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Optimal Placement and Sizing of Distributed Energy Generation in an Electrical Network Using the Hybrid Algorithm of Bee Colonies and Newton Raphson

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Abstract

Distributed generation (DG) is gaining in importance due to the growing demand for electrical energy and the key role it plays in reducing actual energy losses, lowering operating costs and improving voltage stability. In this paper, we propose to inject distributed power generation into a distribution system while minimizing active energy losses. This injection should be done at a grid node (which is a point where energy can be injected into or recovered from the grid) that will be considered the optimal node when total active losses in the radial distribution system are minimal. The focus is on meeting energy demand using renewable energy sources. The main criterion is the minimization of active energy losses during injection. The method used is the algorithm of bee colony (ABC) associated with Newtonian energy flow transfer equations. The method has been implemented in MATLAB for optimal node search in IEEE 14, 33 and 57 nodes networks. The active energy loss results of this hybrid algorithm were compared with the results of previous searches. This comparison shows that the proposed algorithm allows to have reduced losses with the power injected that we have found.

Keywords

Optimization, Distributed Power Generation, Bee Colony Algorithm, Newton Raphson

1. Introduction

Driven by a favorable context (political will, economic interest, etc.), decentralized generation is developing in many countries. To compensate for the lack of electrical energy, power producers are then turning much more towards renewable energies, which offer the possibility of producing electricity in a clean and above all less resource-dependent way, provided that they accept their natural and sometimes random fluctuations, by building decentralized power plants. However, the decentralized nature of these plants poses a problem of distribution to a maximum number of users. In order to meet the energy demand in these areas, it is necessary to inject the energy produced into the existing grid. Injecting decentralized energy such as PV into an electrical grid has the advantage of reducing the load supplied by the source stations and under specific conditions, a reduction in Joule losses, a possible improvement of the voltage profile, and the reliability of the grid [1] [2].

In order for the injection of PV distributed generation to be beneficial to the power grid, it is necessary to maximize its power output while minimizing losses. To achieve this, it is necessary to control the amount and location of injection [2]. This reduces the cost of production. Intelligent optimization methods are effective ways to facilitate the integration of energy production into the power system while minimizing losses and having a stable voltage network. Among the intelligent methods are metaheuristics, also called "Swarm Intelligence", which are algorithms that mimic the collective intelligent behavior of species to solve overly complex problems [3]. In Cameroon, the problem of energy injection also arises because the photovoltaic energy produced remains mostly isolated from the electricity grid. The fundamental question we can ask ourselves is whether we should increase the energy supply in a grid by injecting energy produced in isolation into the grid, where and how we can inject this photovoltaic energy in order to make an optimal production. So, it will be a matter of finding the node(s) where the PV energy is to be injected. To answer this fundamental question, we need to be able to supply all the loads in the grid with sufficient and good quality energy. The ideal node for energy injection will be the one with minimal joule losses and negligible voltage sensitivity [4].

The work reported in the literature to date has addressed the issue of determining the size and location of distributed energy in the distribution network using various conventional optimizations. Orge *et al.* (2006), L.F. OCHOA *et al.* (2011) have used meta-heuristic algorithms such as the genetic algorithm to optimize the optimal distribution of DGs in the grid [5] [6]. The optimization particle swarm was used by Zokonsi E (2011) to inject a DG into the array [7]. N. Jain; S. Sultana *et al.* (2013) used Learning Base Optimization (LBO) for the optimal placement of a DG in a 33-node IEEE network [8]. Ketfi Nadhir (2013) used the firefly algorithm to determine the position and size of a DG in a network while minimizing active energy losses [9]. In this work, an attempt to optimize the placement and sizing of the DG in the power grid is made with the combined methods of the Newton Raphson (NR) algorithm and the simplified bee colony algorithm (ABC). The choice of ABC is motivated by the work of Karaboga (2007) [10] and Dusan T. (2009) and Kumar *et* *al.* (2013) [11] who all discussed the advantages of the bee colony algorithm such as the search for an overall minimum; a method that gives reduced power losses with a relatively short convergence time; a relatively new method. The paper is organized as follows. Section I gives the state of the art on the subject. The method for calculating active power losses in the distribution network and the optimization methods used will be described in Section II. The implementation of the hybrid algorithm will be presented in Section III. The results of the placement and sizing of the DP in the distribution network obtained by the algorithms and the discussion are presented in section IV through a case study on IEEE radial networks of 14, 33.57 nodes. The paper is organized as follows. Section I gives the state of the art on the subject. The method for calculating active power losses in the distribution network and the optimization methods used will be described in Section II. The implementation of the hybrid algorithm will be presented in Section III. The results of the placement and sizing of the DP in the distribution network obtained by the algorithms and the discussion are presented in Section IV through a case study on IEEE radial networks of 14, 33.57 nodes.

2. Methods

As we need to minimize losses in our network, it is a question of optimization. Optimization is a mathematical method devoted to the study of the minimum (s) or maximum (s) of a function with one or more variables over a certain domain of definition, from the study of their existence to their determination, generally through the implementation of an algorithm and consequently a program.

Optimization can be done in three possibilities: [12] [13] [14] [15]

- Minimization of fuel costs and/or CO_2 emissions;
- Minimization of joule loss; improved profile stability and tension;
- Maximizing transmittable power;

This is the second possibility we use because we have set ourselves the goal of minimizing active losses in our network.

In this work, the objective will be to optimize by minimizing the loss of joules and improving the profile and voltage stability. Four elements are necessary to solve an optimization problem: the definition of the parameters; the choice of the objective function with its constraints; the choice of the model; the choice of the optimization algorithm. The definition of the parameters, the objective function and its constraints constitute the formulation of the optimization problem.

2.1. Formulation of the Optimization Problem

In a power grid, we can make the grid optimal by reducing active losses. However, the active losses in a network are a function of the current and line parameters of each branch. In order to have the best possible location of the

DG, we have set ourselves the goal of minimizing the total active losses in the network while keeping the voltages within acceptable ranges.

2.1.1. Objective Function

Our objective function will therefore be total active losses. In a distribution network, the total losses in joules are a function of the currents of each line and the line parameters [16] [17]. First we look for the power of the different nodes using the formulas:

$$P_{i+1} = P_i - P_{loss,i} - P_{L,i+1} \tag{1}$$

$$Q_{i+1} = Q_i - Q_{loss,i} - Q_{L,i+1} \tag{2}$$

$$P_{loss,i} = R_{i,i+1} * I_i^2 = R_{i,i+1} * \left(\frac{P_i^2 + Q_i^2}{V_i^2} \right) \tag{3}$$

$$Q_{loss,i} = X_{i,i+1} * I_i^2 = X_{i,i+1} * \left(\frac{P_i^2 + Q_i^2}{V_i^2} \right) \tag{4}$$

$$P_{loss,T} = \sum_{i=1}^{N} P_{loss,i} \tag{5}$$

In these formulas P_i and Q_i are respectively the active and reactive power at node *i*.

V_i is the voltage of node i.

N is total number of nodes.

$R_{i,i+1}$ is line resistance between node i and node $i+1$.

$X_{i,i+1}$ is line reactance between node i and node $i+1$.

Since we want to minimize the total losses in the in the network the objective function is:

$$F_{obj} = \min\left(P_{loss,T}\right) \tag{6}$$

2.1.2. Containers

The constraints are linked to the parameters of the network which must be constantly monitored [5]. One of the parameters is the tension of the knots. Plus, the maximum power to inject.

$$\forall i \in [1; N]$$

$$V_{\min} \le V_i \le V_{\max} \tag{7}$$

$$P_{\min} \le P_i \le 0.4 * P_{gen} \tag{8}$$

where, $V_{\min}$ and $V_{\max}$ are the minimum and maximum limits of the voltages of the bus number *i*. These values are respectively equal to 0.9 pu and 1.1 pu according to [17]. P_{gen} is the power of the generator at the source node. The maximum value of P_i (the power injected) is fixed at $0.4 * \text{Pgen}$ according to [1] because the power injected must not exceed 40% of the power of the source generator.

2.2. Presentation of the Different Optimization Algorithms

Using the power flow equations [18] and the ABC given below, we applied our program to 33 node radial network. After obtaining the network parameters at each node (powers, voltages and phases), the powers are injected at each node according to a percentage of the maximum power ranging from 10% to 40%. Then we apply the ABC according to the algorithm in **Figure 2** to find the local objective function and then the global objective function. We combined two algorithms for our work. They are the NR algorithm we obtained from [18] (**Figure 1**) and the ABC (**Figure 2**). The first one allows us to circulate energy through the network and the second one allows us to optimize.

2.2.1. Presentation of Newton Raphson's Algorithm

The NR algorithm has been used in our work for power flow. Thanks to this algorithm we looked for the active and reactive powers, then the voltage module and the phase at each node.

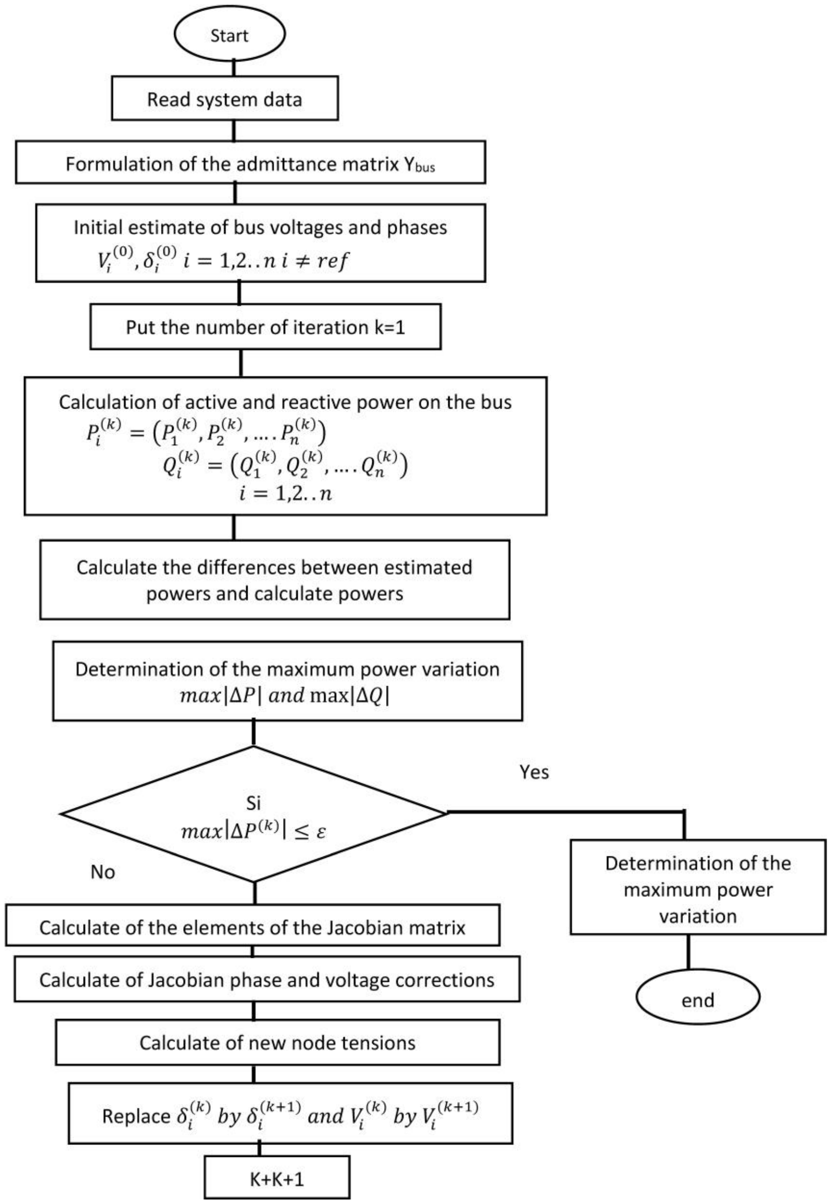

Figure 1. Organization chart of the Newton Raphson method [18].

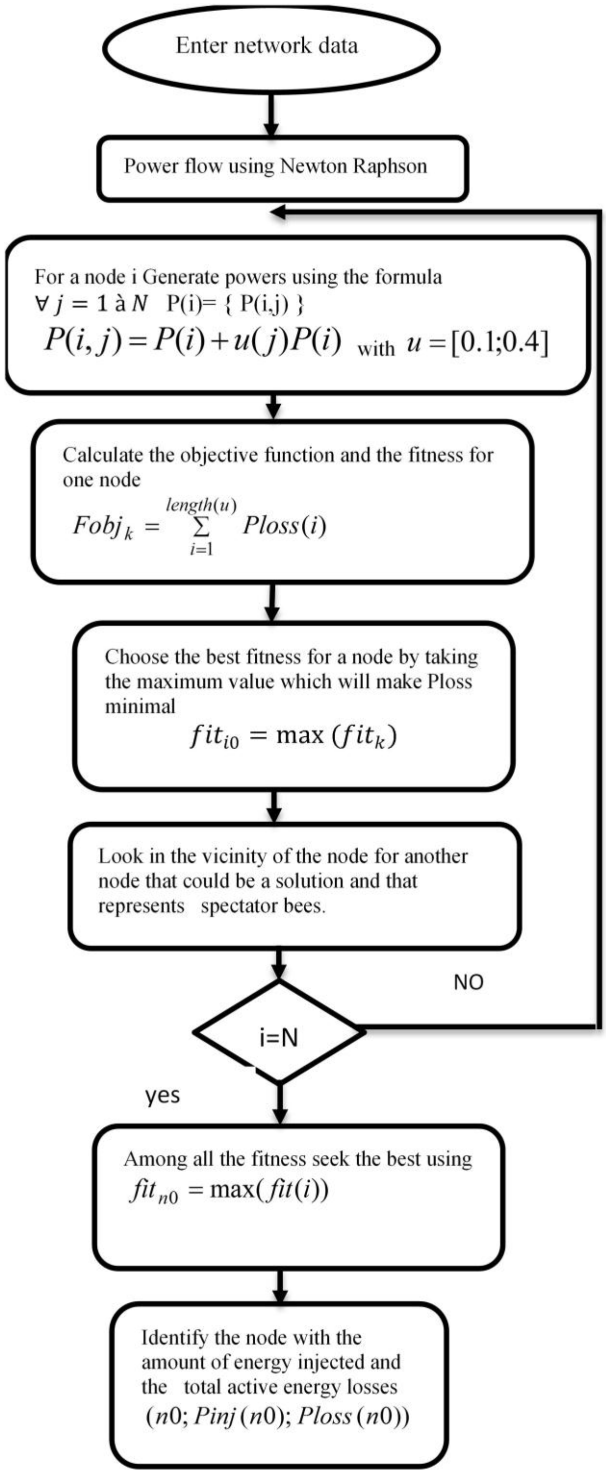

Figure 2. Hybrid algorithm for the placement of decentralized energy generation.

2.2.2. Bee Colonies Algorithm

Optimization by ABC is a recent metaheuristic which is inspired by the natural model of the behavior of honey bees when searching for their food. In this algorithm, the location of the food source represents the possible solution to the problem, and the amount of nectar from this source corresponds to an objective value called fitness [19]. Foragers are assigned to different food sources to maximize the total intake of nectar. The colony must optimize the overall efficiency of the collection. The distribution of bees is therefore a function of many factors such as the amount of nectar and the distance between the food source and the hive. The number of active or inactive foragers represents the number of solutions in this population. In the first step, the algorithm generates an initial population of SN solutions distributed randomly. Each solution is initialized by the scouts, and represents a vector of solution to the optimization problem. The variables contained in each vector must be optimized.

After initialization, the solution population is subjected to repeated cycles. These cycles represent research processes carried out by active, inactive foragers and scouts. Active foragers look for new sources with more nectar in the vicinity of the previous source. They then calculate their fitness. In order to produce a new food source from the old one, we use the expression above:

$$v_{ij} = x_{ij} + \phi_{ij}\left(x_{ij} - x_{kj}\right) \quad [19]\ [20]\ [21] \tag{10}$$

where $k \in \{1, 2, \cdots, BN\}$ (BN is the number of active foragers) and $j \in \{1, 2, \cdots, SN\}$ are indices chosen at random. Although k is randomly determined, it must be different from i. ϕ_{ij} is a random number in the range [−1, 1], it controls the production of a food source in the vicinity of x_{ij}. After the discovery of each new source of food, a greedy selection mechanism is adopted, that is to say that this source is evaluated by artificial bees; its performance is compared to that of x_{ij}. If the nectar from this source is equal to or better than that from the previous source, the latter is replaced by the new one. Otherwise the old one is kept.

For a minimization problem, Fitness is calculated according to this formula:

$$fit_i\left(\vec{x_i}\right) = \begin{cases} \dfrac{1}{1 + f_i\left(\vec{x_i}\right)} & \text{si } f_i\left(\vec{x_i}\right) \geq 0 \\ 1 + abs\left(f_i\left(\vec{x_i}\right)\right) & \text{si } f_i\left(\vec{x_i}\right) > 0 \end{cases} \tag{11}$$

Such that $f_i\left(\vec{x_i}\right)$ is the value of the objective function of the solution.

At this stage, the inactive foragers and the scouts who are in the waiting position within the hive. At the end of the research process, the active foragers share information on the nectar from the food sources as well as their locations with the other bees via the waggling dance. The latter evaluate this information drawn from all active foragers, and choose the food sources according to the probability value associated with this source, and calculated by the following formula [20] [21]:

$$P_i = \frac{fit_i}{\sum_{n=1}^{SN} fit_n} \tag{12}$$

where is the fitness of the solution, which is proportional to the amount of nectar from the position food source. The food source whose nectar is abandoned by bees; the scouts replace it with a new source. If during a predetermined number of cycles called "limit" a position cannot be improved, then this food source is supposed to be abandoned. All of these steps are summarized in the hybrid algorithm in **Figure 2**.

3. Implementation of Optimization Algorithms

The method was implemented in the 14.33 and 69 node networks. The characteristics of the networks are given in [22]. The number of nodes is taken as the total number of bees as spectators. The number of total power's generated in a node is the number of worker bees. When there is no ideal power in a node to have minimal losses, the node is abandoned and becomes like a scout bee.

We have three types of bees. The worker bees send out information about the quality of the nectar, exploiting the food source. The Spectator bees processes the information received from the workers to choose the source. The Scout bee is a worker bee that has no food source left to exploit and is looking for a food source site.

At each node, the energy injected varies between 1% and 40% of the source's generator power. The number of energy injected is 10, which represents the number of worker bees. At each injection, the program calculates the total grid losses and takes the minimum value of the active grid losses and the injected power that made it possible to obtain the latter. This minimum value is the local minimum. Having the local minimum of all the nodes, we will look for the global minimum corresponding to the whole network

4. Results and Discussion

The written program has been tested on IEEE 14, 33, 57 nodes networks. The data are obtained from [22]. Active energy losses per network and per node (**Figure 3**) show the losses at the different nodes and for the three types. It is important to know how our program evolves with the network.

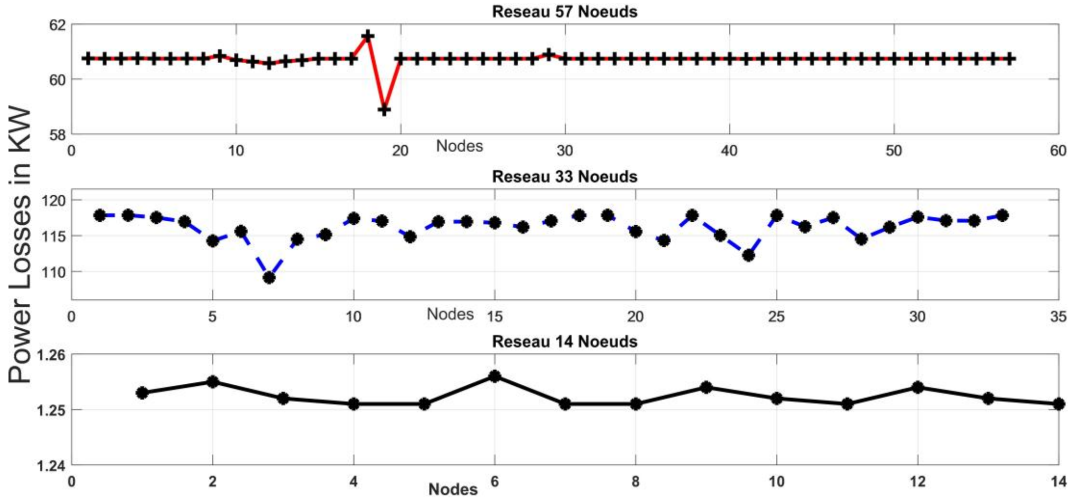

Figure 3. Curves of active energy losses in (Kw).

By observing these curves of Figure 3, we can see the variation of active energy losses in the different IEEE networks. Each node gives the local optimum. The global optimum is deduced from all the local optimums. Thus, we see that for the IEEE 33 node radial network, the global optimum (which represents the best value) is 109.1 KW and is located at node 7. For the IEEE 14 node radial network, the global optimum (which represents the best value) is 1.25 KW and is located at node 5. For the IEEE 57 node radial network, the global optimum (which represents the best value) is 58.89 KW and is located at node 19. The constraint of our optimization being the maintenance of the voltage at each node within a well-defined interval [V_{min}; V_{max}], we have drawn the voltage curves at the different nodes for the three IEEE networks.

According to these curves of Figure 4, the node voltage moduli remain between the minimum (0.9 pu) and maximum (1.1 pu) values in the range [0.98; 1.1] pu. In order to make a comparison with the results in the literature, we used data from the work of [9]. An example of a 33-node IEEE network is shown in Figure 5.

For this IEEE 33 knots radial network, the total power of the loads is 3.715 MW and 2.3 MVAr [9]. The total number of branches is 32 the base voltage 16.66 KV and the apparent base power 10.00 MVA. The program is developed in MATLAB R2018b. the AMD A4-5000 APU with Radeon (TM) hd gRAPHICS computer with 1.5 GHz frequency and 4.00 GB RAM. Figure 6 shows the variation of the active energy losses in the IEEE network 33 nodes as a function of the nodes.

In this Figure 6, it can be seen that the losses are minimal at node 7 with a value of 109.1 KW. This is the global optimum. Table 1 below compares the

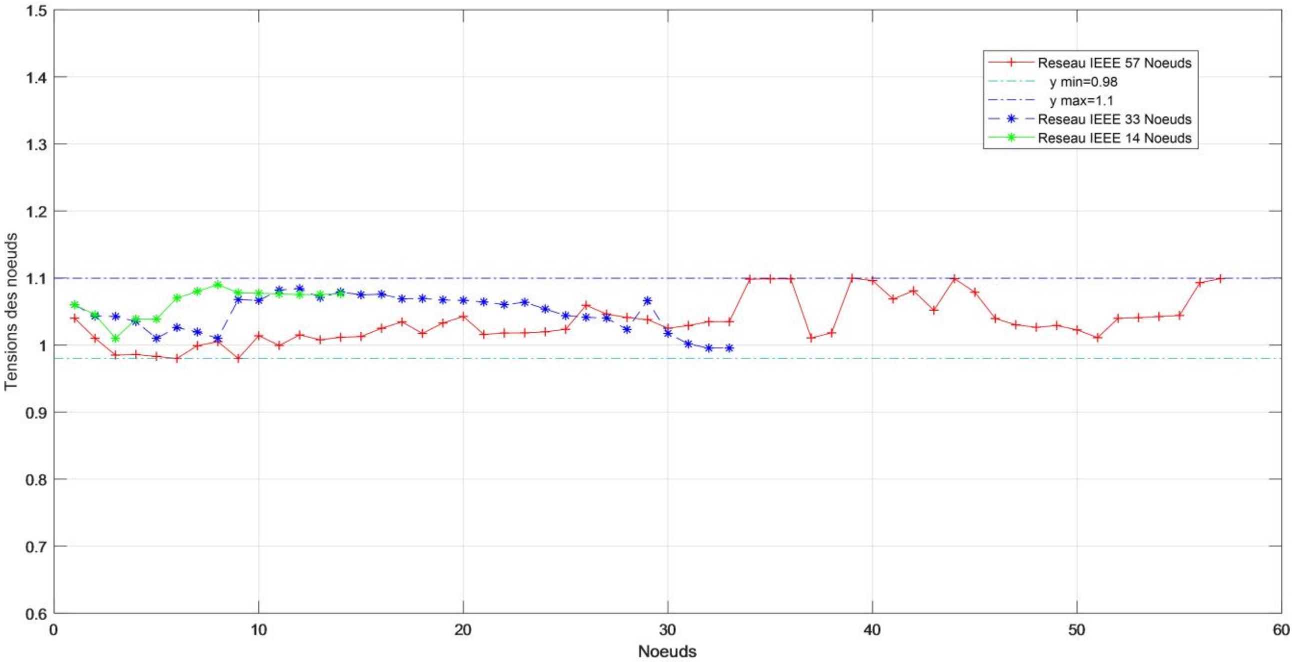

Figure 4. Voltage curves of the different nodes for the three IEEE networks in pu.

results with the data in the literature.

The comparison is made with the active power losses in an IEEE 33 node network. Table 1 gives the values of the minimum losses and the DG power values to obtain these minimum losses. It can be seen that the method used allows to obtain the minimum value of active losses which is equal to 109.1 kW. Compared to other values in the literature, we can see that our method has resulted in a significant reduction in losses. This allows us to validate the method.

Figure 7 shows the different DG values to obtain the minimum losses at each node. The DG value that allowed us to obtain the overall minimum losses is 9.7

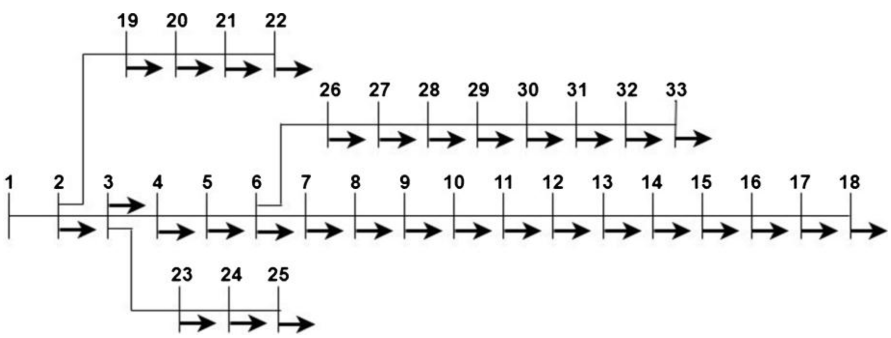

Figure 5. Structure of the IEEE 33-node network [9].

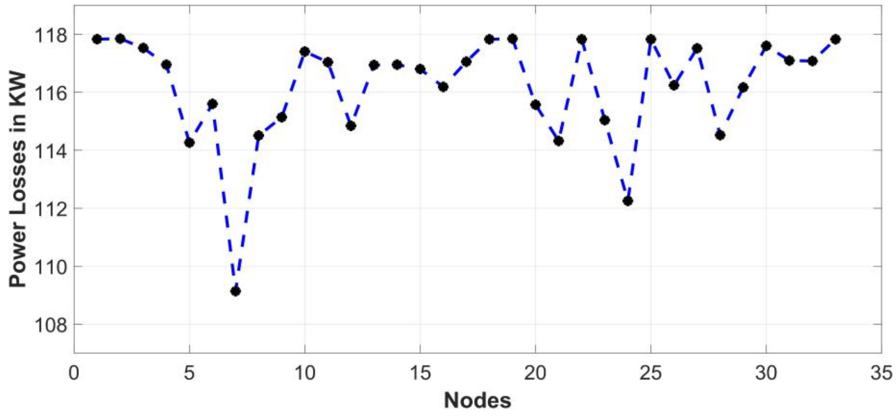

Figure 6. Curve of active energy losses in (Kw).

Table 1. Comparison of the results of the 33 bus system between our results and some results in the literature.

	Power loss in KW	DG size in MW	Bus N°
Particle swarm optimization [23]	111.03	2.59	6
Hybrid analytical and PSO approach [23]	111.17	2.49	6
Back tracking search algorithm [24]	118.12	1.857	8
Firefly algorithm [9]	116.7	1.19	30
Moth-Flame Optimization [16]	111.02	2.59	6
Shuffled Frog Leaping Algorithm [9]	118.2	1.2	30
Hybrid NR and ABC (proposed)	109.1	9.7	7

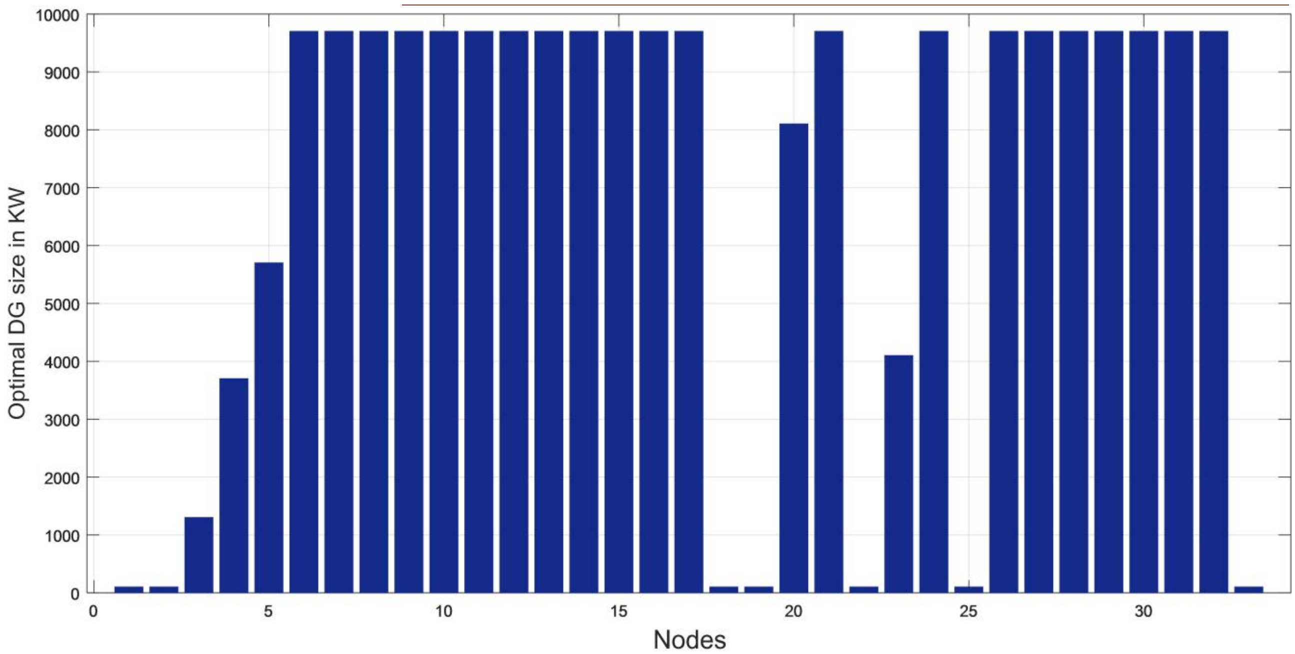

Figure 7. Optimal size of DG on individual bus for optimal losses.

MW. This value is a bit high compared to the other values in column 2 of the table. This led us to plot the voltage curve at the different nodes.

Figure 4 shows the voltages at the different nodes of the network. If we consider the IEEE 33 node network, we can see that the minimum value of the network voltage is 0.9131 pu and is located at node 17 and the maximum value is 1.084 and is located at node 12. These voltage values are acceptable.

5. Conclusion

In this paper, a hybrid algorithm including the NR algorithm and the simplified ABC has been proposed to determine the placement and amount of energy of a DG in a distribution network. This hybrid algorithm has been tested on IEEE 14.33 and 57 node networks. We calculated the energy flow and found the optimal point from our objective function using the bee colony algorithm. The results show that the losses are very low when the network has a large number of nodes. A comparison was made with previous work for the case of the IEEE 33 node network. The results show that the proposed method improves the value of active energy losses compared to other algorithms proposed in the literature, such as Particle swarm optimization [23], Hybrid analytical and PSO approach [23], Back tracking search algorithm [24], Firefly algorithm [9], Moth-Flame Optimization [16], Shuffled Frog Leaping Algorithm [9] on the one hand, and on the other hand that the value of total active losses is significantly improved compared to research work carried out with other forms of ABC.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Tajayouti, M. (2015) Electrical Network, Power Quality and Study of the Impact of PV Energy Injection Book. Mohammed V University, Rabat Higher School of Technology.

[2] Dang, X.L. (2014) Contribution to the Study of Distributed PV/Storage Systems: Impact of Their Integration into a Fragile Network. Doctoral Thesis, ENS, Cachan.

[3] Slimani, L. (2009) Contribution to the Application of Optimization by Metaheuristic Methods to the Optimal Power Flow in a Deregulated Electricity Environment. Doctoral Thesis, Batna University, Batna.

[4] Hamza, L. (2017) Study of Integration of Decentralized Production in an Electrical Distribution Network. Master's Thesis, Academic Kasdi Merbah Ouargla University, Ouargla.

[5] Borges, C.L.T. and Falcao, D.M. (2006) Optimal Distributed Generation Allocation for Reliability, Losses and Voltage Improvement. *Journal of Power and Energy Systems*, **28**, 413-420. https://doi.org/10.1016/j.ijepes.2006.02.003

[6] Ochoa, L.F. and Harrison, G.P. (2011) Minimizing Energy Losses: Optimal Accommodation and Smart Operation of Renewable Distributed Generation. *IEEE Transactions on Power Systems*, **26**, 198-205. https://doi.org/10.1109/TPWRS.2010.2049036

[7] El-Zonkoly, A.M. (2011) Optimal Placement of Multidistributed Generation Units Including Different Load Models Using Particle Swarm Optimization. *Swarm and Evolutionary Computation*, **1**, 50-59. https://doi.org/10.1049/iet-gtd.2010.0676

[8] Jain, N., *et al.* (2013) A Generalized Approach for DG Planning and Viability Analysis under Market Scenario. *IEEE Transactions on Industrial Electronics*, **60**, 5075-5085. https://doi.org/10.1109/TIE.2012.2219840

[9] Nadhir, K. (2013) Distributed Generation Location and Size Determination to Reduce Power Losses of a Distribution Feeder by Firefly Algorithm. *International Journal of Advanced Science and Technology*, **56**, 61-72.

[10] Karaboga, D. (2007) A Powerful and Efficient Algorithm for Numerical Function Optimization: Artificial Bee Colony (ABC) Algorithm. *Journal of Global Optimization*, **39**, 459-471. https://doi.org/10.1007/s10898-007-9149-x

[11] Kumar, N., Singh Parmar, K.P. and Dahiya, S. (2012) A Genetic Algorithm Approach for the Solution of Economic Load Dispatch Problem. *International Journal on Computer Science and Engineering*, **4**, 1063-1068.

[12] Srinivasa, R. (2008) Optimization of Distribution Network Configuration for Loss Reduction Us in Artificial Bee Colony Algorithm. *International Journal of Electrical*, *Computer*, *Energetic*, *Electronic and Communication Engineering*, **2**, 1964-1970.

[13] Ngueouele, Y.B. (2012) Modeling of Power Injections of a PV System on a Public Memory Network. Doctoral Thesis, International Institute 2IE.

[14] Mladjao, M.M. (2017) Contribution to the Modeling and Optimization of Multi-Source and Multi-Charge Energy Systems. Doctoral Thesis, Université De Lorraine, Lorraine.

[15] Loubière, P. (2016) Improvement of Optimization Metaheuristics Using Sensitivity Analysis. Doctoral Thesis, Paris-Est University, Paris.

[16] Anurag, D. and Laxmi, S. (2017) Optimal Placement and Sizing of Distributed Generation Units for Power Loss Reduction Using Moth-Flame Optimization Algorithm. *International Conference on Intelligent Computing*, *Instrumentation and Control Technologies*, p. 1577.

[17] Gargi, T., Anikumar, M. and Praghnesh, B. (2019) Optimal Sizing and Placement of Multiple Distributed Generators Using Teaching Learning Based Optimization Algorithm in Radial Distributed Network. 6*th International Conference on Control*, *Decision and Information Technologies*, Paris, 23-26 April 2019, 960.

[18] Thanatchai, K. (2009) Simplified Newton-Raphson Power-Flow Solution Method, Power System Research Unit. School of Electrical Engineering, Institute of Engineering, Suranaree University of Technology, Nakhon.

[19] Busayo, H.A., Abdoulie, S.M. and Ahmed, S.T. (2017) An Improved Artificial Bee Colony Using Cultural Algorithm for Optimization Problem. *International Journal of Computer Applications*, **160**, 14-18.

[20] Dušan, T. (2009) Bee Colony Optimization (BCO). University of Belgrade, Belgrade.

[21] Sandeep, K., Sharma, V.K. and Kumari, R. (2013) A Novel Hybrid Crossover Based Artificial Bee Colony Algorithm for Optimization Problem. *International Journal of Computer Applications*, **82**, 18-25.

[22] Sahoo, N.C. and Prasad, K. (2006) A Fuzzy Genetic Approach for Network Reconfiguration to Enhance Voltage Stability in Radial Distribution Systems. *Energy Conversion and Management*, **47**, 3288-3306. https://doi.org/10.1016/j.enconman.2006.01.004

[23] Kansal, S., Kumar, V. and Tyagi, B. (2016) Hybrid Approach for Optimal Placement of Multiple DGs of Multiple Types in Distribution Networks. *International Journal of Electrical Power & Energy Systems*, **75**, 226-235. https://doi.org/10.1016/j.ijepes.2015.09.002

[24] El-Fergany, A. (2015) Optimal Allocation of Multi-Type Distributed Generators Using Backtracking Search Optimization Algorithm. *International Journal of Electrical Power & Energy Systems*, **64**, 1197-1205. https://doi.org/10.1016/j.ijepes.2014.09.020