Optimal Reactive Power Dispatch Using Artificial Bee Colony Method

Vo Ngoc Dieu, Nguyen Huu Thien An*, and Vo Trung Kien

Abstract— *This paper proposes an artificial bee colony (ABC) algorithm for solving optimal reactive power dispatch (ORPD) problem. The proposed ABC can deal with different objectives of the problem such as minimizing the real power losses, improving the voltage profile, and enhancing the voltage stability and properly handle various constraints for reactive power limits of generators and switchable capacitor banks, bus voltage limits, tap changer limits for transformers, and transmission line limits. The proposed method has been tested on the IEEE 30-bus and IEEE 118- bus systems and the obtained results are compared to those from Particle Swarm Optimizer (PSO), Self-Organizing Hierarchical Particle Swarm Optimizer - Time Varying Acceleration Coefficients (HPSO-TVAC), Particle Swarm Optimization - Time Varying Acceleration Coefficients (PSO-TVAC), and other methods in the literature. The result comparison has shown that the proposed method can obtain total power loss, voltage deviation or voltage stability index less than the others for the considered cases. Therefore, the proposed ABC can be a favorable method for implementation in the optimal reactive power optimization problems.*

Keywords— **Constriction factor, optimal reactive power dispatch, artificial bee colony method, voltage deviation, voltage stability index.**

1. INTRODUCTION

Optimal reactive power dispatch (ORPD) is to determine the control variables such as generator voltage magnitudes, switchable VAR compensators, and transformer tap setting so that the objective function of the problem is minimized while satisfying the unit and system constraints [1]. In the ORPD problem, the objective can be total power loss, voltage deviation at load buses for voltage profile improvement [2], or voltage stability index for voltage stability enhancement [3]. ORPD is a complex and large-scale optimization pro[1]blem with nonlinear objective and constraints. In power system operation, the major role of ORPD is to maintain the load bus voltages within their limits for providing high quality of services to consumers.

The problem has been solved by various techniques ranging from conventional methods to artificial intelligence based methods. Several conventional methods have been applied for solving the problem such as linear programming (LP) [4], mixed integer programming (MIP) [5], interior point method (IPM) [6], dynamic programming (DP) [7], and quadratic programming (QP) [8]. These methods are based on successive linearizations and use gradient as search directions. The conventional optimization methods can properly deal with the optimization problems of deterministic quadratic objective function and differential constraints. However, they can be trapped in local minima of the ORPD problem with multiple minima [9]. Recently, meta-heuristic search methods have become popular for solving the ORPD problem due to their advantages of simple implementation and ability to find near optimum solution for complex optimization problems. Various meta-heuristic methods have been applied for solving the Problem such as evolutionary programming (EP) [9], genetic algorithm (GA) [3], ant colony optimization algorithm (ACOA) [10], differential evolution (DE) [11], harmony search (HS) [12], etc. These methods can improve optimal solutions for the ORPD problem compared to the conventional methods but with relatively slow performance.

Artificial bee colony (ABC) algorithm is a search method, which is inspired by the foraging behavior of honeybee swarm, and target discrete optimization problems. The ABC algorithm that was developed by Karaboga [13] is a population-based heuristic algorithm. In this algorithm, bees are members of a family which live in organized honeybee swarm. The bees consist of two groups. ABC algorithm has been applied to various optimization problems such as compute-industrial engineering, hydraulic engineering, aviation and space science and electronic engineering since 2005 [14-16]. ABC algorithm was firstly applied to ORPD problem by Ozturk and is tested on IEEE 10 bus-test system [17].

In this paper, the proposed method has been tested on the IEEE 30-bus and IEEE 118-bus systems and the obtained results are compared to those from particle swarm optimizer (PSO), self-organizing hierarchical particle swarm optimizer - time varying acceleration coefficients (HPSO-TVAC), particle swarm optimization - time varying acceleration coefficients (PSO-TVAC), and other methods in the literature. The result comparison has shown that the proposed method can obtain total power loss, voltage deviation or voltage stability index less than the others for the considered cases. Therefore, the proposed ABC can be a favorable method for implementation in the optimal reactive power

---

Vo Ngoc Dieu, Nguyen Huu Thien An (corresponding author), and Vo Trung Kien are with Ho Chi Minh City University of Technology, Ho Chi Minh City, Vietnam. Email: annht.bk@gmail.com.

optimization problems.

2. PROBLEM FORMULATION

The objective of the ORPD problem is to minimize is to optimize the objective functions while satisfying several equality and inequality constraints.

Mathematically, the problem is formulated as follows:

$$MinF(x,u) \tag{1}$$

where the objective function *F(x,u)*can be expressed in one of the forms as follows:

- Real power loss:

$$F(x,u) = P_{loss} = \sum_{i=1}^{N_l} g_l \begin{bmatrix} V_i^2 + V_j^2 \\ -2V_iV_j\cos(\delta_i - \delta_j) \end{bmatrix} \tag{2}$$

- Voltage deviation at load buses for voltage profile improvement [2]:

$$F(x,u) = VD = \sum_{i=1}^{N_d} \left| V_i - V_i^{sp} \right| \tag{3}$$

where V_i^{sp} is the pre-specified reference value at load bus *i*, which is usually set to 1.0 pu.

- Voltage stability index for voltage stability enhancement [3], [18]:

$$F(x,u) = L_{\max} = \max\{L_i\}; i = 1,...,N_d \tag{4}$$

where L_i is voltage stability index at load bus *i*

For all the considered objective functions, the vector of dependent variables *x* represented by:

$$x = [Q_{gl},...,Q_{gN_g}, V_{l1},...,V_{lN_d}, S_1,...,S_{N_l}]^T \tag{5}$$

and the vector of control variables *u* represented by:

$$u = [V_{gl},...,V_{gN_g}, T_1,...,T_{N_t}, Q_{c1},...,Q_{cN_c}]^T \tag{6}$$

The problem includes the equality and inequality constraints as follows:

a) Real and reactive power flow balance equations at each bus:

$$P_{gi} - P_{di} = V_i \sum_{j=1}^{N_b} V_j \left[G_{ij}\cos(\delta_i - \delta_j) + B_{ij}\sin(\delta_i - \delta_j) \right] \tag{7}$$
$$i = 1,...,N_b$$

$$Q_{gi} - Q_{di} = V_i \sum_{j=1}^{N_b} V_j \left[G_{ij}\sin(\delta_i - \delta_j) - B_{ij}\cos(\delta_i - \delta_j) \right] \tag{8}$$
$$i = 1,...,N_b$$

b) Voltage and reactive power limits at generation buses:

$$V_{gi,\min} \le V_{gi} \le V_{gi,\max}; i = 1,...,N_g \tag{9}$$

$$Q_{gi,\min} \le Q_{gi} \le Q_{gi,\max}; i = 1,...,N_g \tag{10}$$

c) Capacity limits for switchable shunt capacitor banks:

$$Q_{ci,\min} \le Q_{ci} \le Q_{ci,\max}; i = 1,...,N_c \tag{11}$$

d) Transformer tap settings constraint:

$$T_{k,\min} \le T_k \le T_{k,\max}; k = 1,...,N_t \tag{12}$$

e) Security constraints for voltages at load buses and transmission lines:

$$V_{li,\min} \le V_{li} \le V_{li,\max}; i = 1,...,N_d \tag{13}$$

$$S_l \le S_{l,\max}; l = 1,...,N_l \tag{14}$$

where the S_l is the maximum power flow between bus *i* and bus *j* determined as follows:

$$S_l = \max\left\{ \left| S_{ij} \right|, \left| S_{ji} \right| \right\} \tag{15}$$

3. ARTIFICIAL BEE COLONY ALGORITHM

3.1 Artificial bee colony (ABC) algorithm:

ABC algorithm was proposed by Karaboga in 2005 [15] and the flow chart of this algorithm is shown in Fig. 1. ABC algorithm is a population-based algorithm to be developed by taking into con-sideration the thought that how honeybee swarm finds food. The honeybee swarm in this algorithm is divided into two groups: worker bees and non-worker bees including onlooker bees and explorer bees. The onlooker bees are produced with certain intervals around the worker bees. If the produced onlooker bees find a source having higher fitness value, these bees are replaced by worker bees; otherwise the base value is increased by 1. If the base value exceeds its certain limit, this source is abandoned and the bee of the source is reproduced with the explorer bee. The bees having the best fitness value among all the reproduced bees are repre-sented in the next iteration. The following steps are implemented until the stopping criterion in ABC algorithm has been achieved.

3.1.1. Initial population:

The initial population is very important in heuristic methods and can be produced by different ways. One of them is the random producing and is used in this study. The initial population of the algorithm is produced within its limits according to the equation below:

$$u_{ij} = u_{\min i,j} + rand \times (u_{\max,j} - u_{\min,j}) \tag{16}$$

where $u_{min,j}$ and $u_{max,j}$ represent the minimum and maximum of the variable j. The value of *rand* is between 0 and 1.

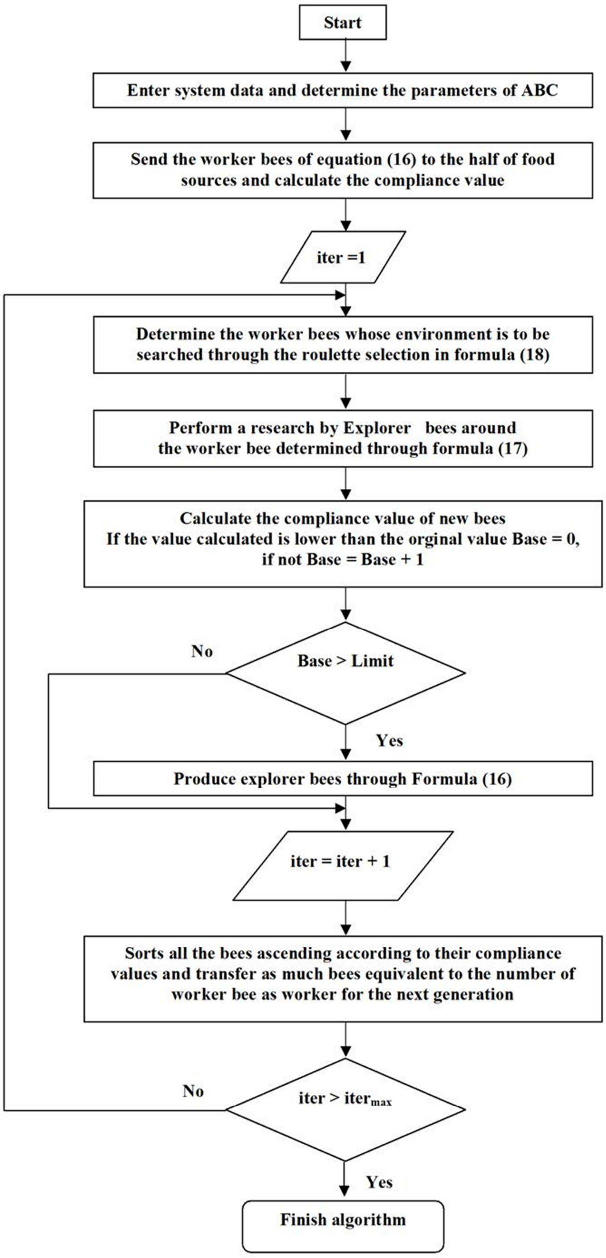

Fig.1. Flow chart of the ABC algorithm.

3.1.2. Worker bees

The worker bees are produced according to Eq. (17) and by using knowledge of the bees in the population. The feature of worker bees is that they are produced by taking the advantage from the sources which is previously discovered.

$$v_{ij} = \min(u_{ij}, u_{kj}) + \max(u_{ij}, u_{kj}) \times (rand - 0.5) \times 2] \quad (17)$$

where v_{ij} represents the produced worker bee, $\min(u_{ij}, u_{kj})$ and $\max(u_{ij}, u_{kj})$ represent the lower and upper limit of the variables u_{ij} and u_{kj}, respectively.

3.1.3. Onlooker bees:

The onlooker bees are produced by local searching with certain intervals around the bees determined by roulette selection method among worker bees. If the source found by the produced onlooker bees is better than one found by worker bees, the onlooker bee is assigned as worker bee. Then the base value is increased by 1. The efficiency of a bee in the population is determined with Eq. (18) . In the roulette method, the probability of a bee having high efficiency to be selected is high.

$$P_i = \frac{fit_i}{\sum_{n=1}^{SN} fit_n} \quad (18)$$

where *SN* is the number of the food sources which is equal to the number of employed bees, fit_i is the modified fitness value of *i*th solution which is proportional to the nectar amount of the food source in the position *i* and is given as follows:

$$fit_i = \frac{1}{f_i} \quad (19)$$

where f_i is the fitness value that is obtained separately for each individual through Eq. (20) .

3.1.4. Explorer bees

Worker bees whose the sources have been come an end become explorer bees and start to search new food source nectar randomly, for example by Eq. (16). There is not any guidance of the explorer bee for searching new food sources. They primarily try to find any kind of food source. The worker bee whose food source nectar has been come an end or the profitability of the food source drops under a certain level is selected and classified as the explorer bee.

3.1.5 ABC for the ORPD problem

For implementation of the proposed ABC to the problem, each particle position representing for control variables is defined as follows:

$$x_d = [V_{g1d}, ..., V_{gN_g d}, T_{1d}, ..., T_{N_t d}, Q_{c1d}, ..., Q_{cN_c d}]^T \quad (20)$$
$$d = 1, ..., NP$$

The fitness function to be minimized is based on the problem objective function and dependent variables including reactive power generations, load bus voltages, and power flow in transmission lines. The fitness function is defined as follows:

$$F_T = F(x,u) + K_q \sum_{i=1}^{N_g} (Q_{gi} - Q_{gi}^{\lim})^2 + K_v \sum_{i=1}^{Nd} (V_{li} - V_{li}^{\lim})^2 + K_s \sum_{l=1}^{N_l} (S_l - S_{l\max})^2 \quad (21)$$

where K_q, K_v and K_s are penalty factor for reactive power generations, load bus voltages, and power flow in transmission lines, respectively.

The limits of the dependent variables in (21) are determined based on their calculated values as follows:

$$x^{\lim} = \begin{cases} x_{\max} & x > x_{\max} \\ x_{\min} & x < x_{\min} \end{cases} \quad (22)$$

where x and x^{lim} respectively represent for the calculated value and limits of Q_{gi}, V_{li}, S_{lmax}.

The overall procedure of the proposed ABC for solving the ORPD problem is addressed as follows:

Step 1: Choose the controlling parameters for ABC including number of particle *NP*, maximum number of iterations $iter_{max}$, and penalty factors for constraints.

Step 2: The ith individual position in ABC method is initialized as follows (16).

Step 3: Set the iterators: *iter* = 1

Step 4: For each particle, calculate value of dependent variables based on power flow solution using Matpower toolbox 4.1.

Calculate the fitness function as follows (21).

Set the current value of the X_{id} is the best value.

Set the best value of the *i*th individual as follows (18)

In which X_{id} is the best position of individual *i* in the group of individuals in the population.

Step 5: Locate X_d employed bees as follows (17).

Step 6: Solve power flow using Matpower toolbox based on the newly obtained value of position for each particle.

Recalculate Fitness function for Employed bees.

Compare the value of this position Fitness with Fitness initialization values.

If the value calculated is lower than the orginal value *Base*= 0, if not *Base* = *Base* + 1.

Step 7: If *Base* >*Limit*, go to ther next step. Otherwise, go to step 9.

Step 8: Produce explorer bees through Formula (16)

Step 9: *iter* = *iter* +1.

Step 10: Sorts all the bees ascending according to their compliance values and transfer as much bees equivalent to the number of worker bee as worker for the next generation.

Step 11: If *iter* < $iter_{max}$ return to Step 4. Otherwise, stop.

4. NUMERICAL RESULTS

The proposed ABC has been tested on the IEEE 30-bus and 118-bus systems with different objectives including power loss, voltage deviation, and voltage stability index. The data for these systems can be found in [19], [20]. The characteristics and the data for the base case of the test systems are given in Tables 1 and 2, respectively.

The algorithms of the ABC methods are coded in Matlab R2009b and run on an Intel Core 2 Duo CPU 2.00 GHz with 2 GB of RAM PC. The parameters of the ABC methods for the test systems are summarized in Table 3. Number of individuals in a population for each test system is decided based on trial simulation run.

4.1 IEEE 30-bus system

In the test system, the generators are located at buses 1, 2, 5, 8, 11, and 13 and the available transformers are located on lines 6-9, 6-10, 4-12, and 27-28. The switchable capacitor banks will be installed at buses 10, 12, 15, 17, 20, 21, 23, 24, and 29 with the minimum and maximum values of 0 and 5 MVAR, respectively. The limits for control variables are given in [11], generation reactive power in [21], and power flow in transmission lines in [22].

The results obtained by the ABC methods for the system with different objectives including power loss, voltage deviation for voltage profile improvement, and voltage stability index for voltage enhancement are given in Tables 4, 5, and 6, respectively and the solutions for best results are given in Tables A1, A2, and A3 of Appendix.

The obtained best results from the proposed ABC method are compared to Gravitational Search Algorithm (GSA), comprehensive learning particle swarm optimization (CLPSO) [23], Self-Organizing Hierarchical Particle Swarm Optimizer - Time Varying Acceleration Coefficients (HPSO-TVAC), Particle Swarm Optimization - Time Varying Acceleration Coefficients (PSO-TVAC) [24] for different objectives as given in Table 7.

It can be seen from the data in Table 7 that the results obtained from the ABC method are less than another methods with total power loss, voltage deviation, and voltage stability index. As shown in Table 4,5,6, the computational time of ABC method is highest but the difference is not much. Best results are given in Tables A1, A2, and A3 of Appendix with all the constraint of voltage, reactive power at the generator node and the transformer index are satisfied.

4.2 IEEE 118-bus system

In this system, the position and lower and upper limits for switchable capacitor banks, and lower and upper limits of control variables are given in [23].

Table 1. Characteristics of test systems

System	No. of branches	No. of Generation buses	No. of transformers	No. of capacitor banks	No. of control variables
IEEE 30 bus	41	6	4	9	19
IEEE 118 bus	186	54	9	14	77

Table 2. Base case for test systems

System	$\sum P_{di}$	$\sum Q_{di}$	$\sum P_{gi}$	$\sum Q_{gi}$
IEEE 30 bus	283.4	126.2	287.92	89.2
IEEE 118 bus	4242	1438	4374.86	795.68

Table 3: Parameters for ABC algorithm

Worker bees	Onlooker bees	Explorer bees	Limit	Run ABC many times
10	10	10	20	100

Table 4. Results by ABC methods for the IEEE 30-bus system with power loss objective

Method Function	PSO-TVAC[22]	HPSO-TVAC[22]	ABC
Min P_{loss} (MW)	4.5356	4.5283	4.5194
Avg. P_{loss} (MW)	4.5912	4.5581	4.8892
Max P_{loss} (MW)	4.9439	4.6112	5.3815
Std.dev. P_{loss} (MW)	0.0592	0.0188	0.1885
VD	1.9854	1.9315	2.0317
L_{max}	0.1257	0.1269	0.1263
Avg. CPU time (s)	10.85	10.38	14.477

Table 5. Results by ABC methods for the IEEE 30-bus system with voltage deviation objective

Method Function	PSO-TVAC[22]	HPSO-TVAC[22]	ABC
Min VD	0.1210	0.1136	0.0992
Avg. VD	0.1529	0.1340	0.1870
Max VD	0.1871	0.1615	0.4394
Std.dev. VD	0.0153	0.0103	0.0718
P_{loss} (MW)	5.3829	5.7269	5.4582
L_{max}	0.1485	0.1484	0.1494
Avg. CPU time (s)	9.88	9.59	11.747

Table 6. Results by ABC methods for the IEEE 30-bus system with voltage stability index objective

Method Function	PSO-TVAC[22]	HPSO-TVAC[22]	ABC
Min L_{max}	0.1248	0.1261	0.1247
Avg. L_{max}	0.1262	0.1275	0.1296
Max L_{max}	0.1293	0.1287	0.1545
Std.dev. L_{max}	0.0009	0.0006	0.0049
P_{loss} (MW)	4.8599	5.2558	4.7359
VD	1.9174	1.6830	2.1461
Avg. CPU time (s)	13.39	13.05	15.760

Table 7. Comparison of best results for the IEEE 30-bus system

Method Function	Power loss (MW)	Voltage deviation (VD)	Stability index (L_{imax})
GSA[27]	4.6166	0.1064	-
CLPSO[28]	4.5615	-	-
PSO-TVAC[22]	4.5356	0.1210	0.1248
HPSO-TVAC[22]	4.5283	0.1136	0.1261
ABC	4.5194	0.0992	0.1247

Table 8. Results by ABC methods for the IEEE 118-bus system with power loss objective

Method Function	PSO-TVAC[22]	PSO[28]	CLPSO[28]	ABC
Min P_{loss} (MW)	124.3335	131.99	130.96	122.6792
Avg. P_{loss} (MW)	129.7494	132.37	131.15	138.7797
Max P_{loss} (MW)	134.1254	134.5	132.74	160.8688
Std.dev. P_{loss} (MW)	2.1560	0.00032	0.000085	5.4653
VD	1.4332	3.0027	1.8525	2.8697
L_{max}	0.0679	0.2049	0.1461	0.0629
Avg. CPU time (s)	85.32	1215	1472	98.203

Table 9. Results by ABC methods for the IEEE 118-bus system with voltage deviation objective

Method Function	PSO-TVAC[22]	PSO[28]	CLPSO[28]	ABC
Min VD	0.3921	2.2359	1.6177	0.3212
Avg. VD	0.4724	-	-	0.4315
Max VD	0.5407	-	-	0.5231
Std.dev. VD	0.0316	-	-	0.0488
P_{loss} (MW)	179.7952	132.16	132.06	176.5858
L_{max}	0.0667	0.1854	0.1210	0.0680
Avg. CPU time (s)	78.70	-	-	84.464

Table 10. Results by ABC methods for the IEEE 118-bus system with stability index objective

Method Function	PSO-TVAC[22]	PSO[28]	CLPSO[28]	ABC
Min L_{max}	0.0607	0.1388	0.0965	0.0599
Avg. L_{max}	0.0609	-	-	0.0662
Max L_{max}	0.0613	-	-	0.0733
Std.dev. L_{max}	0.0001	-	-	0.0029
P_{loss} (MW)	184.5627	133.08	132.08	217.0914
VD	1.2103	2.3262	2.8863	2.0428
Avg. CPU time (s)	119.22	-	-	128.582

Table 11. Comparison of best results for the IEEE 118-bus system

Method Function	Power loss (MW)	Voltage deviation (VD)	Stability index (L_{imax})
PSO-TVAC[22]	124.3335	0.3921	0.0607
PSO[28]	131.99	2.2359	0.1388
CLPSO[28]	130.96	1.6177	0.0965
ABC	122.6792	0.3212	0.0599

The obtained results by the ABC methods for the system with different objectives similar to the case of IEEE 30 bus system are given in Tables 8, 9, and 10, respectively and the comparison of best results from methods for different objectives is given in Table 11. It can be seen from the data in Table 11 that the results obtained from the ABC method are less than others methods with total power loss, voltage deviation, and voltage stability index. As shown in Table 8, 9, the computational time of ABC method is slower than others methods but in Table 10, the computational time of ABC method is very fast. So that, the computational time of ABC method is fast but in a few cases, it is slow.

5. CONCLUSION

In this paper, the ABC method has been effectively and efficiently implemented for solving the ORPD problem. The proposed ABC has been tested on the IEEE 30-bus and IEEE 118-bus systems with different objectives including power loss, voltage deviation, and voltage stability index. The test results have shown that proposed method can obtain total power loss, voltage deviation, or voltage stability index less than other methods for test cases. Therefore, the proposed ABC could be a useful and powerful method for solving the ORPD problem.

REFERENCES

[1] J. Nanda, L. Hari, and M. L. Kothari, „Challenging algorithm for optimal reactive power dispatch through classical co-ordination equations", *IEE Proceedings - C*, 139(2), 1992, pp. 93-101.

[2] J. G. Vlachogiannis, and K. Y. Lee, "A Comparative study on particle swarm optimization for optimal steady-state performance of power systems", *IEEE Trans. Power Systems*, *21*(4), 2006, pp. 1718-1728.

[3] D. Devaraj and J. Preetha Roselyn, "Genetic algorithm based reactive power dispatch for voltage

stability improvement", *Electrical Power and Energy Systems*, *32*(10), 2010, pp. 1151-1156.

[4] D. S. Kirschen, and H. P. Van Meeteren, "MW/voltage control in a linear programming based optimal power flow," *IEEE Trans. Power Systems*, *3*(2), 1988, pp. 481-489.

[5] K., Aoki, M. Fan and A. Nishikori, "Optimal VAR planning by approximation method for recursive mixed integer linear programming", *IEEE Trans. Power Systems*, *3*(4), 1988, pp. 1741-1747.

[6] [6] S. Granville, "Optimal reactive power dispatch through interior point methods", *IEEE Trans. Power Systems*, *9*(1), 1994, pp. 136-146.

[7] F. C. Lu and Y. Y. Hsu, "Reactive power/voltage control in a distribution substation using dynamic programming", *IEE Proc. Gen. Transm. Distrib.*, *142*(6), 1994, pp. 639–645.

[8] N. Grudinin, "Reactive power optimization using successive quadratic programming method", *IEEE Trans. Power Systems*, *13*(4), 1998, pp.1219-1225.

[9] [9] L. L. Lai and J. T. Ma, "Application of evolutionary programming to reactive power planning - Comparison with nonlinear programming approach", *IEEE Trans. Power Systems*, *12*(1), 1997, pp. 198-206.

[10] A. Abou El-Ela, A. Kinawy, R. El-Sehiemy, and M. Mouwafi, "Optimal reactive power dispatch using ant colony optimization algorithm", *Electrical Engineering* (Archiv fur Elektrotechnik), 2011, pp. 1-14. Retrieved Feb. 20, 2011, from http://www.springerlink.com/ content/k02v3 60632653864.

[11] A. A. Abou El Ela, M. A. Abido, and S. R. Spea, "Differential evolution algorithm for optimal reactive power dispatch", *Electric Power Systems Research*, 81(2), 2011, pp. 458- 464.

[12] A. H. Khazali and M. Kalantar, "Optimal reactive power dispatch based on harmony search algorithm", *Electrical Power and Energy Systems*, Article in press.

[13] D. Karaboga, An idea based on honey bee swarm for numerical optimization, Technical Report TR06, Computer Engineering Department, Erciyes University, Turkey, 2005.

[14] Y. Marinakis, M., Marinaki, N. Matsatsinis, A hybrid discrete artificial bee colony-GRASP algorithm for clustering, Comput. Ind. Eng., art. no. 5223810 (2009) 548–553.

[15] F. Kang, J.J. Li, Q. Xu, Hybrid simplex artificial bee colony algorithm and its application in material dynamic parameter back analysis of concrete dams, Shuili Xuebao/J. Hydraul. Eng. 40 (6) (2009) 736–742.

[16] C. Xu, H. Duan, F. Liu, Chaotic artificial bee colony approach to Uninhabited Combat Air Vehicle (UCAV) path planning, *Aerospace Sci. Technol.* 14 (8) (2010) 535–541.

[17] A. Ozturk, S. Cobanli, P. Erdosmus, S. Tosun, Reactive power optimization with artificial bee colony algorithm, Sci. Res. Essays (ISI) 5 (19) (2010) 2848–2857.

[18] P. Kessel and H. Glavitsch, "Estimating the voltage stability of power systems", *IEEE Trans Power Systems*, 1(3), 1986, pp. 346–54.

[19] I. Dabbagchi and R. Christie, "Power systems test case archive", University of Washington, 1993. Retrieved Feb. 20, 2011, from http://www.ee.washington.edu/ research/pstca/.

[20] R. D. Zimmerman, C. E. Murillo-Sánchez, and R. J. Thomas, "Matpower's extensible optimal power flow architecture", *In Proc. Power and Energy Society General Meeting*, IEEE, 2009, pp. 1-7.

[21] K. Y. Lee, Y. M. Park, and J. L. Ortiz, "A united approach to optimal real and reactive power dispatch," IEEE Trans. Power Apparatus and Systems, PAS-104(5), 1985, pp. 1147-1153.

[22] O. Alsac and B. Stott, "Optimal load flow with steady-state security", IEEE Trans. Power Apparatus and Systems, 93, 1974, pp. 745-751.

[23] K. Mahadevan and P. S. Kannan, "Comprehensive learning particle swarm optimization for reactive power dispatch", *Applied Soft Computing*, 10(2), 2010, pp. 641-652.

[24] Vo Ngoc Dieu and Peter Schegner, "particle swarm optimization with constriction factor for optimal reactive power dispatch", *In Proceedings of the fifth Global Conference on Power Control and Optimization*, PCO 2011, 1-3 June, 2011, Dubai, Unites Arab Emirate.

APPENDIX

The best solutions by ABC methods for the IEEE 30- bus system with different objectives are given in Tables A1, A2, and A3.

Table A1. Best solutions by PSO methods for the IEEE 30-bus system with power loss objective

Variables	PSO-TVAC	HPSO-TVAC	ABC
V_{g1}	1.1000	1.1000	1.1000
V_{g2}	1.0957	1.0941	1.0948
V_{g5}	1.0775	1.0745	1.0714
V_{g8}	1.0792	1.0762	1.0759
V_{g11}	1.1000	1.0996	1.1000
V_{g13}	1.0970	1.1000	1.1000
$T_{6\text{-}9}$	1.0199	1.0020	1.0262
$T_{6\text{-}10}$	0.9401	0.9498	0.9164
$T_{4\text{-}12}$	0.9764	0.9830	0.9782
$T_{27\text{-}28}$	0.9643	0.9707	0.9718
Q_{c10}	4.5982	2.3238	5.0000
Q_{c12}	2.8184	2.8418	5.0000
Q_{c15}	2.3724	3.6965	3.9341
Q_{c17}	3.6676	4.9993	5.0000
Q_{c20}	4.3809	3.1123	4.2164
Q_{c21}	4.9146	4.9985	5.0000
Q_{c23}	3.6527	3.5215	3.2097
Q_{c24}	5.0000	4.9987	4.9997
Q_{c29}	2.1226	2.3743	2.5913

Table A2. Best solutions by PSO methods for the IEEE 30-bus system with voltage deviation objective

Variables	PSO-TVAC	HPSO-TVAC	ABC
V_{g1}	1.0282	1.0117	1.0232
V_{g2}	1.0256	1.0083	1.0219
V_{g5}	1.0077	1.0169	1.0142
V_{g8}	1.0014	1.0071	1.0034
V_{g11}	1.0021	1.0707	1.0460
V_{g13}	1.0046	1.0060	0.9914
T_{6-9}	1.0125	1.0564	1.0508
T_{6-10}	0.9118	0.9076	0.9000
T_{4-12}	0.9617	0.9545	0.9545
T_{27-28}	0.9663	0.9695	0.9781
Q_{c10}	5.0000	1.5543	2.5433
Q_{c12}	1.5065	1.4242	4.0442
Q_{c15}	3.9931	2.5205	5.0000
Q_{c17}	3.7785	1.6400	0.0000
Q_{c20}	3.2593	5.0000	4.7873
Q_{c21}	4.1425	1.8539	4.8628
Q_{c23}	4.9820	3.3035	5.0000
Q_{c24}	4.5450	4.5941	5.0000
Q_{c29}	4.1272	3.5062	4.5742

Table A3. Best solutions by PSO methods for the IEEE 30-bus system with objective of stability index

Variables	PSO-TVAC	HPSO-TVAC	ABC
V_{g1}	1.1000	1.0979	1.1000
V_{g2}	1.0934	1.0997	1.0947
V_{g5}	1.0969	1.0500	1.1000
V_{g8}	1.0970	1.0663	1.0884
V_{g11}	1.1000	1.0561	1.1000
V_{g13}	1.1000	1.0886	1.0983
T_{6-9}	1.0935	0.9939	0.9821
T_{6-10}	0.9000	1.0150	0.9552
T_{4-12}	0.9579	0.9121	0.9753
T_{27-28}	0.9651	0.9406	0.9816
Q_{c10}	3.1409	3.7685	5.0000
Q_{c12}	3.0186	4.6323	3.4219
Q_{c15}	1.4347	2.6542	3.0048
Q_{c17}	3.8498	2.6897	3.8582
Q_{c20}	0.0000	2.8806	0.0000
Q_{c21}	5.0000	2.1071	5.0000
Q_{c23}	0.0000	3.1044	4.9760
Q_{c24}	2.1733	2.1797	4.7488
Q_{c29}	2.2708	3.5843	5.0000