques in the literatures. Such classical optimization methods [1] are highly sensitive to starting points and often converge to local optimum or diverge altogether. Lately, heuristic search techniques such as bacterial foraging algorithm [2], Genetic algorithm [3], Wait-and-See approach [4], evolutionary algorithm [5], Artificial Bee Colony [6], Gravitational search algorithm [7] and

[1]Department of Electrical Engineering, Azarbaijan Shahid Madani University, Tabriz, Iran;
E-mail: safari@azaruniv.edu;
[2]Engineering Department of Pars Oil and Gas Company (POGC), Iran

Here-and-Now approach [8] are being used to find global or near global optimal solution.

Several approaches have been proposed to model the specific intelligent behaviors of honey bee colonies and applied for solving combinatorial type problems. The behavior of honey bees shows many characteristics like synergy and cooperation, so honey bees colonies have aroused great interests in modelling intelligent performance these years [9, 10], but these algorithms are most mechanism by the marriage in bees. This algorithm considered an artificial bee colony as dynamical system gathering information from an environment and regulating its behavior in accordance to it. They instated a robotic idea on the foraging behavior of bee colonies. Usually, all these robots are physically and functionally identical, so that any robot can be randomly substituted by the others. The colony possesses a significant tolerance, the failure in a single agent does not stop the performance of the whole system. The individual robots, like to have limited capabilities and limited knowledge of the environment. On the other hand, the colony extends collective intelligence.

In our study, we compare the two forms of electrical network performance of the ABC algorithm. This paper is organized as follows: Section 2 presents the formulation of ELD problems. Section 3 presents the formulation of ELD problems with wind power penetration. Section 4 then describes the ABC algorithm. A detailed process of using the ABC method to solve the ELD problems is presented in Section 5. Section 5 shows four application cases using the proposed method to solve the ELD problems and the results have been compared two forms of power network.

2 Economic Load Dispatch Formulation

The ELD problem is minimizing the fuel cost of generation units so as to accomplish optimal generation dispatch among operating units and in return satisfying the system load demand and losses, generator operation constraints.

2.1 Objective function

The cost function of ELD corresponding to the total generation cost is approximated by a quadratic function of the power output of the generating units. It can be mathematically described as follows [2]:

$$F_T = \sum_{i=1}^{Ng} F_i(P_i) = \sum_{i=1}^{Ng} (a_i P_i^2 + b_i P_i + c_i) \,. \tag{1}$$

Because the fuel cost is the main factor in determining the economic operation, the fuel input-output curves are important. In this curve, the slope of the curve at any point is efficiency of generative unit fuel at that point. Power cost function is not always a convex and due to the effects of some steam valves and it has a non-convex shape and form of this cost function equation, is considered to be in two sentences. The input-output characteristic curve of large steam turbine generators is not always convex and smooth. This type of generation units has some supply steam valves, upon increase production request the valves open one by one and respectively for increasing output power. When the unit load's increase, the input (fuel) to the unit increases, and between points in each of the two valves open, the incremental heat rate increases, however, when the valve is first opened, due to rapid losses the throttling, the incremental heat rate to be large and suddenly rise, which will rise to discontinuities in the incremental heat rate characteristic. The valve point loading effects introduce ripples in the heat rate curves and make the cost function discontinuous, non-convex and multiple minimum [11]. One of the ways to model the valve effect is adding a second sentence to the *sine* function for the generator cost function. These features are non-convex and could not easily used in optimization methods that need convex characteristics.

$$C=\sum_{i=1}^{Ng}F_i(P_i)=\sum_{i=1}^{Ng}\left(a_i\times P_i^2+b_i\times P_i+c_i+\left|e_i\times\sin\left(f_i\times(P_i^{\min}-P_i)\right)\right|\right). \quad (2)$$

2.2 Equality and Inequality constraints

2.2.1 Power balance

A fundamental constraint on the operation of this system is known as the power balance constraint, so that the total power output $(\sum_{i=1}^{Ng}P_i)$ must be equal to the total load (P_D) and total loss of the system (P_L). Namely:

$$P_L+P_D=\sum_{i=1}^{Ng}P_i. \quad (3)$$

System losses equation is a function of the *B* coefficients and the sum of the generators generation. The most famous system loss equation is the formula known as Kron (4). It is noticeable that using any other loss function (E.g. Jorge equation ($P_L=\sum_{i=1}^{Ng}\sum_{j=1}^{Ng}P_i\times B_{ij}\times P_j$) and …) for ELD will produce the same results and only will change cost [12]. The *B* coefficient matrixes are achieved by using a series of conversions on the total impedance matrixes related to the transmission network.

$$P_L=B_{00}+\sum_{i=1}^{Ng}B_{0i}\times P_i+\sum_{i=1}^{Ng}\sum_{j=1}^{Ng}P_i\times B_{ij}\times P_j. \quad (4)$$

2.2.2 Generator ramp rate limits

Often, it is supposed that the output of the generating units, soft and instantly adjusts to changing times and changes consumable load. But in reality, when the consumable load changes, the unit output can not change, and interval operation of production units within the production is into ramp rate limitation. District operation of all production units being produced by the limit, i.e. up rate limit UR_i, within the previous down rate limit DR_i and P_i^0 are finite. When the ramp rate limitation of generator is proposed, namely the operation of the *i*th unit has been changed as follows:

$$\text{Max}\left(P_i^{\min},\ P_i^0 - DR_i\right) \le P_i \le \text{Min}\left(P_i^{\max},\ P_i^0 + UR_i\right). \tag{5}$$

2.2.3 Prohibited operating zone

Generators are practically discontinuous cost curve, as all units operating ranges (between maximum production and minimum production) for the work is not always possible. In other words, generating units due to some faults on the shaft bearing or mechanical vibrations or other accessories such as pumps, compressors or boilers, etc., are prohibited operating zone [13]. The prohibited operating zone, loading within a unit is divided into several maximum and minimum generating ranges. Due to the following number sub zone convex regions, the total cost curve of the piece-the piece. Best economy is achieved when the operating units don't be in these prohibited zones. A production unit with a prohibited operating zone, input-output characteristic curve is discontinuous. The forbidden operating zone can be exploited for ELD issues to be formulated this way [14]:

$$P_i \in \begin{cases} P_i^{\min} \le P_i \le P_{i1}^{L} \\ P_{ik-1}^{U} \le P_i \le P_{ik}^{L} \\ P_{izi}^{U} \le P_i \le P_i^{\max} \end{cases}. \tag{6}$$

P_i is the electrical output of the *i*-th generator, $P_i^{\min}$ and $P_i^{\max}$ are lower and upper bounds for power outputs of the *i*-th generating unit.

3 Wind Power Generation

Equation (3) is modified so that the power generated by wind source P_w is deducted from the total power demand [2].

$$P_L + P_D = \sum_{i=1}^{Ng} P_i + P_w. \tag{7}$$

The wind power (P_w) in (7) is limited by the availability amount from the wind park P_{av} [2]

$$P_L + P_D - \sum_{i=1}^{Ng} P_i \le P_{av}. \tag{8}$$

4 ABC Algorithm

Colonies of social insects such as bees have instinct ability recognized as swarm intelligence. This type of intelligent, organized behavior enables the populations of insects to optimize the engineering problems beyond capability of individual members of functioning collectively and interacting primitively amongst members of the population. This behavior allows that honey bees to explore the environment in search of flower patches (food sources) and then indicate the food source for the other honey bees of the population when they are coming back to the apiary. Such a colony is characterized by self organization, adaptability and robustness [15].

In the ABC algorithm, the colony of honey bees contains three groups of bees: employed, onlookers and scouts bees. In the ABC algorithm, each cycle of the random search contains of three steps: sending the employed bees onto the food sources and then measuring their molasses amounts, selecting of the food sources by the onlooker bees after sharing the information of employed bees and determining the molasses amount of the feasible food sources, determining the scout honey bees and then sending them on to feasible sources. Therefore, arriving at the selected area, she selects a new source in the neighborhood of the one in the memory depending on feasible information. When the molasses amount of a food source is abandoned by the bees, new sources are randomly specified by scout bees and replaced with the abandoned one. In this structure, at each process at most one scout goes outer space for exploring a new source and the number of onlookers and employed bees were equal [9].

In the ABC algorithm, the position of a food source represents a possible solution of the optimization problem and the nectar amount of a food corresponds to the fitness of the associated solution. Firstly, the ABC algorithm generates a randomly distributed initial population of possible solutions where, it denotes the size of the population. After initialization, the population of the positions is subjected to repeated cycles of the exploration processes of the employed bees, the onlooker bees and scout bees. In this model, the production of a new food source position is also based on a comparison process of food source positions. They randomly select a food source position and produce a modification of the one existing in their memory as described in next section [10].

5 Solution Methodology

Considering the equality and inequality constraints are very difficult to solve these equations, that exclusively we can solve it with the constraints expressed as a function of output units [14]. The optimization process of the ABC algorithm for solving ELD problems can be illustrated as follows:

Step 1: Initialize the population of solutions $x_{i,j}$, $i=1,2,\ldots,D$, $j=1,2,\ldots,N$;

Step 2: Evaluate the population;

Step 3: Produce new solutions (food source positions) $v_{i,j}$ in the neighborhood of $x_{i,j}$ for the employed bees using the formula $v_{i,j}=x_{i,j}+\Phi_{i,j}(x_{i,j}-x_{k,j})$ and evaluate them, $k=1,2,\ldots,D$;

Step 4: Apply the greedy selection between x_i and v_i;

Step 5: find the probability values P_i for the solutions x_i by means of their fitness values using the equation (9):

$$P_i=\frac{fit_i}{\sum_{i=1}^{N} fit_i}. \tag{9}$$

The evaluation function is defined as follows [14]:

$$C=\sum_{i=1}^{Ng}F_i(P_i)+\alpha\left[\sum_{i=1}^{Ng}P_i-P_L-P_D\right]+\beta\left[\sum_{k=1}^{n_i}P_i(violation)_k\right]. \tag{10}$$

where, α is the penalty factor for real power balance constraint, β is the penalty factor for prohibited operating zone constraint, and $P_i(violation)$ is an indicator of falling into the prohibited operating zone. When optimization algorithms are used for constrained optimization problems, it is common to handle constraints using concepts of penalty functions, i.e., one attempt to solve an unconstrained problem in the search space using a modified objective function. The popular penalty function method employs functions to reduce the fitness of the particle in proportion to the magnitude of the constraint violation. The penalty parameters are chosen carefully to distinguish between feasible and infeasible solution. In order to find the fitness values of positions, we employed the following equation (11):

$$fit_i=\begin{cases}\dfrac{1}{1+f_i}, & \text{if } f_i\geq 0,\\[2ex] \dfrac{1}{1+|f_i|}, & \text{if } f_i<0;\end{cases} \tag{11}$$

Normalize P_i values into $[0,1]$;

Step 6: Generate the new positions v_i for the onlooker bees from the positions x_i selected depending on and evaluate them;

Step 7: Apply the greedy selection process for the onlookers between x_i and v_i;

Step 8: Determine the abandoned solution (source), if exists, and replace it with a new randomly produced solutions x_i for the scout using the equation (12):

$$x_{ij} = \min_j + \text{rand}(0,1) \times (\text{Max}_j - \min_j); \tag{12}$$

Step 9: Memorize the best food source solution (position) achieved so far;

Step 10: Continue until termination condition.

6 Case Study

6.1 Problem characteristics and setup for all the referred algorithm

To validate the performance of the proposed ABC efficiently, four standard case studies have been taken from the literature of multi-minima ELD for thorough analysis. The performance of the proposed ABC is compared with those of networks with the following problem setup.

1) In each case study, 50 independent runs were made for each of the networks.
2) In implementation of the proposed algorithm, some ABC parameters should be predefined.
3) We consider the number of iterations to end criteria, and the number of iterations to solve ELD problems for four cases is 200.
4) The initial population and number of food were selected 500 and the generator cost range between the minimum and maximum and the average generator cost is achieved in 20 iterations.
5) The wind generated power share is assumed to be 8% of the total load demand in each of the four case studies.
6) All computation is performed with MATLAB 7.11 and 32-bit microcomputer with Intel Core 2 Duo P8700@2.53GHz CPU and 4 GB RAMs. In order to clarify this issue, we compared the ABC with two power networks.

6.2 Description of the case studies

Case I: The first small case contains three thermal units whose characteristics are given in [13]. The load demand of the system is $P_D = 850\,\text{MW}$. The power network losses are obtained by the *B* matrix loss formula. The characteristics of the three thermal units are shown in [13]. Fig. 1 shows that the convergence characteristics of ABC in the process of searching for the minimum objective function. The best solutions using the proposed ABC are shown in **Table 1** that satisfies the generator constraints to prove its effectiveness. The best solutions using the proposed ABC are shown in **Table 2** that satisfy the generator constraints. It can be evident from **Table 2** that the technique provided better results compared with other reported evolutionary algorithm techniques.

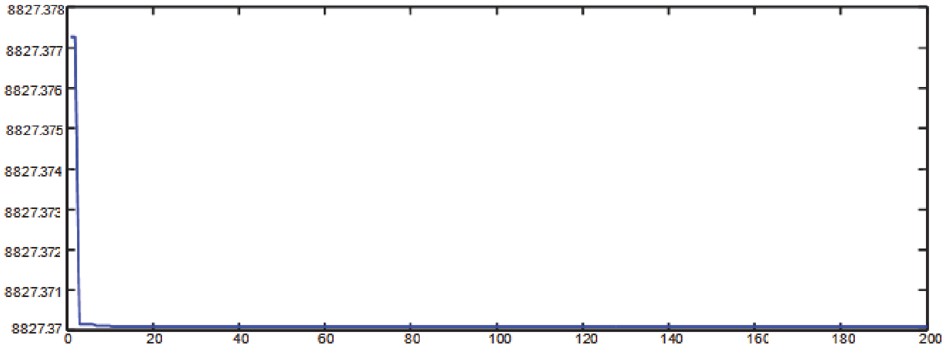

Fig. 1 – *Convergence characteristic of ABC on a system with 3 generators.*

Table 1
The result obtained by different networks for Case I.

Solution Technique	Total Fuel Cost [$/h]			CPU Time [s]
	Best Value	Mean Value	Worst Value	
Generation with wind power	8099.1299839	8099.151135899718	8099.199124728493	30.913651
Generation without wind power	8827.37008605	8827.384720349886	8827.392351727640	30. 475619

Table 2
Best dispatch for Case I.

Unit power output (MW)	ABC		RPSO	CPSO
	Wind power	Without wind power		
P1	302.8768	355.04865	401.98831	390.93977
P2	400	400	294.70046	372.52796
P3	99.23759	119.05966	184.39115	112.7714
Total loss	20.13331	24.134938	31.046463	26.174076

Case II: The second small case contains six thermal generating limits, 26 buses and 46 transmission lines. The consumer demand is $P_D = 1263\,\text{MW}$. The characteristics of the six thermal units are given in [16]. The network losses are calculated by *B*-matrix loss formula. The characteristics of the six thermal units are in [16]. Fig. 2 shows the convergence characteristic of ABC on a system with 6 generators. It can be seen that the convergence characteristic of the proposed method is dramatically improved and the algorithm discovers optimal cost in accepting region by effective control of food sources. **Table 3** presents the best cost achieved by the ABC algorithms in the six unit system. It can be seen from **Table 3** that the ABC perform for networks with a wind power generator better than the ABC perform for networks without a wind power generator. In this second case, the results of numerical simulation of the tested ABC method are shown in **Table 4** that also satisfy the system constraints. It can be seen from **Table 4** that the proposed method performs better than the rough PSO and crazy PSO methods in terms of solution quality.

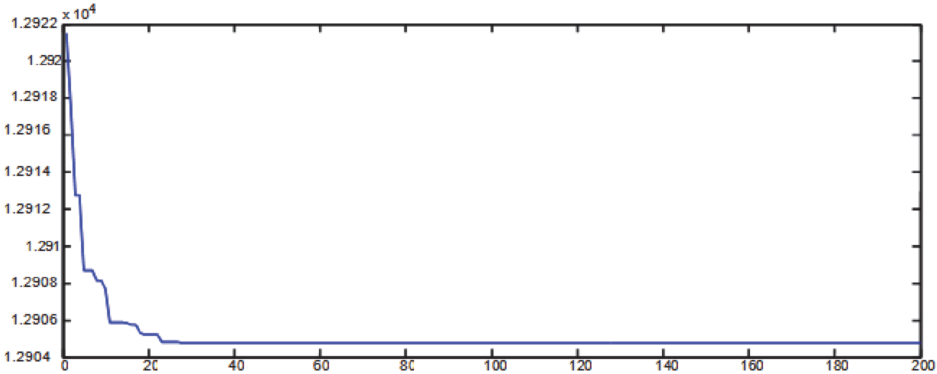

Fig. 2 – *Convergence characteristic of ABC on a system with 6 generators.*

Table 3

The result obtained by different networks for Case II.

Solution Technique	Total Fuel Cost [$/h]			CPU Time [s]
	Best Value	Mean Value	Worst Value	
Generation with wind power	11860.27641578565	11860.29202354726	11860.34230851671	50.484108
Generation without wind power	12904.74621534203	12904.77028013789	12904.79419178760	50. 578770

Table 4

Best dispatch for Case II.

Unit power output [MW]	ABC		RPSO	CPSO
	Wind power	Without wind power		
P1	389.86506	440.02651	442.87502	440.44834
P2	200	200	182.18627	185.77588
P3	221.0957	250.15661	258.25773	255.35009
P4	150	150	134.13769	128.75086
P5	124.40293	138.06887	168.6197	172.35847
P6	86.5246781	96.761467	89.575119	93.092126
Total loss	9.92837498	12.013458	12.594264	12.719708

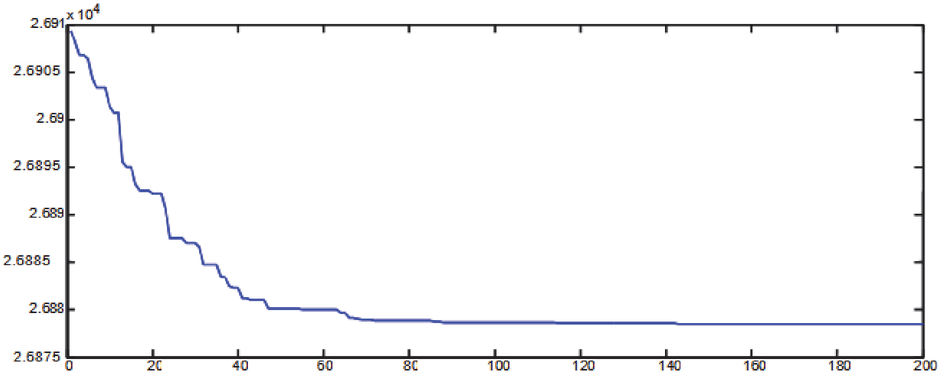

Fig. 3 – *Convergence characteristic of ABC on a system with 15 generators.*

Case III: The system contains fifteen thermal units whose characteristics are given in [16]. The consumer demand of the system is $P_D = 1630\,\text{MW}$. The convergence of optimal solution using ABC is shown in Fig. 3. **Table 5** shows the optimal solutions with execution time determined by ABC for the fifteen units. It can be seen from **Table 5** that the ABC algorithm at network with wind power is significantly better than the other electric network. **Table 6** presents the best solutions achieved by the different algorithms for the 15-unit system while satisfying the constraints.

Case IV: The system contains forty thermal units whose characteristics are given in [17]. The load demand of the system is $P_D = 10500\,\text{MW}$. The network losses are zero. Fig. 4 represents the evolution of the ABC for the forty units test system. Through the evolutionary process of the proposed method, it best solutions are shown in **Table 7**. All of the constraints mentioned before are all satisfied. **Table 8** compares the results obtained in this paper with those of other studies reported in the literature.

Table 5
The result obtained by different networks for Case III.

Solution Technique	Total Fuel Cost [$/h]			CPU Time [s]
	Best Value	Mean Value	Worst Value	
Generation with wind power	24709.93950362974	24711.61972422299	24712.64972755618	55.550193
Generation without wind power	26878.52762530638	26899. 73282161950	26924.0911215852	58. 406801

Table 6
Best dispatch for Case III.

Unit power output [MW]	ABC		RPSO	CPSO
	Wind power	Without wind power		
P1	386.809434	558.33377	398.543207	410.84619
P2	335	335.00547	402.746238	386.29837
P3	130	130	122.93246	101.13023
P4	119.4170826	130	113.926802	66.683741
P5	150.004599	156.43753	172.030308	157.17093
P6	460	460	455.974402	456.97968
P7	452.7370805	465	420.622794	420.10214
P8	60	60	191.320289	254.65885
P9	25	25	108.332484	48.894716
P10	35.8144327	46.121623	33.0232058	114.365
P11	80	80	51.5435669	52.030282
P12	80	80	69.2989878	69.911696
P13	85	85	50.7399075	46.864723
P14	25.84317989	29.480898	26.6673447	39.450851
P15	15	15	46.5571407	44.404067
Total loss	20.88727498	25.121773	34.2693246	39.786492

Table 7
The result obtained by different networks for Case IV.

Solution Technique	Total Fuel Cost [$/h]			CPU Time [s]
	Best Value	Mean Value	Worst Value	
Generation with wind power	97743.63429439227	97751.85564722104	97793.41023808092	71.739589
Generation without wind power	106249.4329921153	106258.4848886936	106269.7597867691	72.006801

Table 8
Best dispatch for Case IV.

Unit power output [MW]	ABC		RPSO	CPSO
	Wind power	Without wind power		
P1	565.769	490.35327	85.841429	96.121065
P2	114	114	107.65707	112.1994
P3	120	120	117.69826	104.61556
P4	155.2758	177.4048	153.02788	113.43586
P5	47	97	92.362998	90.227351
P6	140	140	100.29765	111.26965
P7	216.0025	213.93746	280.74981	249.85306
P8	218.1805	187.10832	257.67519	266.1692
P9	296.0274	266.49795	289.40983	235.1332
P10	181.4354	174.9846	183.83606	181.49639
P11	166.4338	154.39994	212.07973	224.20044
P12	104.364	178.53414	153.36363	211.48815
P13	311.9076	380.65117	371.62959	381.9768
P14	392.8371	442.78967	444.73098	444.97291
P15	352.841	398.19343	396.43807	310.03468
P16	187.2453	354.03762	369.06964	447.6874
P17	343.5384	500	467.15043	419.39658
P18	429.9781	475.91115	477.53097	494.08436
P19	546.7704	482.92021	403.00971	526.08464
P20	443.2867	545.08637	546.95911	483.59595
P21	471.9404	365.51114	451.48031	525.85877
P22	400.8371	509.4237	403.66621	493.01847
P23	385.9699	493.38755	428.22918	542.60422
P24	500.5326	501.94724	539.06536	528.01232
P25	543.841	443.99792	516.34894	453.00172
P26	371.5385	453.38111	529.75683	452.17928
P27	23.62277	24.85781	44.662373	37.209948
P28	24.72683	43.16725	57.900718	62.028842
P29	10	44.51605	69.603842	77.984528
P30	72.41109	47	79.318009	93.608463
P31	187.1033	180.05107	185.89492	155.96307
P32	94.13038	144.11858	189.12158	136.0609
P33	108.9036	155.32745	172.67105	169.43899
P34	96.57297	96.678605	190.94946	148.71601
P35	90	169.39254	179.24313	171.96586
P36	175.4442	147.49768	166.4187	196.12491
P37	98.62625	91.869245	106.61195	106.33922
P38	95.22589	105.51895	87.227424	95.041683
P39	45.63443	75.584052	100.27335	99.990958
P40	530.0458	512.96195	491.79582	450.62382

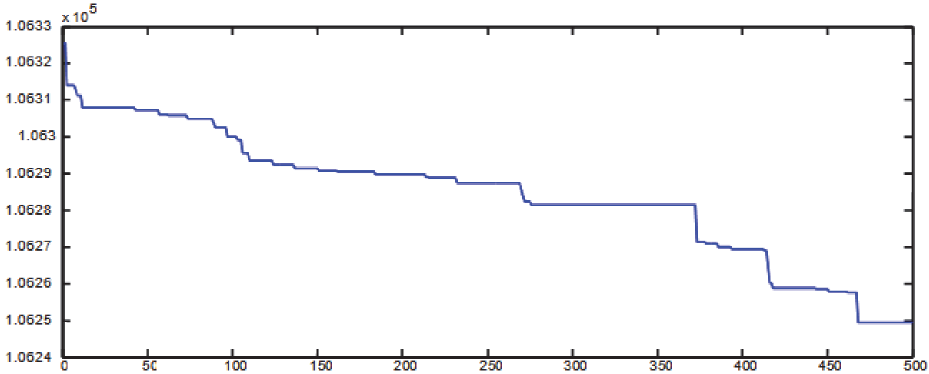

Fig. 4 – *Convergence characteristic of ABC on a system with 40 generators.*

7 Conclusion

In this work, to enrich the searching behavior uses artificial bee colony algorithm. The integration of wind power into generation and its impact on the ELD are explored. The application feasibility of artificial bee colony for solving economic load dispatch with smooth and non-smooth cost function by taking into account of various system constraints have been investigated and analyzed successfully. Furthermore, problem formulation incorporated wind energy to demonstrate and asses the economic benefits of integration wind power plant into power networks. The numerical results obtained for four cases clearly demonstrated that the proposed algorithm which is capable of achieving global solutions is simple, computationally efficient and has stable dynamic convergence characteristics.

8 References

[1] A.J. Wood, B.F. Wollenberg: Power Generation, Operation and Control, John Wiley and Sons, NY, USA, 1984.

[2] I.A. Farhat, M.E. El–Hawary: Dynamic Adaptive Bacterial Foraging Algorithm for Optimum Economic Dispatch with Valve–Point Effects and Wind Power, IET Generation, Transmission and Distribution, Vol. 4, No. 9, Sept. 2010, pp. 989 – 999.

[3] M. Li, J. Wu, J. Zeng, L. Gao: Power Dispatching of Distributed Wind–solar Power Generation Hybrid System based on Genetic Algorithm, International Conference on Power Electrics System and Applications, Hong Kong, 20–22 May 2009.

[4] X. Liu: Economic Load Dispatch Constrained by Wind Power Availability: A Wait–and–see Approach, IEEE Transaction on Smart Grid, Vol. 1, No. 3, Dec. 2010, pp. 347 – 355.

[5] G.C. Liao: A Novel Evolutionary Algorithm for Dynamic Economic Dispatch with Energy Saving and Emission Reduction in Power System Integrated Wind Power, Energy, Vol. 36, No. 2, Feb. 2011, pp. 1018 – 1029.

[6] D.M. Sheibai, B. Mohamadi, A. Safari: Artificial Bee Colony for Large Scale Economic Load Dispatch, International Academic Journal of Innovative Research, Vol. 2, No. 11, Nov. 2015, pp. 12 – 24.

[7] S. Mondal, A. Bhattacharya, S.H. nee Dey: Multi-objective Economic Emission Load Dispatch Solution using Gravitational Search Algorithm and Considering Wind Power Penetration, International Journal of Electrical Power and Energy System, Vol. 44, No. 1, Jan. 2013, pp. 282 – 292.

[8] X. Liu, W. Xu: Economic Load Dispatch Constrained by Wind Power Availability: A Here–and–Now approach, IEEE Transactions on Sustainable Energy, Vol. 1, No. 1, April 2010, pp. 2 – 9.

[9] T.K. Sharma, M. Pant: Enhancing different phases of artificial bee colony for continuous global optimization problems, International Journal of Advanced Intelligence Paradigms, Vol. 5, No. 1/2, 2013, pp. 103 – 122.

[10] J.C. Bansal, H. Sharma, S.S. Jadon: Artificial Bee Colony Algorithm: A Survey, International Journal of Advanced Intelligence Paradigms, Vol. 5, No. 1/2, 2013, pp. 123 – 159.

[11] X. Yuan, A. Su , Y. Yuan, H. Nie, L. Wang: An Improved PSO for Dynamic Load Dispatch of Generators with Valve-point Effects, Energy, Vol. 34, No. 1, Jan. 2009, pp. 67 – 74.

[12] A. Safari, D.M. Sheibai: A Hybrid Rough Set Theory–PSO Technique for Solving of Non–convex Economic Load Dispatch, International Journal of Hybrid Information Technology., Vol. 8, No. 12, Dec. 2015, pp. 283 – 298.

[13] T.C. Krishna, P.L.S. Manjaree: Particle Swarm Optimization with Crazy Particles for Non–Convex Economic Dispatch, Applied Soft Computing, Vol. 9, No. 3, June 2009, pp. 962 – 969.

[14] A. Safari, H. Shayeghi: Iteration Particle Swarm Optimization Procedure for Economic Load Dispatch with Generator Constraints, Expert Systems with Applications, Vol. 38, No. 5, May 2011, pp. 6043 – 6048.

[15] D.T. Pham, A. Ghanbarzadeh, E. Koc, S. Otri, S. Rahim, M. Zaidi: The Bees Algorithm: A Novel Tool for Complex Optimization Problems, Intelligent Production Machines and Systems - 2nd International Virtual Conference on Intelligent Production Machines and Systems, 03-14 July 2006, pp. 454 – 459.

[16] Z.L. Gaing: Particle Swarm Optimization to Solving the Economic Dispatch Considering the Generator Constraints, IEEE Transaction on Power Systems, Vol. 18, No. 3, Aug. 2003, pp. 1187 – 1195.

[17] S.K. Wang, J.P. Chiou, C.W. Liu: Non-smooth/Non–convex Economic Dispatch by a Novel Hybrid Differential Evolution Algorithm, IET Generation, Transmission and Distribution, Vol. 1, No. 5, Sept. 2007, pp. 793 – 803.