

Artificial Bee Colony Algorithm for Optimal Placement and Sizing of Distributed Generation

Ayşe Aybike Seker¹, Mehmet Hakan Hocaoglu²

¹⁻²Gebze Institute of Technology, Department of Electronics Engineering, 41400, Gebze, Kocaeli, Turkey
aseker@gyte.edu.tr, hocaoglu@gyte.edu.tr

Abstract

In electric power networks, to satisfy the increasing demand, various methods have been improved and implemented. Distributed generation (DG) is one of these methods which has many advantages as providing loss reduction, improving voltage profile, and increasing reliability. Besides renewable energy sources like solar cells, wind turbines, fuel cells, and small hydro turbines can be used as a DG-unit. In this paper, DG-unit placement and sizing process is performed with Artificial Bee Colony (ABC) algorithm. ABC algorithm is a meta-heuristic approach inspired by the intelligent foraging behavior of honey bee swarms. 33, 69, 229 bus radial test systems are used in order to show the performance of ABC algorithm in solving nonlinear optimization problems. The results show that ABC algorithm can successfully determines optimal place and size of DG-unit.

I. Introduction

The ever increasing environmental concerns and demand of energy has brought many challenges on power system companies. Distributed generation (DG) is an alternative to solve these problems [1]. DG means integrating small generators in a distribution system in order to meet required level of load demand thereby improving the voltage profile, increasing life of system equipment, providing reliability and economic benefit such as minimum power loss and energy efficiency [2]. There is many reasons for increasingly use of DG technologies. It is more economic than running a power line to remote locations and DG-unit usually requires shorter installation times and the investment risk is not so high. It provides backup power during system outages and for system black-start it makes starting generation and restoring a portion of the utility system possible without outside support after system collapse [3].

The capacity of DG-unit is ranging from 15 kW to 50 MW and it gains more importance as it make use of renewable energy sources such as Solar Cells, Fuel Cells, Small Wind Turbines and Small Hydro Turbines as well as non renewable energy sources [2].

Significant impact of embedded distributed generators on voltages, load demand, power loss, system reliability and economy make it a key issue for distribution system planning

and automation in the deregulated power system environment [1]. As the penetration of DG units in distribution system increases allocating them in an optimal way becomes necessary to achieve the maximum benefits [4].

The DG-unit application is a mixed integer nonlinear optimization problem which is the determination of the optimal location and size for DG-unit to be installed on a network [5]. It includes maximizing system voltages or minimizing power loss and cost [6].

DG-unit placement has been solved by using many different approaches. As a classical approach second order algorithm method used in [7] to allocate DG-units for minimum power loss. In analytical approaches as [8-9] optimal place of DGs are determined for the various load profiles in radial systems. As another analytical method in [10] optimal placement is determined with unity power factor in radial as well as networked systems. In [11] an analytical method is introduced based on the equivalent current injection techniques without use of admittance matrix, inverse of admittance matrix or Jacobian matrix which are proved to be problematic for the radial systems [12]. A methodology, which is based on exact loss formula used in [13] and tested in three typical distribution systems. Meta-heuristic approaches are used as well as analytical ones for DG setting and sizing. Tabu search application is used in [14], Fuzzy-GA method is used in [15], Hereford Ranch Algorithm used in [16] to reduce power loss. In [2] Craziness based Particle Swarm Optimization (CRPSO) used to consider the optimal location for DG which in turn improves the voltage profile of overall system. A method called harmony search algorithm with differential operator is studied both for minimizing active power loss and improving voltage profile. [6] presents a new optimization approach called Artificial Bee Colony algorithm as another meta-heuristic method and applied it in 69-bus test system. In this study ABC algorithm is also applied to 229 bus real system to optimize the size and place of DG-unit. In [17] a new method which employs a Modified Teaching-Learning Based Optimization algorithm used. These studies show that DG placement is important for efficiency of system. However DG-units still need time to integrate decently in real systems. Due to various technical challenges and DG-units is one of the solutions for this issue.

In this paper Artificial Bee Colony algorithm, proposed by Karaboga [18] is used for optimization problem of DG-units in distribution systems. The proposed method is tested on 33, 69

bus test systems and 229 bus real system. Results are compared with grid search method.

The paper is organized as follows: Section II provides the formulation of problem; Section III presents the ABC algorithm; Section IV describes the use of ABC algorithm in DG-unit allocation; Section V includes results and Section VI outlines conclusions and further studies.

II. Problem Formulation

DG-unit optimization problem can be explained as finding the optimal size and location of that DG-unit to minimize the system total power loss subject to inequality constraints.

- The objective function is to minimize the total system real power loss. n is number of buses. P_i and Q_i are the real and reactive power flows from bus i to bus $i + 1$. Bus voltage at bus i is V_i . r_{i+1} is the resistance of line connecting buses i and $i + 1$.

$$ObjFun = \min \sum_{i=1}^n \left(\frac{P_i^2 + Q_i^2}{|V_i|^2} \right) r_{i+1} \quad (1)$$

- The inequality constraints are voltage limits of system

$$|V_{min}| \leq |V_i| \leq |V_{max}| \quad (2)$$

where min-max voltage is $\pm 5\%$ of the nominal voltage that satisfy operating constraints.

- Other inequality constraint is size of DG-unit

$$S_{max} \geq S_{iDG} \geq S_{min} \quad (3)$$

where DG-units sizes are preselected discretely between 10% and %80 of the total system demands.

- Power factor of DG-unit is the last inequality constraint which is set to operate practical values that is 0.95, 0.90 and 0.85 towards the optimal result [6]

$$p \cdot f \cdot max \geq p \cdot f \cdot iDG \geq p \cdot f \cdot min \quad (4)$$

- Power balance is satisfied with power flow constraints.

$$P_i = P_i^{DG} - P_i^D \quad Q_i = Q_i^{DG} - Q_i^D$$

$$P_i = |V_i| \sum_{k=1}^n |V_k| [g_{ik} \cos(\theta_i - \theta_k) + b_{ik} \sin(\theta_i - \theta_k)] \quad (5)$$

$$Q_i = |V_i| \sum_{k=1}^n |V_k| [g_{ik} \sin(\theta_i - \theta_k) - b_{ik} \cos(\theta_i - \theta_k)]$$

where V_i is the voltage magnitude of bus i . θ_i is the voltage angle of bus i . P_i^{DG} , Q_i^{DG} are active and reactive power of DG in bus i . P_i^D , Q_i^D are active and reactive power of load in bus i . P_i , Q_i are net active and reactive power injected in bus i . b_{ik} , g_{ik} are the real and imaginary part of admittance between bus i and k .

The values P, Q and V in the objective function is calculated with Thukaram's power flow algorithm for radial distribution networks that uses forward backward sweeps to calculate branch currents and node voltages [19].

III. Artificial Bee Colony (ABC) Algorithm

The artificial bee colony algorithm approach is established from foraging behavior of real honey bees. ABC is introduced

by Karaboga [18] as a new heuristic method for solving multidimensional optimization problems. At first it was proposed for unconstrained problems, and then another version is published for constrained optimization problems [20]. Additionally the performance of ABC algorithm was compared with differential evolution (DE), particle swarm optimization (PSO) and evolutionary algorithm (EA) for a set of multi-dimensional numeric problems [21]. A modified version of ABC algorithm was published for constrained problems [22].

Honey bee swarm consists of three kinds of bees: employed bees, onlooker bees, and scout bees [22].

- Employed bees: Randomly search for food source positions (solutions) and then share the information that is nectar amounts by dancing with the bees waiting in the hive. Duration of dance depends on the nectar amount (fitness value) of the food source.

- Onlooker bees: Watch dances of various employed bees and chose the good food source position according to quality of that food source.

- Scout bees: An employed bee of the source which is abandoned becomes a scout and starts to search a new food source randomly [21].

Onlookers are placed on food sources by using probability based selection, as the nectar amount increases on source onlooker bees prefer that source too. Scout bees are the explorers and have no guidance while looking for food. That creates the possibility of both low or rich quality sources may be discovered. In ABC one of employed bee is selected as the scout bee and this selection is controlled by a parameter "limit". If the food source (solution) is not improved by a predetermined number of trials, its employed bee abandons the source and it convert to a scout. So "limit" is the number of trials before leaving a food source [18].

Pseudo-code of main body of ABC algorithm [22]:

-
- 1: Initialization
 - 2: Evaluation
 - 3: cycle = 1
 - 4: **repeat**
 - 5: Employed Bees Phase
 - 6: Calculate Probabilities for Onlookers
 - 7: Onlooker Bees Phase
 - 8: Scout Bees Phase
 - 9: Memorize the best solution achieved so far
 - 10: cycle = cycle + 1
 - 11: **until** cycle = Maximum Cycle Number
-

In ABC algorithm employed bees number is equal to onlooker bees number. At initialization step a randomly distributed population of solutions is generated. Each solution x_i ($i = 1, 2, \dots, E_b$) is a D-dimensional vector. Here E_b is the number of employed bees and D is the number of optimization parameter. After initialization the population of the positions (solutions) is subjected to repeated cycles (cycle= 1,2,...,MCN) of the search process of the employed, onlooker and scout bees. Then, an employed bee produces a modification on the position (solution) in her memory depending on the local information (visual information) and tests the nectar amount (fitness value)

of the new source (modified solution). If the nectar amount of the modified solution is higher than the previous one the bee memorizes the new position and forgets old one. Otherwise she keeps the position of previous one in her memory. After all employed bees complete the search process; they share the nectar information of the food source and their positions information with the onlooker bees on the dance area. An onlooker bee evaluates the nectar information taken from all employed bees and chooses a food source with a probability related to its nectar amount. Same procedure is applied as in the case of employed bee.

Following expression is to calculate probability value related with that food source:

$$p_i = \frac{fitness_i}{\sum_{i=0}^{E_b} fitness_i} \quad (6)$$

where $fitness_i$ is the fitness value of the solution i and E_b is the number of food source positions (solution) in other words, half of the colony which is equal to number of employed bees.

Onlooker bees select their food source among the high value of p_i . They produce a neighbor food source position $i + 1$ to the selected one i , then compare nectar amounts (fitness values) of neighbour and previous position. And the same selection criterion used by employed bees is applied to onlooker bees. This is repeated until all onlookers are distributed. If a solution i does not improve for a predetermined number of time (limit), its employed bee abandon this solution and she becomes a scout and search for a new random food source position. Once the new position is determined, next ABC algorithm cycle (MCN) starts

Neighbor food source position is determined with the following expression:

$$x_{ij}^{new} = x_{ij}^{old} + u(x_{ij}^{old} - x_{kj}) \quad (7)$$

where $k \neq i$ and both $i, j \in \{1, 2, \dots, E_b\}$. u is a random number between $[-1, 1]$ and $j \in \{1, 2, \dots, D\}$. When the food source position is abandoned, its employed bee becomes a scout. Scout produces a new food source position as follows:

$$x_i^{j(new)} = minx_i^j + u(maxx_i^j - minx_i^j) \quad (8)$$

where u is a number between $[-1, 1]$.

ABC algorithm has three control parameters: 1) the colony size CS (E_b employed bees + O_b onlooker bees). 2) *limit* value 3) maximum cycle number MCN.

IV. ABC Algorithm for DG-unit Allocation

Flowchart of ABC algorithm is shown in Fig.1. The steps of proposed ABC algorithm for DG-unit allocation are described as follows.

- 1) Set control parameters of ABC: MCN (maximum cycle number), D (parameter number to optimize) and *limit* which depends on colony size and D.
- 2) Read system data which contains bus and line data of the test system.
- 3) Run power flow based on Thukaram's technique [19].
- 4) Initialize the food source positions x_i (solutions population), here $i = 1, 2, \dots, E_b$.

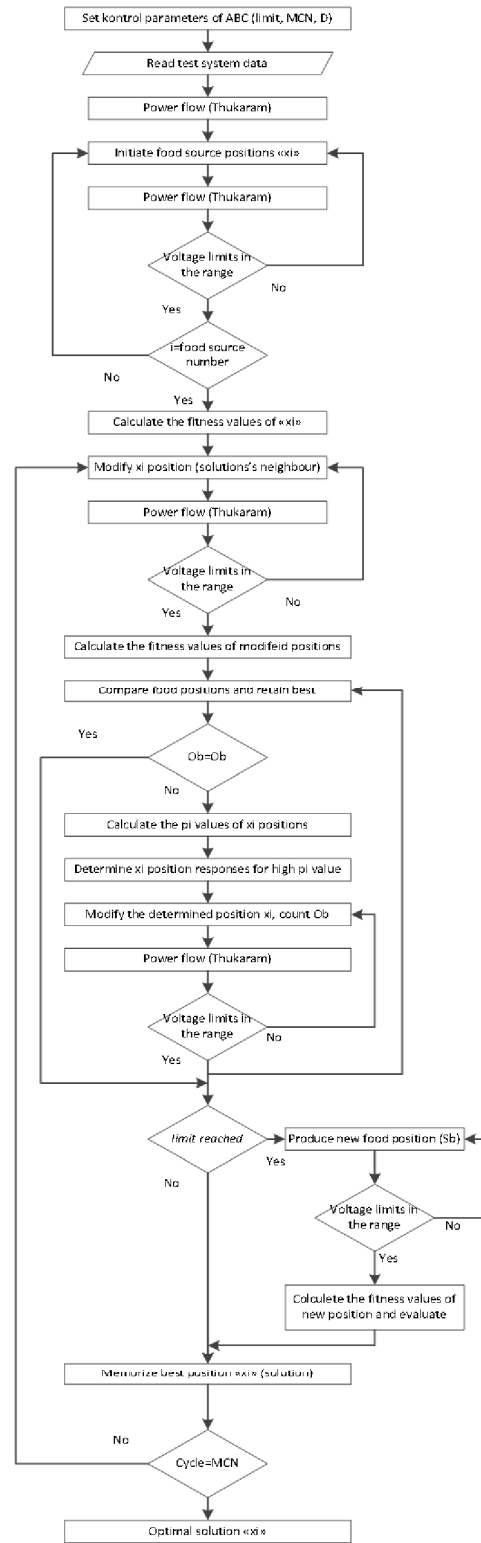


Fig. 1. Flowchart of ABC algorithm for DG-unit allocation

- 5) Make power flow for each position and check results if the voltage limits are in the given range.
- 6) If voltages are between the range check if all food sources are produced, otherwise turn to step 4.
- 7) If all food sources are produced calculate fitness values of x_i using

$$fitness_i = \frac{1}{1 + ObjFun_i} \quad (9)$$

where $ObjFun_i$ is the response of (1) at solution i . Otherwise turn to step 4.

8) Modify x_i solutions to produce neighbor with the equation given in (6). And evaluate them as indicated by step 5. Follow as step 6 and 7 with turning back to modifying step 8 instead of step 4

9) Compare food positions and apply selection process.

10) If all onlooker bees are distributed go to step 13. Otherwise go to next step.

11) Calculate probabilities by using (5).

12) For the selected onlooker bee, produce neighbor solution using (6) and evaluate them as step 5. Follow as step 6 and 7 with turning back to producing neighbor step 12, instead step 4.

13) Go back step 9.

14) Determine the abandoned solution and replace it with a new solution using (7). Check voltage limits, if it is in the range calculate fitness and go to next step. Otherwise produce a new solution using (7).

15) Memorize the next solution x_i .

16) If cycle=MCN, stop and print optimal solution x_i .

In meta-heuristic optimization algorithms' parameter setting has significant impact on the performance. As an advantage ABC has few control parameters. Furthermore structure of the ABC algorithm directs the solutions to feasible region. *limit* parameter is important in the algorithm and is taken as $0.5 \times CS \times D$.

V. Results

ABC algorithms performance and validity is checked in 33 and 69 radial distribution test systems and also using a real test system with 229 nodes [23]. Results are compared with grid search method and an optimization package in [24]. In this study ABC algorithm implemented in MATLAB platform and executed on an Intel Pentium 4 with 3.20 GHz speed and 2GB RAM.

33, 69 and 229 bus tests systems data without DG-unit is shown on the Table-1. It shows that all bus voltages are satisfied 10% limits however the regulations are restricted to 5%.

Table-1. Tests Systems Default Case

	33-bus	69-bus	229-bus
Total MW loss	0.2110	0.2250	0.0429
Total MVar loss	0.1430	0.1021	0.0163
Vmin (p.u.)	0.9038	0.9092	0.9159
Vmax (p.u.)	1.0000	1.0000	1.0000
Load (MVA)	3.7150+2.3000i	3.8021+2.6945i	0.7900+0.4869i

Place and size of DG-units calculated with grid search to verify results of ABC algorithm. In this method all possible combinations examined. DG-unit sizes are determined with a 100 step interval between %10-%80 of total system demands. And power factor (pf) is set to 0.85 (lagging). Results of grid search method are shown on Table-2. Total active losses decrease in all systems after DG-unit placement. In 33 bus test system total loss reduces 68%, in 69 bus it reduces 90%, and in 229 bus system total loss is 88% less than the systems default loss.

Table-2. Grid Search Method Optimal Results for DG-unit

	33-bus	69-bus	229-bus
Optimal placement	6	61	155
Optimal size (MW)	3.0921	2.2456	0.7293
Total MW loss	0.0682	0.0239	0.0052
CPU time (s)	20.06	137.99	4094.96
Vmax / Vmin	1 / 0.9126	1 / 0.9126	1/0.9212

ABC algorithm results are recorded in Table-3, 4, 5 for 33, 69 and 229-bus systems. ABC parameters are set to different values according to systems size and experiment results. Optimal placement, optimal size, total system real power loss and calculation time are shown. Simulation has been run 30 times and results of total loss are given as its best, worst and mean value.

Table-3. Simulation Results of ABC for 33 bus system

33-bus (30 independent runs)			
Optimal placement	Bus 6		
Optimal size (MW)	3.0971 (pf=0.85)		
ABC parameters	CS=20, MCN=30		
	Best	Worst	Mean
Total MW loss	0.0679	0.0692	0.0681
CPU time (s)	2.03		

In 33 bus system 6th and 26th buses are connected. ABC algorithm finds randomly 6th or 26th bus in each run. In both cases total losses are between the best and worst values given in Table-3 which shows both buses are acceptable as the optimal place.

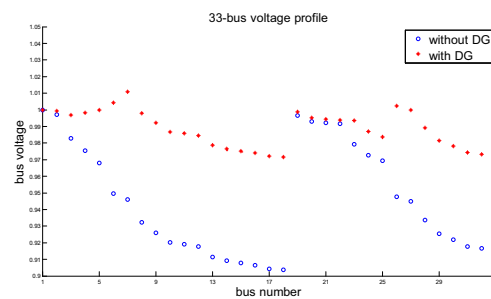
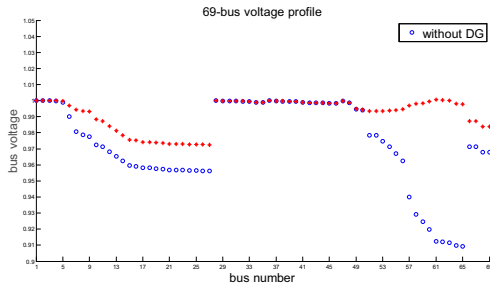


Fig. 2. Voltage profile of 33 bus system

Results of ABC algorithm are identical to those calculated using grid search method. The real power loss reduction is 68% in 33-bus system. Furthermore Vmin is improved by 0.0589 p.u.

Table-4. Simulation Results of ABC for 69 bus system

69 bus (30 independent runs)			
Optimal placement	Bus 61		
Optimal size (MW)	2.2389 (pf=0.85)		
ABC parameters	CS=30, MCN=40		
	Best	Worst	Mean
Total MW loss	0.0238	0.0238	0.0238
CPU time (s)	26.84		

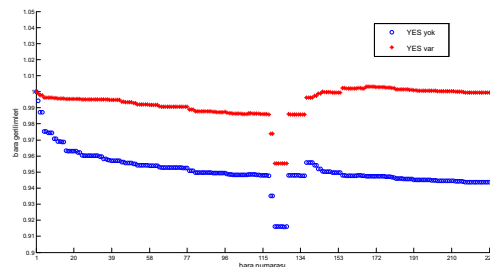
**Fig. 3.** Voltage profile of 69 bus system

In 69 bus system ABC algorithm results shows that total power loss is reduced 90% and V_{min} improved by 0.0634 p.u. In addition it is 5 times faster than grid search method.

Table-5. Simulation Results of ABC for 229 bus system

229-bus (30 independent runs)			
Optimal placement	Bus 155		
Optimal size (MW)	0.7320 (pf=0.85)		
ABC parameters	CS=40, MCN=40		
	Best	Worst	Mean
Total MW loss	0.0052	0.0052	0.0052
CPU time (s)	273.78		

In 229-bus system total power loss is reduced 88% and system V_{min} improved 0.0395 p.u. In addition as the size of the system increase importance of time factor is seen from the results. As in the 229-bus system ABC algorithm is 15 times faster than the grid search method.

**Fig. 4.** Voltage profile of 229 bus system

VI. Conclusion

A population based ABC algorithm is used for an optimization problem. Simulations were tested on IEEE 33 and 69 bus test systems and 229-bus real system. Objective function is chosen to minimize total system real power loss and ABC algorithm successfully finds optimized size and place of DG-units. The ABC results are in close agreement with the grid search method.

In further studies, different cases can be tested as multiple DG-unit allocation, or different combinations of active and reactive power injection which depends on the DG-unit's variety.

VII. References

- [1] P. N. Hrisheeksha and J. Sharma, "AI Applications to Distribution System with Distributed Generation", International Journal of Computer Applications 1(14):38-42, February 2010.
- [2] K. Mistry; R. Roy, "CRPSO based optimal placement of multi-distributed generation in radial distribution system", Power and Energy (PECon), 2012 IEEE International Conference on , vol., no., pp.852,857, 2-5 Dec. 2012.
- [3] M. Gandomkar, M. Vakilian, M. Ehsan, "Optimal distributed generation allocation in distribution network using Hereford Ranch algorithm", Proceedings of the Eighth International Conference on Electrical Machines and Systems, 2005.Vol.2, Issue , 27-29 Sept. 2005, pp. 916 – 918.
- [4] A. Pigazo, M. Liserre, R. A. Mastromauro, V. M. Moreno, and A. Dell'Aquila, "Wavelet-based islanding detection in grid-connected PV systems," IEEE Trans. Ind. Electron., vol. 56, no. 11, pp. 4445-4455, Nov. 2009.
- [5] M. R. Aghaebrahimi, M. Amiri, "Distributed generator placement techniques using artificial intelligence," Sustainable Power Generation and Supply, SUPERGEN '09. International Conference on , vol., no., pp.1,6, 6-7 April 2009.
- [6] F. S. Abu-Mouti, M. E. El-Hawary, "Optimal Distributed Generation Allocation and Sizing in Distribution Systems via Artificial Bee Colony Algorithm", Power Delivery, IEEE Transactions on, vol.26, no.4, pp.2090,2101, Oct. 2011.
- [7] S. Rau and Y.H. Wan, "Optimum Location of Resources in Distributed Planning", IEEE Trans. Power Syst., Vol. 9, Nov. 1994, pp.2014-2020.
- [8] H. L. Willis, "Analytical Methods and Rules of Thumb for Modelling DG-Distribution Interaction", IEEE PES Summer Meeting, vol. 3, Seattle, WA, July 2000, pp. 1643-1644.
- [9] T. Griffin, K. Tomsovic, D. Secrest, and A. Law, "Placement of Dispersed Generation Systems for Reduced Losses", 33rd Annu. Hawaii Int. Conf. Systems Sciences, Maui, HI, 2000, pp.1-9.
- [10] C. Wang, M. H. Nehrir, "Analytical Approaches for Optimal Placement of DG Sources in Power Systems", IEEE Trans. On Power Syst., Vol. 19, No. 4, November 2004; pp. 2068-2076.
- [11] T. Gozel, M. H. Hocaoglu, "An analytical method for the sizing and siting of distributed generators in radial systems", Electric Power Systems Research, Volume 79, Issue 6, June 2009, Pages 912-918, ISSN 0378-7796
- [12] T. Gozel, "Optimal Allocation of Distributed Generators in Distribution Systems", PhD Thesis, Gebze Institute of Technology, 2009
- [13] N. Acharya, P. Mahat and N. Mithulananthan, "An analytical approach for DG allocation in primary distribution network", Int. J. Electr. Power Energy Syst., 2006, 28, (10), pp. 669-746.
- [14] K. Nara, Y. Hayashi, K. Ikeda, and T. Ashizawa, "Application of Tabu Search to Optimal Placement of Distributed Generators", IEEE PES Winter Meeting, 2001, Vol. 2, pp.918 – 923.
- [15] K. H. Kim, Y. J. Lee, S. B. Rhee, S. K. Lee, and S.K. You, "Dispersed Generator Placement Using Fuzzy-GA in Distribution Systems", IEEE PES, Summer Meeting, Vol. 3, July 2002, pp.1148-1153
- [16] J. O. Kim, S. W. Nam, S. K. Park, and C. Singh, "Dispersed Generation Planning Using Improved Hereford Ranch Algorithm", Electric Power System Research , Vol. 47, No. 1, Oct. 1998, pp.47-55.
- [17] Juan Andrés Martín García, Antonio José Gil Mena, "Optimal distributed generation location and size using a modified teaching-learning based optimization algorithm", International Journal of Electrical Power & Energy Systems, Volume 50, September 2013, Pages 65-75, ISSN 0142-0615
- [18] D. Karaboga, "An idea based on honey bee swarm for numerical optimization," Technical Report TR06, Computer Engineering Department, Erciyes University, Turkey, 2005
- [19] D. Thukaram, H.M. Wijekoon Banda, Jovitha Jerome, "A robust three phase power flow algorithm for radial distribution systems", Electric Power Systems Research, Volume 50, Issue 3, 1 June 1999, Pages 227-236.
- [20] D. Karaboga and B. Basturk, "Artificial Bee Colony (ABC) Optimization Algorithm for Solving Constrained Optimization Problems". Berlin, Germany: Springer-Verlag, 2007, vol. LNAI 4529, pp. 789-798.
- [21] D. Karaboga, B. Basturk, "On the performance of artificial bee colony (ABC) algorithm", Applied Soft Computing, Volume 8, Issue 1, January 2008, Pages 687-697, ISSN 1568-4946.
- [22] D. Karaboga, B. Akay, "A modified Artificial Bee Colony (ABC) algorithm for constrained optimization problems", Applied Soft Computing, Volume 11, Issue 3, April 2011, Pages 3021-3031, ISSN 1568-4946.
- [23] A. S. Safiaggianni, G. J. Salis, "Optimum voltage regulator placement in a radial power distribution network", IEEE Trans. on Power Systems, vol. 15, no. 2, pp. 879-886, May 2000.
- [24] T. Gözel, U. Eminoglu, M.H. Hocaoglu, "A tool for voltage stability and optimization (VS&OP) in radial distribution systems using matlab graphical user interface (GUI)", Simulation Modelling Practice and Theory, Volume 16, Issue 5, May 2008, Pages 505-518, ISSN 1569-190X.