Periodica Polytechnica
Electrical Engineering
and Computer Science

59(3), pp. 104-109, 2015
DOI: 10.3311/PPee.8579

RESEARCH ARTICLE

A Modified Firefly Algorithm for Optimal Sizing and Siting of Voltage Controlled Distributed Generators in Distribution Networks

Mahmoud M. Othman[1], Yasser G. Hegazy[2 *], Almoataz Y. Abdelaziz[1]

Received 30 April 2015; accepted after revision 21 August 2015

Abstract
This paper presents a modified firefly algorithm for optimal placement and sizing of voltage controlled distributed generators in unbalanced distribution networks. The proposed algorithm modifies the traditional firefly method to be able to deal with the practically constrained optimization problems by proposing formulas for tuning the algorithm parameters and updating equations. The proposed algorithm rigidly determines the optimal location and size of the distributed generation units in order to minimize the system power loss without violating the system practical constraints. The proposed algorithms is implemented in MATLAB and tested on the IEEE 69 bus and the IEEE 123 -nodes feeder, the results that are validated by comparing them to published results obtained from other competing methods shows the effectiveness, accuracy and speed of the proposed method.

Keywords
distributed generators, Firefly algorithm, optimization

[1] Department of Electrical Power and Machines, Faculty of Engineering, Ain Shams University, Cairo, Egypt

[2] Faculty of Information Engineering and Technology, German University in Cairo (GUC), Cairo, Egypt

[*] Corresponding author, e-mail: yasser.higazi@guc.edu.eg

1 Introduction

Artificial intelligence optimization methods occupy a prominent place in solving the optimization problems concerning the optimal distributed generation (DG) placement and sizing. Several methods are used for solving the aforementioned optimization problem. In this context, genetic algorithm (GA), tabu search (TS), particle swarm optimization (PSO), ant colony optimization, artificial bee colony (ABC), harmony search (HS) and Firefly Algorithm (FA) are from the most efficient methods used.

Genetic algorithm (GA) is proposed in [1] for evaluating the optimal size of multiple DGs in order to minimize the system power loss. GA is applied to solve an optimal multiple DGs sizing and siting problem with reliability constraints in [2]. Paper [3] proposes a GA based method for optimal sizing and siting of DGs in radial as well as networked systems for the sake of power loss minimization. A GA is utilized in [4] to solve the optimization problem that maximizes the profit of the system by the optimal placement of DGs. A GA methodology is implemented to optimally allocate renewable DG units in distribution network to maximize the worth of the connection to the local distribution company as well as the customers connected to the system [5]. A value-based approach, taking into account the benefits and costs of DGs, is developed and solved by a GA that computes the optimal number, type, location, and size of DGs [6].

Tabu search (TS) is used to solve the optimal sizing and siting of DG units simultaneously with the optimal placement of reactive power sources in [7]. A stochastic multiple DGs optimal sizes and locations are determined for cost minimization by a combined TS and scatter search [8].

A multiobjective with weight method based on particle swarm optimization (PSO) is applied for determining the optimal size and location of multiple DGS in distribution system with non unity power factor considering variable power load models [9]. PSO is used for optimal selection of types, locations and sizes in order to maximize the DG penetration considering standard harmonic limits and protection coordination constraints [10]. A PSO is utilized for cost minimization through the optimal sizing and placement of multiple DG units [11].

In [12] an optimization approach that utilizes an artificial bee colony (ABC) algorithm to determine the optimal DG size, power factor, and location in order to minimize the total system real power loss is proposed. A multiobjective ant colony system (ACS) algorithm is proposed to solve the optimization problem concerning multiple DGs location and sizes [13]. The optimal DG location is based on loss sensitivity factors and the optimal DG size is obtained by HS algorithm [14].

Firefly Algorithm (FA) was first introduced by Xin-She Yang [15] for solving nonlinear multidimensional optimization problems. Few publications utilize the firefly method for optimizing the power flow problem [16-19]. In [16] the authors applied the FA algorithm to solve economic dispatch problem. The results were compared with continuous genetic algorithm to show the effectiveness of FA. Authors in [17, 18] use FA to evaluate the optimal location and size of one or two distributed generators on a balanced radial feeder for power loss minimization. In [19] an application of FA on optimal allocation of DG based on real and reactive power loss and voltage profile optimization for different load models.

This paper presents a modified firefly algorithm for determining the optimal location and capacity of voltage controlled DG connected to unbalanced distribution feeders in order to minimize the active power loss. The proposed algorithm modifies the traditional firefly method by proposing formulas for the FA parameters and updating equations in order to be applicable for the current optimization problem. The proposed algorithm is implemented in MATLAB and tested on the 69 -bus feeder for validation of the proposed algorithm via comparing its results with published results done using artificial bee colony and genetic algorithm methods. The proposed algorithm is also tested on the IEEE 123-node feeder for proving its efficiency in dealing with unbalanced distribution systems.

2 Problem statement

The objective functions are to minimize the active power loss using (1)

$$\text{Minimize Obj. Fun.} = \sum_{f=1}^{Nf} P_{loss,f} \tag{1}$$

Where f is feeder number, Nf is total number of feeders, $P_{loss,f}$ is the power loss at certain feeder f.

It is required to select the optimal location and capacity of a DG unit in order to minimize the system power loss under the following practical constraints:

- Voltage limits: voltage at each bus should be within a permissible range usually:

$$0.95\ p.u. \le V \le 1.05\ p.u. \tag{2}$$

- DG power limits: active, reactive and complex powers of the DG unit are constrained between minimum and maximum values and this range should not be violated.

$$P_g^{\min} \le P_g \le P_g^{\max} \tag{3}$$

$$Q_g^{\min} \le Q_g \le Q_g^{\max} \tag{4}$$

$$s_g^{\min} \le S_g \le \Sigma S_{load} \tag{5}$$

In the proposed method DG maximum active power is limited by:

$$P_g^{\max} \le \sum P_{loads} \tag{6}$$

The previous relation is bounded by the thermal capacity limit of the feeder lines. The DG power factor is bounded between two preset values; hence, the reactive power is also bounded in return.

- Lines thermal limit (line Ampacity): it represents the maximum current that the line can withstand at certain DG penetration, exceeding this value leads to melting of the line.

$$I_{flow} \le I_{Thermal} \tag{7}$$

- Power balance: the sum of input power should be equal to the sum of output active power in addition to the active power loss. The input power may include the DG active power and the active power supplied by the utility. The active output power is the sum of loads active power.

$$P_{substaion} + \sum P_{DG} = \sum P_{loads} + P_{loss} \tag{8}$$

The modified firefly (FA) based algorithm is applied to optimally determine the DG location and minimum size required to minimize the active power loss. DG in the proposed algorithm is modeled as PV node with the flexibility to be converted to PQ node in case of reactive power limit violation.

3 Modified Firefly Algorithm

In comparison with the other evolutionary algorithms, FA has many major advantages to be used in solving complex multidimensional nonlinear optimization problems. Some of these advantages are simple concepts, easy implementation, and higher stability mechanism. Despite these features, it often experiences inappropriate convergence because the fireflies are trapped in local optima, loss of diversity through the fireflies, or slow proceeding of the algorithm search. It should be noted that the performance of the Firefly optimization algorithm is dependent on the tuning of its different parameters. A small change in the parameters may result in a large change in the solution of the algorithm.

The proposed modified FA method grips the demerits of the traditional FA through the following modifications:

- Proposing formulas for tuning the system parameters to be suitable for different applications.
- Amendment of the updating equations of the FA method to be suitable for the current optimization problem and

for accelerating the convergence as the randomization term delay the convergence.

- Annexing the stopping criteria helps in decreasing the number of parameters to be tuned by excluding the maximum number of iteration from them.
- The fireflies are compared and attracted to the brightest firefly only unlike the traditional FA that compares all the fireflies with each other. Thus, the computational effort and time are much reduced.
- Keeping the brightest firefly of iteration within the variables of the next iteration in order not to lose a candidate solution.

3.1 Tuning of the FA parameters

Unlike the traditional algorithm that assume constant values for tuning the FA parameters. The modified FA algorithm proposes the following equations for adaptive tuning of the FA parameters:

$$\beta_0 = 1 \tag{9}$$

$$\gamma_l = 1/loc^{\max,it}, \gamma_p = 1/P_g^{\max,it} \tag{10}$$

$$\alpha_l = loc^{\max}/it^2, \alpha_p = P_g^{\max}/it^2 \tag{11}$$

where $loc^{\max,it}$ and $P_g^{\max,it}$ are the maximum values of the DG locations and DG active power at certain iteration (*it*) respectively. $loc^{\max}$ and $P_g^{\max}$ are the upper boundaries of the DG locations and DG active power. γ_l and γ_p are the FA absorption coefficients for the DG location and power. α_l and α_p are the FA randomization parameters for the DG location and power. The main contribution of proposing formulas for the FA parameters is to allow the FA method to be applicable for the optimization problems concerning sizing and placement of DG. Moreover, the square of the iteration step is used in α_l and α_p equations in order to quicken the convergence.

3.2 Updating equations of the modified FA

The distance between each firefly (i) that has two dimensions (DG location and DG active power) and the brightest firefly (the best DG location and power that achieve minimum power loss) is calculated using (12).

$$r_i = \sqrt{\left(\frac{loc_{best} - loc_i}{loc_{\max}}\right)^2 + \left(\frac{P_g^{best} - P_g^i}{P_g^{\max}}\right)^2} \tag{12}$$

The new fireflies (DG locations and DG powers) are updated using (13) and (14). DG locations and powers are upper and lower bounded.

$$loc_i = loc_i + \beta_0 \exp\left(-\gamma_l r_i^2\right) \times \left(loc_{best} - loc_i\right) + \alpha_l \left(rand - \frac{1}{2}\right) \tag{13}$$

$$P_g^i = P_g^i + \beta_0 \exp\left(-\gamma_p r_i^2\right) \times \left(P_g^{best} - P_g^i\right) + \alpha_p \left(rand - \frac{1}{2}\right) \tag{14}$$

3.3 Modified FA

For guaranteeing of reaching the optimal solution with less effort and with rapid convergence the modified FA algorithm is proposed. Figure 1 shows the flow chart of the modified FA and it is discussed in the following step by step procedure.

1) Read system data and tune the FA method parameters.
2) The initial values of the fireflies (DGs active power, DGs locations) are generated randomly.
3) Calculate the active power loss corresponding to all initial fireflies by running the unbalanced load flow.
4) Select the best DG location and power that achieve minimum active power loss (the brightest firefly).
5) Calculate the distance between each firefly (i) and the brightest firefly using (12)
6) Update the fireflies (DG locations and powers) using (13) and (14). Keep the best DG location and power as a one of the new fireflies (system variables), round the DG locations to the nearest integer.
7) Repeat steps (4-6) until the convergence criteria is met, the convergence is considered achieved when more than 50% of the fireflies are converged to a certain value.

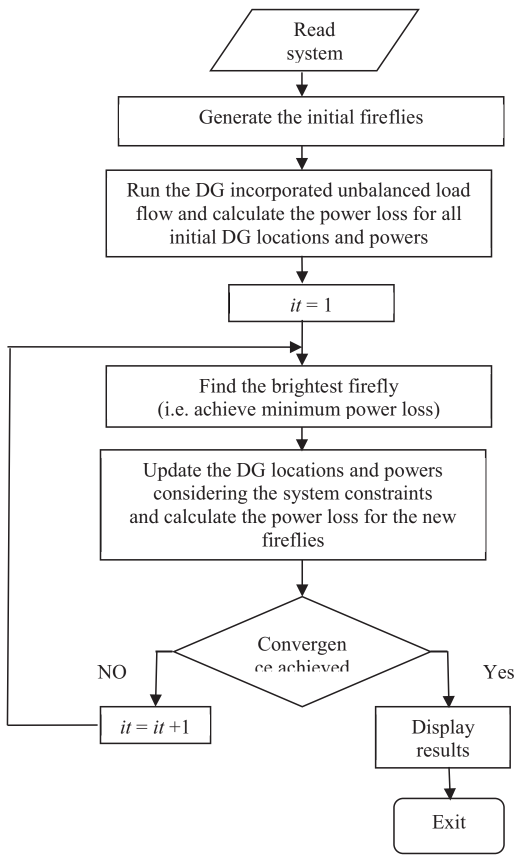

Fig. 1 Flow chart of the modified FA method

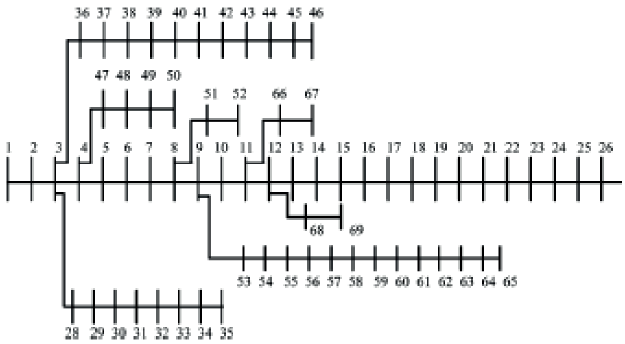

Fig. 2 Layout of 69-bus feeder

Table 1 Comparison of optimal location and power for 69 bus feeder with [22] and [23]

Method	Proposed		ABC [22]	GA [23]
	Case 1	Case 2		
Optimal Location	Bus 61	Bus 61	Bus 61	Bus 61
Optimal active power (KW)	1872.5	1800.2	1955	1955
DG reactive power (KVAr)	0	1304.3	0	0
DG capacity (KVA)	1872.5	2222.7	1955	1955
Ploss (KW)	83.2246	23.1737	83.31	83.45
Ploss reduction (%)	63.012	89.70	62.97	62.91

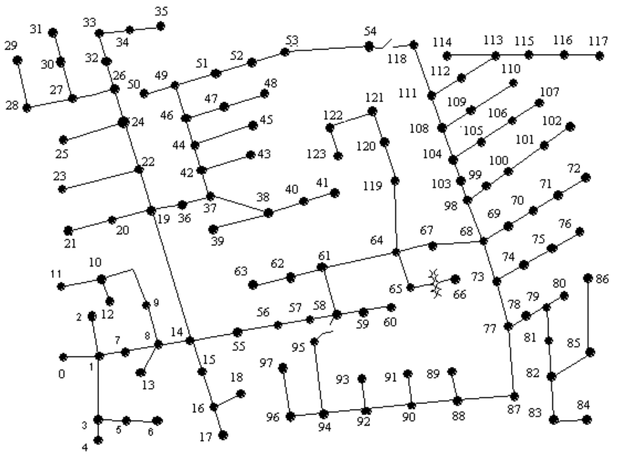

Fig. 3 Layout of the renumbered IEEE 123 nodes test feeder

4 Analysis and results

The proposed algorithm is implemented in MATLAB and the following studies are done on the IEEE 69 bus [20] and the IEEE 123 nodes [21] feeders presented in Fig. 2 and Fig. 3 respectively to evaluate the optimal DG location and size.

The IEEE 69 bus feeder is a balanced feeder with constant active and reactive power loads used to validate the proposed algorithm. While the IEEE 123 nodes feeder is complex as it is characterized by Spot loads, single phase and three phases balanced and unbalanced loads, star and delta connected loads, constant active and reactive power, constant impedance, and constant current type loads. The feeder is edited by removing the connected regulators and capacitors to clearly evaluate the impact of DG on power loss and voltage profile, closing the normally closed switches and opening the normally open switches. In addition, the feeder is renumbered for simplicity.

The DG in the proposed study is modeled as PV node with the flexibility to be converted to PQ node in case of reactive power limit violation; the reactive power limits is calculated by varying the power factor from 0.8 lagging to 0.8 leading. Moreover, the DG model could be switched to PQ node only whenever required.

4.1 Validation of the proposed modified FA algorithm

The proposed algorithm is applied to the 69 bus feeder in order to minimize its power loss through optimal selection of DG power and location. Two cases are done using the proposed method, the first case is to find the optimal location and power of DG able to supply active power only and the second is for DG able to supply reactive power within the permissible range. The optimal DG active power and location are compared with results published in [22] that use artificial bee colony algorithm (ABC) and with results published in [23] that use genetic algorithm (GA). The two methods are used to determine optimal location and size of DG that supplies active power only. The comparison results are presented in Table 1, results of case (1) is closely matched to the results of [22, 23] as their studies are done on DG that supply active power only. While case (2) shows that the proposed algorithm is more efficient in finding the DG optimal location and power as the power loss is much reduced, this can be explicated that the proposed algorithm not only evaluate the optimal DG active power but also evaluate the optimal DG reactive power within the permissible range that is able to keep the bus voltage at the specified voltage which is 1 p.u.

4.2 Optimal placement and sizing of DG in IEEE 123-nodes feeder for power loss minimization

The optimization problem is constrained as mentioned before in Section 2. All constraints are taken into account in the proposed method; the maximum active power of each DG is calculated in order not to exceed the feeder thermal limit.

The proposed modified FA method is applied on the IEEE 123 nodes feeder, two cases are done using the proposed method, the first case is to find the optimal location and power of DG able to supply active power only and the second is for DG able to supply reactive power within the permissible range. The optimal DG locations and powers for minimizing the power loss for the two test cases are presented in Table 2.

Table 2 optimal location and power for 123 bus feeder

Method	Modified FA	
	Case 1	Case 2
Optimal Location	Bus 68	Bus 68
Optimal active power (kW)	2098	2103.3
DG reactive power (kVAr)	0	1159.4
DG capacity (kVA)	2098	2401.68
Ploss (kW)	11.9364	6.755
Ploss reduction	67.4204%	81.563%

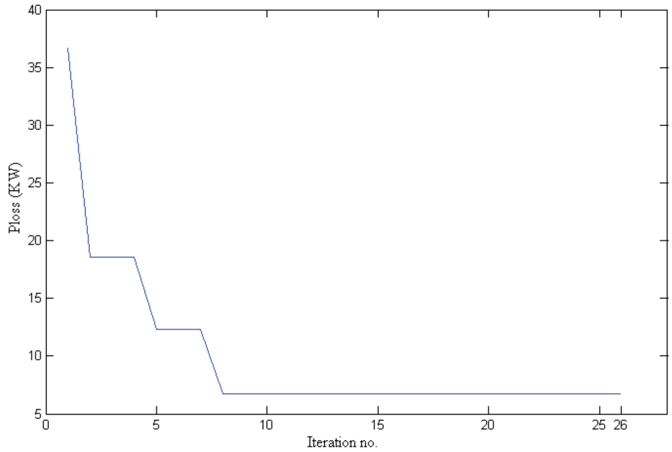

Fig. 4 Convergence characteristics of the IEEE 123 nodes feeder power loss

To evaluate the speed of convergence of the proposed method, the power loss versus iterations is plotted in Fig. 4. However, the active power loss converged to its optimal values after 8 iterations only, meeting the stopping criteria previously mentioned in Section 3 need 26 iterations which shows the high speed of convergence of the proposed method.

A Comparison is done between the traditional FA method and the modified FA method to emerge the advantages of the subsequent method. Ten trials were done using the two methods at different number of fireflies (DG powers, DG locations) with different initial values and random tuning of the traditional FA parameters. Any method is considered failed if it converges to values other than the optimal values. Figure 5 shows the success percentage comparison between traditional and modified FA at different number of fireflies. The comparison shows the robustness of the proposed method at small number of fireflies.

5 Conclusion

A modified FA method is presented in this paper. The proposed method modifies the traditional FA method via proposing formulas for the FA parameters and updating equations. The modified FA method determines accurately the optimal location, capacity of voltage controlled DG in order to minimize the system power loss. The method is applied on balanced and unbalanced distribution feeders and validated via comparing its

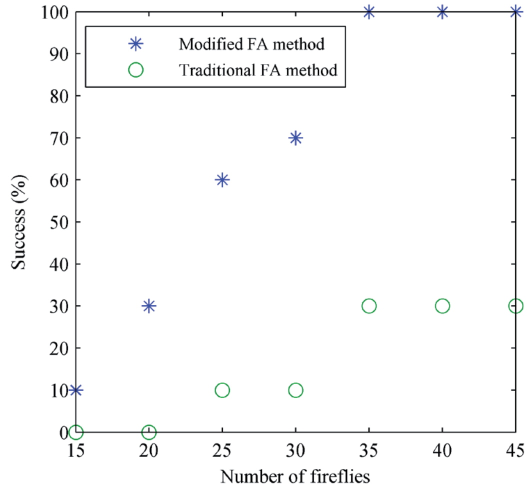

Fig. 5 Comparison between traditional and modified FA methods

results with published results done using ABC and GA methods. In addition, the proposed method is compared with the traditional FA method to confirm its efficiency and robustness. The proposed FA method shows a high speed of convergence, less computational effort and a high effectiveness as compared to traditional FA method.

References

[1] Kim, J. O., Nam, S. W., Park, S. K., Singh, C. "Dispersed generation planning using improved Hereford ranch algorithm." *Electric Power Systems Research.* 47 (1). pp. 47-55. 1998. DOI: 10.1016/s0378-7796(98)00038-8

[2] Borges, C. L. T., Falcão, D. M. "Optimal distributed generation allocation for reliability, losses, and voltage improvement." *International Journal of Electrical Power & Energy Systems.* 28 (6). pp. 413-420. 2006. DOI: 10.1016/j.ijepes.2006.02.003

[3] Singh, R. K., Goswami, S. K. "Optimum siting and sizing of distributed generations in radial and networked systems." *Electric Power Components and Systems.* 37 (2). pp. 127-145. 2009. DOI: 10.1080/15325000802388633

[4] Singh, R. K., Goswami, S. K. "Optimum allocation of distributed generations based on nodal pricing for profit, loss reduction, and voltage improvement including voltage rise issue." *International Journal of Electrical Power & Energy Systems.* 32 (6). pp. 637-644. 2010. DOI: 10.1016/j.ijepes.2009.11.021

[5] Shaaban, M. F., Atwa, Y. M., El-Saadany, E. F. "DG allocation for benefit maximization in distribution networks." *IEEE Transactions on Power Systems.* 2 (2). pp.639-649. 2013. DOI: 10.1109/tpwrs.2012.2213309

[6] Teng, J.-H., Liu, Y.-H., Chen, C.-Y., Chen, C.-F. "Value-based distributed generator placements for service quality improvements." *International Journal of Electrical Power & Energy Systems.* 29 (3). pp. 268-274. 2007. DOI: 10.1016/j.ijepes.2006.07.008

[7] Golshan, M. E. H., Arefifar, S. A. "Optimal allocation of distributed generation and reactive sources considering tap positions of voltage regulators as control variables." *European Transactions on Electrical Power.* 17 (3). pp. 219-239. 2007. DOI: 10.1002/etep.130

[8] Novoa, C., Jin, T. "Reliability centered planning for distributed generation considering wind power volatility." *Electric Power Systems Research.* 81 (8). pp. 1654-1661. 2011. DOI: 10.1016/j.epsr.2011.04.004

[9] El-Zonkoly, A. M. "Optimal placement of multi-distributed generation units including different load models using particle swarm optimisation." *IET Generation, Transmission & Distribution.* 5 (7). pp. 760-771. 2011. DOI: 10.1049/iet-gtd.2010.0676

[10] Pandi, V. R., Zeineldin, H. H., Xiao, W. "Determining optimal location and size of distributed generation resources considering harmonic and protection coordination limits." *IEEE Transactions on Power Systems.* 28 (2). pp.1245-1254. 2013. DOI: 10.1109/tpwrs.2012.2209687

[11] Gomez-Gonzalez, M., López, A., Jurado, F. "Optimization of distributed generation systems using a new discrete PSO and OPF." *Electric Power Systems Research.* 84 (1). pp. 174-180. 2012. DOI: 10.1016/j.epsr.2011.11.016

[12] Abu-Mouti, F. S., El-Hawary, M. E. "Optimal distributed generation allocation and sizing in distribution systems via artificial bee colony algorithm." *IEEE Transactions on Power Delivery.* 26 (4). pp. 2090–2101. 2011. DOI: 10.1109/tpwrd.2011.2158246

[13] Wang, L., Singh, C. "Reliability-constrained optimum placement of reclosers and distributed generators in distribution networks using an ant colony system algorithm." *IEEE Transactions on Systems, Man, Cybernetics, Part C.* 38 (6). pp. 757-764. 2008. DOI: 10.1109/tsmcc.2008.2001573

[14] Rao, R. S., Ravindra, K., Satish, K., Narasimham, S. V. L. "Power loss minimization in distribution system using network reconfiguration in the presence of distributed generation." *IEEE Transactions on Power Systems.* 28 (1). pp. 317-325. 2014. DOI: 10.1109/tpwrs.2012.2197227

[15] Yang, X. S. "Firefly algorithms for multimodal optimization." *Stochastic Algorithms: Foundation and Applications SAGA 2009.* 5792. pp. 169-178. 2009. DOI: 10.1007/978-3-642-04944-6_14

[16] Sulaiman, M. H., Mustafa, M. W., Zakaria, Z. N., Aliman, O., Adul Rahim, S. R. "Firefly Algorithm Technique for Solving Economic Dispatch problem." In: *Power Engineering and Optimization Conference (PEDCO).* Melaka, Malaysia, 2012 Ieee International, pp. 90-95, 6-7 June 2012. DOI: 10.1109/PEOCO.2012.6230841

[17] Nadhir, K., Chabane, D., Tarek, B. "Distributed generation location and size determination to reduce power losses of a distribution feeder by Firefly Algorithm." *International Kournal of Advanced Science and Technology.* 56. pp. 61-72. 2013.

[18] Nadhir, K., Chabane, D., Tarek, B. "Firefly algorithm based energy loss minimization approach for optimal sizing and placement of distributed generation." In *Modeling, Simulation and Applied Optimization (ICMSAO), 2013 5th International Conference on*, pp. 1-5, 28-30 April 2013. DOI: 10.1109/ICMSAO.2013.6552580

[19] Saravanmutthukumaran, S., Kumarappan, N. "Sizing and siting of Distribution Generator for Different Loads using Firefly Algorithm." In*: Advances in Engineering, Science and Management (ICAESM), 2012 International Conference on.* pp. 800-803, 30-31 March 2012.

[20] Baran, M. E., Wu, F. F. "Optimal capacitor placement on radial distribution systems." *IEEE Transactions on Power Delivery.* 4 (1). pp. 725-734. 1989. DOI: 10.1109/61.19265

[21] Radial Distribution Test feeders. [Online] Available from: http://ewh.ieee.org/soc/dsacom/testfeeders.html [Accessed: February 2015]

[22] Abu-Mouti, F. S., El-Hawary, M. E. "Optimal distributed generation allocation and sizing in distribution systems via artificial bee colony algorithm." *IEEE Transactions on Power Delivery.* 26 (4). pp. 2090-2101. 2011. DOI: 10.1109/tpwrd.2011.2158246

[23] Shukla, T. N., Singh, S. P., Srinivasarao, V., Naik, K. B. "Optimal sizing of distributed generation placed on radial distribution systems." *Electric Power Components and Systems.* 38 (3). pp. 260-274. 2010. DOI: 10.1080/15325000903273403