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M. Frahat
Assistant Lecture, Electrical Engineering Department, Faculty of Engineering, Mansoura University, Egypt, eng.mohamed_frahat86@yahoo.com

A. Y. Hatata
Associated Professor in Electrical Engineering Dept., Faculty of Engineering, Mansoura Univ., Egypt., a_hatata@mans.edu.eg

M. M. Saadawi
Prof. in Electrical Engineering Department, Faculty of Engineering Mansoura University, Egypt, m_saadawi@mans.edu.eg

S. S. Kaddah
Prof. in Electrical Engineering Department, Faculty of Engineering Mansoura University, Egypt, skaddah@mans.edu.eg

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Grasshopper Optimization-based Optimal Sizing of DG/DSTATCOM in Distribution Networks

M. Frahat *, A. Y. Hatata, M. M. Saadawi and S. S. Kaddah

KEYWORDS:
Loss Sensitivity Factor, VSI, DSTATCOM, Distributed Generators, Multi-objective Grasshopper Optimization Algorithm

Abstract— **This paper adopts the application of the new optimization technique to attain the optimal size and location of the distributed static synchronous compensators (DSTATCOMs) and distributed generators (DGs) in the electrical distribution network. The optimization technique is based on simulating the behavior of the Grasshopper insects and is called grasshopper optimizer algorithm (GOA). The proposed objective function that is used to obtain the size and locations of the DSTATCOMs and DGs is devised for reducing the losses in the active power and improving the voltage stability index, which is employed to detect the weak busses in the distribution network (DN). First, the optimal locations of the DGs and the DSTATCOMs are identified by using the loss sensitivity factor (LSF). Then, the proposed Multi-objective GOA is implemented to obtain the optimal penetration of the DGs and DSTATCOMs in the DNs. This methodology is tested on a radial distribution system (IEEE 33-bus) for different scenarios to inspect its effectiveness. The results proved that the reduction in the total power losses (TPLs) and the improvement in the voltage stability index (VSI) were 81.5% and 30.7%, respectively at cases which combined multi DGs and DSTATCOMs for the modified IEEE 33-bus test system. Also, the proposed method is compared with several existing algorithms; Particle Swarm Optimization technique, Backtracking Search, Immune Algorithm, Sine Cosine Algorithm, lightning Search Algorithm, and Bacterial Foraging Optimization Algorithm. The results confirm that the GOA method has better performance**

I. INTRODUCTION

Nowadays most of the electrical energy losses of the power system are consumed in the Distribution Networks (DNs) [1]. The increase in energy demand led to developing the DNs and the search for new alternatives to electric power generations such as renewable energy sources based-DGs. This may cause instability problems, an increase in power losses and load imbalance, and a decrease in bus voltage [2]. To avoid these drawbacks, the compensation devices are highly recommended to be installed at the current DNs. The DGs are applied to generate

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****Corresponding Author** M. Frahat, Assistant Lecture, Electrical Engineering Department, Faculty of Engineering, Mansoura University, Egypt (e-mail: eng.mohamed_frahat86@yahoo.com).*

A. Y. Hatata, Associated Professor in Electrical Engineering Dept., Faculty of Engineering, Mansoura Univ., Egypt. (e-mail: a_hatata@mans.edu.eg).

M. M. Saadawi, Prof. in Electrical Engineering Department, Faculty of Engineering Mansoura University, Egypt. (e-mail: m_saadawi@mans.edu.eg).

S. S. Kaddah, Prof. in Electrical Engineering Department, Faculty of Engineering Mansoura University, Egypt. (e-mail: skaddah@mans.edu.eg).

active/reactive power based on its type [3]. It can exist in the form of microturbines, fuel cells, reciprocating engines, wind, thermal solar, and photovoltaic [2]. Several factors were responsible for the prevalence of the DGs in the DNs. One of these factors is controversial environmental topics such as decreasing fossil fuels and reducing the greenhouse effects. This led to the need to deregulate the electricity market to increase the flexibility of the electrical networks. Many researchers had investigated the integration impacts of the DGs on the DNs. It found that detecting the optimal location of the DGs in these networks can lead to improve the voltage profile, reducing power losses and increasing the stability of voltage, etc. [4].

Reactive power compensation (RPC) devices were used in DNs to maintain the buses' voltages and lines' power losses in the presence of the DGs. Many types of devices can achieve the RPC such as automatic voltage regulators and shunt/series reactors and capacitors. Recently, the distributed flexible AC transmission system (DFACTS) such as unified power flow controller (UPFC), static synchronous series compensator (SSSC), and distributed static compensator (DSTATCOM), and, etc. was developed [5, 6]. Among these devices, the DSTATCOM enjoyed with small compact size, high voltage regulatory capability, and low power loss/cost [7, 8]. In these types of compensation devices, there is no transient harmonic operation problem. Moreover, the DSTATCOM devices alleviate many problems of the power quality such as current/voltage wave distortions, voltage violations, and unbalanced load [3]. The DSTATCOM not only injects reactive power but also it can set up the voltage value of the desired node by injection or absorption of reactive power. The DSTATCOM works as a synchronous voltage source that can regulate and control the bus voltage and power factor [9]. Adding a DSTATCOM to a node while setting the node voltage to a predefined value will change the nodes' nodal currents and affect the currents of feeders and consequently changes the load flow [10].

The optimal penetration and placement of both the DGs and RPC devices were studied in numerous researches and many techniques were developed to solve this problem [11, 21]. The Genetic Algorithm (GA) was advised in [11] to determine the optimal locations and sizes of the DGs in the DN. The objective of the optimization process was based on minimizing the generated active and reactive power. Particle Swarm Optimization (PSO) technique was applied to optimally allocate and size the DGs in the DNs [12]. In addition to reducing the active/reactive power loss costs, the voltage profile and system reliability improvements were included in the objective function. A Bee Colony algorithm was introduced to obtain the solution of the mixed-integer nonlinear optimization problem to minimize the system active power loss by determining the optimal location, power factor, and size of the DGs [13]. To minimize the costs of DGs' generation, power losses, and voltage violations in the DNs, the Honey Bee Mating optimization technique was applied [14]. The Quasi-oppositional teaching-learning method was introduced to optimally placement and size the DGs for reducing the active power loss and voltage deviation and improving the RDS stability [15].

Moreover, the Quasi-Oppositional Swine Influenza model had been used to calculate the optimum locations and sizes of the DGs in different DNs [16]. The main objectives of that proposed model were to improve the voltage stability and reduce the power losses of the DNs. In [17], An optimization method based on the backtracking search was applied to attain the optimal sizes and locations of multi-type DGs in the DNs. The Objective Function (OF) was adapted with weighting factors to lower the DN active power losses and enhance the buses' voltage for high operating performance. Ref. [18] applied the Imperialistic Competitive Algorithm for solving the optimization problem with load variations as a useful tool for planning the network. The Grey Wolf Optimizer (GWO) was used to minimize the reactive power losses, in addition to maintain the buses' voltage in the DNs [19]. The Antlion Optimization (ALO) technique was used to enhance the performance of the DN related to power losses and savings under different demands [20]. The Grasshopper Optimization Algorithm (GOA) was advised to obtain the optimal DN re-configuration to reduce the active power losses [21]. It was considered to locate the DG in the RDS with different objective functions. Most of the aforementioned methods have drawbacks, such as; the computational time being too large; some outputs are not optimal and considering only the DG active power injection.

Many researchers studied the optimal sizing and placement of the RPC devices in the absence of DG units in the DN. Ref. [22] applied a method to decrease the power losses by using an evolutionary algorithm for both sizing the DSTATCOM and reconfiguring the DN. The problem of optimal placement of DSTATCOM while reducing the power loss in an RDS was solved using an Artificial Immune Algorithm in [23]. The load variations in RDS were considered to decrease the active power losses by employing the algorithm of Bio-Inspired Bat for placement the DSTATCOM [6]. Moreover, the time-variant load models in mesh DNs were considered in [24] to solve the optimal DSTATCOM allocation problem by employing sensitivity approaches. Most of the researches did not consider the variation of load in the RDS, however, the optimal size and location of the DSTATCOM are affected by dynamic load changes.

Finally, some efforts were made for obtaining the optimal size and placement of both DGs and DSTATCOMs in the RDS. Ref. [25] used the PSO technique to manage the optimal size and placement of the DG/D-STATCOM to lower the power losses and enhance the voltage profile. The simulations were performed on different RDSs. However, in that paper, the method was not compared with other standard algorithms. Moreover, PSO technology has a significant drawback that may converge in local optima rather than the global optimum [26]. Ref. [27] presented the modified Cat Swarm Optimization technique to locate the DGs/DSTATCOMs in DNs to lower the power losses and maintain the voltage profile. But in general, it suffers from weak affinity and accuracy. In [25], the Bacterial Foraging Optimization technique had been hybridized and applied to optimally allocate the DSTATCOMs and DGs to maintain the buses' voltage and reduce the active power loss of DNs. In [4], the voltage violation, active power losses, and operating costs were minimized. The optimal locations of the DGs/DSTATCOMs in the DN were subjected to the following constraints: voltage deviation limit, DG allocation for active power compensation, and DSTATCOM sizing for reactive power compensation.

Based on the literature review mentioned above, more researches are required on finding the optimal size and location of the DSTATCOMs. Besides, most studies discussed the application of a single DSTATCOM in the DNs for minimizing the power losses. Moreover, it is essential to perform a comparative study related to the accuracy and speed of the various optimization techniques to solve any problem, whatever the conditions.

In this paper, a new Multi-objective GOA (MOGOA) is suggested to obtain the optimal size and locations of multi DGs and DSTATCOMs to enhance the voltage stability and reduce the power losses ~~and~~ in the RDSs. In the proposed technique, the Loss Sensitivity Factor (LSF) is employed to obtain the optimal DGs and DSTATCOMs locations. Then, the MOGOA is proceeded to obtain the optimal penetration of DGs/DSTATCOMs in the RDS. The obtained results from MOGOA are compared with other optimization methods and give more precise results when they are applied to the IEEE 33-bus RDS.

The rest of the article is presented as follows; sections 2 and 3 explain the proposed method for determining the optimal placements and sizes of the DGs/DSTATCOMs, and section 4 describes the MOGOA used in this paper. Section 5 illustrates the MOGOA implementation procedures, and section 6 illustrates the results and discussions. Finally, the conclusions of the paper are illustrated in section 7.

II. OPTIMAL PLACEMENT OF DGS AND DSTATCOMS

In this paper, the LSF has been employed to pre-determine the DGs and DSTATCOM's optimal placements. This decreases the search area and time for the MOGOA based optimization process, which will be applied as a second step. In the first step, the buses which have the largest values of the LSF related to the active/reactive power have a greater chance to place DG and DSTATCOM, respectively [28]. The maximum values of LSF will be sorted in descending order, and then the optimal placement between these busses will be performed by using a trial-and-error method. The buses which give minimum power loss will be chosen as candidate buses for the DGs and DSTATCOMs. The optimal locations of the DGs and DSTATCOMs are employed by (1) and (2), respectively [4]. The partial differentiation of the active power losses relative to the active power is applied to determine the optimal DGs locations as expressed by;

$$\frac{\partial P_{loss}(i,j)}{\partial P_{eff}} = \frac{2P_{j,eff}R_{i,j}}{|V_j|^2} \tag{1}$$

While the partial differentiation of the active power loss with relative to the reactive power is applied to calculate the optimal DSTATCOMs locations as expressed by;

$$\frac{\partial P_{loss}(i,j)}{\partial Q_{eff}} = \frac{2Q_{j,eff}R_{i,j}}{|V_j|^2} \tag{2}$$

where P_{loss} is the power losses, Q_{eff} and P_{eff} are the total effective reactive and active power, respectively, $Q_{j,eff}$ and $P_{j,eff}$ are the total effective reactive and active power supplied to node j, respectively and R_{ij} is the resistance of line from bus i to j and V_j is the voltage at bus j^{th}.

III. OPTIMAL SIZING OF THE DGS/DSTATCOMS

This study aims to minimize the active power losses in lines and enhance the voltage stability index at system buses by selecting the optimal size of both the DGs and the DSTATCOMs. The optimal placements are calculated using the LSF, as illustrated in the foregoing section. To obtain the optimal size of the DGs and DSTATCOMs, a new algorithm called MOGOA will be implemented in this paper. In the following sections, the OF and constraints of the problem are presented.

A. Problem objective function

Most of the literature employed a variety of single-objective functions in the optimal penetration and placement of DGs and DSTATCOMs in the RDS. So, using a multi-objective function is a challenging task to resolve this issue. In this paper, a multi-objective function is developed to improve the Voltage Stability Index (VSI) and reduce the Total Power Losses (TPLs) in the RDSs. The mathematical formulation of each of these indices is explained in the following subsections.

1) Total active power losses

The TPLs are considered as one of the essential factors that affect the design of RDSs. Thus, the power losses are affected by the penetration and location of the DGs and DSTATCOMs. So, the optimal sizing of the DG/DSTATCOM is concerned with the minimization of the active power losses in RDSs. The percentage change of total power losses (ΔTPL) can be expressed by;

$$\Delta TPL = \frac{P_{TL}^{DG/DST}}{P_{TL}^{w}} \tag{3}$$

where $P_{TL}^{DG/DST}$ the total power losses with DG/DSTATCOM and P_{TL}^{w} is the TPLs without DG/DSTATCOM.

2) Voltage Stability Index

The VSI can be defined as the capability of the power system to regulate the voltages at all system buses within the acceptable limits when subjected to disturbance [18]. The DGs and DSTATCOMs have automatically improved the system voltage stability when they are connected to the DNs. Moreover, if the voltage stability is not considered in the objective function, the RDS may be sensitive to the voltage problems [29]. The VSI can be expressed by;

$$VSI(i+1) = |V_i|^4 - 4\left[P_{i+1.eff} * X_t - Q_{i+1,eff} * R_i\right]^2 - 4\left[P_{i+1.eff} * R_i + Q_{i+1} * X_i\right]|V_i|^2 \quad (4)$$

VSI value must reach its maximum limit to avoid the voltage collapse in the RDS. The optimal location and size of the DGs/DSTATCOMs in the RDS can increase the VSI. So, the ratio between the two VSI values with/without DG/DSTATCOM is taken as an OF and can be expressed by,

$$\Delta VSI = \frac{VSI^{DG/DST}}{VSI^{w}} \quad (5)$$

where $VSI^{DG/DST}$ is the VSI with DG/DSTATCOM and VSI^{w} is the VSI without DG/DSTATCOM.

The overall OF can be determined by summation of the ΔTPL and the 1/ΔVSI,

$$OF = Min\left(w_1 \Delta TPL + w_2\left(\frac{1}{\Delta VSI}\right)\right) \quad (6)$$

where w_1 and w_2 are two weighting factors. The summation of w_1 and w_2 should equal one.

B. Constraints

To keep the DN in safe operation limits and improve the VSI, many constraints are satisfied. These constraints include power balance, voltage limits, ~~and~~ DG active/reactive power limits, and D-STATCOM reactive power limits.

1) Balance of active power

The summation of the total power consumed by loads and total power losses should be equal to the total generated power.

$$\sum_{i}^{ng} P_{G,i} = \sum_{i}^{nb} P_{D,i} + TPL \quad (7)$$

where $P_{D,i}$ and $P_{G,i}$ are the active power demand and generation at bus ith, respectively. n_b and n_g are the numbers of the loads and generator buses, respectively. *TPL* is the total active power loss.

2) DG power limits

The injected active and reactive power produced from the DG must be within its limits according to (8) and (9) [28].

$$P_{DG(i)}^{min} \le P_{DG(i)} \le P_{DG(i)}^{max} \qquad i=1, 2,\ n_g \quad (8)$$

$$Q_{DG(i)}^{min} \le Q_{DG(i)} \le Q_{DG(i)}^{max} \qquad i=1, 2,\ n_g \quad (9)$$

where $P_{DG(i)}^{max}$ and $P_{DG(i)}^{min}$ are the upper and lower DG active power at bus ith. $Q_{DG(i)}^{min}$ and $Q_{DG(i)}^{max}$ are the lower and upper DG reactive power at bus ith.

3) D-STATCOM limits

The DSTATCOM size is calculated from the injected reactive power. DSTATCOM must be within its limits to improve the voltage and can be expressed by [29];

$$Q_{DST(i)}^{min} \le Q_{DST(i)} \le Q_{DST(i)}^{max} \quad (10)$$

where $Q_{DST(i)}^{min}$ and $Q_{DST(i)}^{max}$ are the lower and upper limits of the injected reactive power from the D-STATCOM at bus ith.

4) Voltage limits

The magnitude of voltages must be within the appropriate range at each bus [30].

$$V_i^{min} \le V_i \le V_i^{max} \quad (11)$$

where V_i^{min} and V_i^{max} are the upper and lower limits of bus voltage magnitude.

IV. MULTI-OBJECTIVE GRASSHOPPER OPTIMIZATION ALGORITHM

The problems of multi-objective decisions, unlike the problems of individual objectives, address many objective functions to be minimized and/or maximized. There are many mathematical programming techniques for multi-objective optimization. Most of the recent work focuses on the approximation of the Pareto optimal solution set [31]. In other words, as an alternative to identify a single global solution, multi-objective optimization results in several compromise solutions for the set of objectives. This set of compromise solutions is defined as the set of optimal solutions of non-dominated Pareto [32]. A Pareto optimal solution is non-dominated if none of the OFs can be improved without the degradation in one or more of the other objectives [33, 34].

The MOGOA algorithm illustrates the swarming behavior of grasshoppers in nature. Grasshoppers are considered harmful insects that usually damage agriculture as well as crop production, even though grasshoppers are generally seen in nature as individuals, they join the large swarm of all creatures [28]. The grasshopper swarm has one special characteristic found in either adulthood or nymph. The nymph grasshoppers jump like rolling cylinders in enormous numbers. In their way, during their movement, they eat all the plants. After that, when they become adults, they sort in a swarm during flight and migrate for long distances [35].

The mathematical model for this behavior can be expressed in the following sections. The ith grasshopper movement to the target is indicated as Y_i and is expressed as:

$$Y_i = GF_i + SI_i + WA_i \quad (12)$$

where Y_i is the ith grasshopper position, GF_i is the gravity force, SI_i is the social interaction, and WA_i is the wind advection.
To provide random behavior, Eq. (12) can be rewritten as:

$$Y_i = r_1 SI_i + r_2 GF_i + r_3 WA_i \quad (13)$$

where r_1, r_2 and r_3 are random numbers between 0 and 1.

$$SI_i = \sum_{j=1\, j\neq i}^{N} f(d_{ij})\, \overrightarrow{d_{ij}} \quad (14)$$

$$\overrightarrow{d_{ij}} = \frac{x_j - x_i}{d_{ij}} \quad (15)$$

$$f(r) = ae^{\frac{-r}{l}} - e^{-r} \tag{16}$$

where d_{ij} represents the Euclidian distance and unit vector from i^{th} and j^{th} grasshoppers and equal $\left|x_j - x_i\right|$. $\overrightarrow{d_{ij}}$ is a unit vector from the i^{th} to j^{th} grasshopper respectively, l is the attractive length scale, f is the strength of social forces function that represents the attraction intensity and N is the grasshopper's number [36].

The SIs among grasshoppers is described as repulsion and attraction. The distance covered is between 0 to 15, where repulsion takes place in between [0, 2.079] [28]. The strong forces cannot be applied between grasshoppers with large distances. Yet, there is a suitable solution: The distance between grasshoppers must be set or normalized to [1, 4].

The gravity force, GF_i, can be written as;

$$GF_i = -g * \widehat{e_g} \tag{17}$$

where $\widehat{e_g}$ represents the unit vector towards the earth center and g represents the constant of gravity. The wind advection, WA_i can be written as;

$$WA_i = u\widehat{e_\omega} \tag{18}$$

where $\widehat{e_\omega}$ represents a unity vector towards the direction of the wind and u represents the drift constant.

Equation (12) can be rewritten as:

$$Y_{i=} \sum_{\substack{j=1 \\ j \neq i}}^{N} f\left(\left|x_j - x_i\right|\right) \frac{x_j - x_i}{d_{ij}} - g\widehat{e_g} + u\widehat{e_\omega} \tag{19}$$

In order to adjust the accurate approximation of the global optimum, a stochastic algorithm must proceed with exploration and exploitation effectively to solve the optimization problems. The mathematical model described above must have special parameters to illustrate the exploration and exploitation at different stages of improvement. The suggested mathematical model is as follows:

$$X_i^d = c\left(\sum_{\substack{j=1 \\ j \neq i}}^{N} c\,\frac{u_{bd} - l_{bd}}{2}\, f\left(\left|x_j^d - x_i^d\right|\right) \frac{x_j - x_i}{dij}\right) + \widehat{T_d} \tag{20}$$

where l_{bd} and u_{bd} represent the lower and upper boundary in d^{th} dimension, $\widehat{T_d}$ represent the d^{th} dimension in the target, and c is a reduction factor in lessening the repulsion area, attraction area, and comfort area. The inner c takes part in the decreasing of repulsion/attraction forces among grasshoppers proportional to the iterations number. The following equation updates the parameter c to increase exploitation and reduce exploration proportionally to iteration number.

$$c = C_{max} - l\,\frac{C_{max} - C_{min}}{L} \tag{21}$$

where C_{min} is the minimum value of decreasing factor and C_{max} is the maximum value of the decreasing factor. L and l are the maximum and current iteration numbers, respectively. The values used in this work for C_{max} and C_{min} are 1 and 0.0004 respectively [37].

V. OPTIMAL SIZING OF DGS AND DSTATCOMS USING MOGOA ALGORITHM

To apply the MOGOA algorithm for optimal penetration of the DGs/DSTATCOMs, the system parameters, power losses, and bus voltage are firstly calculated. Then, the LSF is determined, and the DGs/DSTATCOMs are optimally located in the system. After that, the MOGOA is implemented to solve the sizing optimization issue of the DGs/DSTATCOMs.

Figure 1 illustrates a flowchart that explains the steps for optimally locating and sizing the DGs/DSTATCOMs in the RDS using the proposed algorithm. The following steps describe the proposed MOGOA procedures.

- ***First step**: Initialize the MOGOA parameters;* like other optimization methods, MOGOA place some random particles in the field of research that the user has specified its limits, refer to (20). These particles moved in the research field, thus improving the formulated OF. The parameters of the MOGOA, such as max_Iteration, dimensions, C_{min} and C_{max} are selected. Also, the lower and upper boundaries of the search agent are considered 0 and 100 respectively. The upper boundaries were selected to be lower than 100 of the rated generation and were selected based on the trial-and-error method in repeated performances of the program.
- ***Second Step**: evaluate the fitness function at each search individual,* the fitness function is evaluated by (6) and then the population is sorted according to the fitness value from best to worst. Few elite solutions are specified as the best search agent.
- ***Third step**: update the deceasing factor c;* c is updated using (21) to achieve a balance between exploration and exploitation. Also, it updates the position of a current agent (i.e., the sizes of DG and DSTATCOM) by (20),
- ***Fourth step**: calculate the best position for each grasshopper;* by checking the constraints and storing the solution according to the best fit. Then, update the best search agent and repeat steps 3 and 4 until reaching the maximum iterations.
- ***Fifth step,** print the optimal size of DGs and DSTATCOMs.*

VI. RESULTS AND DISCUSSIONS

To validate the proposed MOGOA, a modified IEEE 33-bus RDS is used to implement the proposed method for different scenarios. This test system consists of 32 branches and 33 buses. The lines, buses, and loads data are obtained from [26]. The total loads are 3.715 + j2.3 MVA. The one-line diagram of the modified IEEE 33-bus RDS is illustrated in Fig. 2.

In this system, bus-1 is supplied with the electrical power from the generation or transmission network. Three main scenarios are implemented to check the proposed method's accuracy and effectiveness. These scenarios are;

- ***Scenario # 1:*** *Install DGs only*
- ***Scenario # 2:*** *Install DSTATCOMs only*
- ***Scenario # 3:*** *Install DGs and DSTATCOMs*

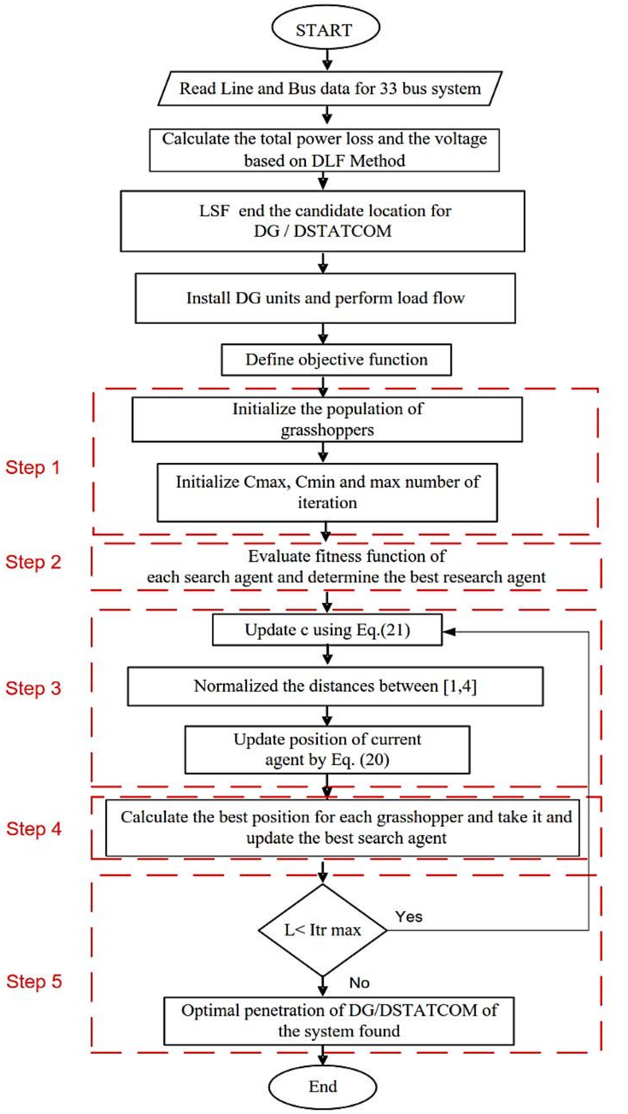

Fig. 1. Flowchart of the proposed MOGOA method

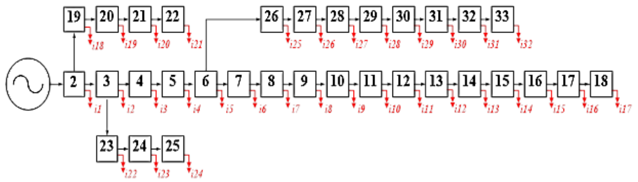

Fig. 2. The single-line diagram of the IEEE 33 bus DS

The proposed MOGOA method is implemented using MATLAB2016a. The parameters of the proposed MOGOA for the modified IEEE 33 bus RDS employed in the simulation are the maximum iterations number, $Iter_{max}$=100, search agents' numbers, N_{sa}=50, C_{min}=0.0004, and C_{max}=1.

The power flow method used in this paper is the Direct Load Flow (DLF) method [25]. The TPLs of the test system without connecting DG/DSTATCOM is 210.97 kW while the total reactive loss is 143.13 kVAR. The lowest value of the voltage magnitude is 0.9039 pu and also the lowest VSI value is 0.6611 pu on bus 18. This case can be considered as a base case for comparison with the other cases. Fig. 3 illustrates the voltage magnitudes at the 33 buses.

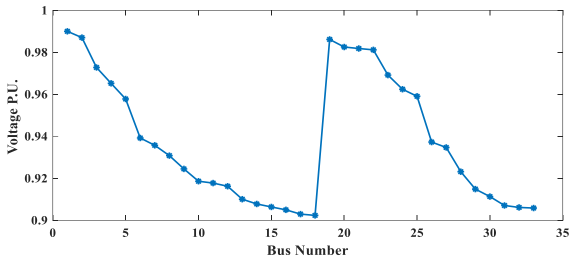

Fig. 3 Buses voltage without DG/DSTATCOM

A. Scenario # 1: Install DGs only

Scenario #1 contains two different cases of connecting the DGs which inject active power only to the test system. These cases are; connect one DG and connect three DGs. In each case study, the proposed method will be applied according to the flowchart in Fig. 1 to obtain the optimal locations and sizes of the DGs.

1) Case# 1 Integrating single DG

In this case, one DG is installed in the test system. The LSF is employed to specify the DGs' optimal locations. The bus which has the largest values of the LSF related to the active power is bus 6. The optimal size of the DG is determined by implementing the proposed MOGOA method and compared with the PSO [2] method to minimize the ΔTPL and the ΔVSI. By applying the MOGOA, the optimal active power generated from the DG is 2343.6 kW. The system TPL is reduced to 109.504 kW. Also, the VSI value is improved to 0.78125 pu as illustrated in Fig. 4. All points in the figure are considered as solutions that achieved the two objective functions (the horizontal axis expresses the power losses, and the vertical axis expresses the inverted VSI). So, the best solution is that achieve the minimum power loss and maximum 1/VSI. The proposed MOGOA method can reduce and improve the value of the ΔTPL and the ΔVSI by 48% and 18% than the PSO [2], respectively as illustrated in Table 1. The minimum value of voltage is 0.9441 pu at busbar 18 as illustrated in Fig. 5. All buses' voltages are between the limits of 0.944 and 0.99 p.u.

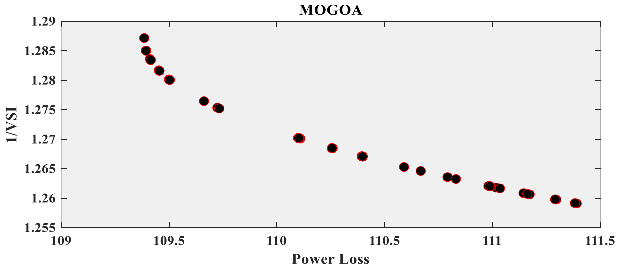

Fig. 4. The best Pareto optimal solution obtained by MOGOA for one DG

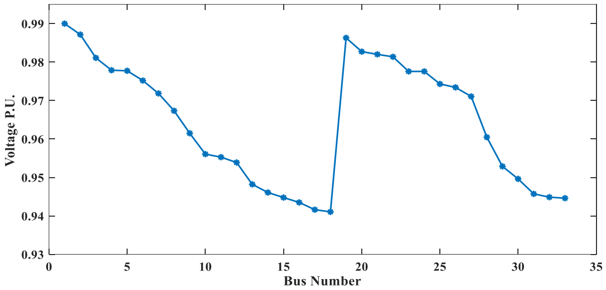

Fig. 5. The buses voltage for one DG

2)Case#2: Integrating three DG

Three DGs are optimally located at buses 12, 28, and 31 at unity pf in this case. The optimal active power generated from these DGs is 123.4 kW, 2396.2 kW, and 241.10 kW, respectively. The power loss is minimized to 84.85 kW compared with the base case (210.97 kW), and the value of the VSI is increased to 0.8465 pu as illustrated in Fig. 6. The minimum value of voltage is 0.9638 pu at bus 18, as illustrated in Fig. 7. The proposed MOGOA method can decrease and improve the amount of the ΔTPL and the ΔVSI by 59.78% and 28% compared with the Backtracking Search algorithm [15].

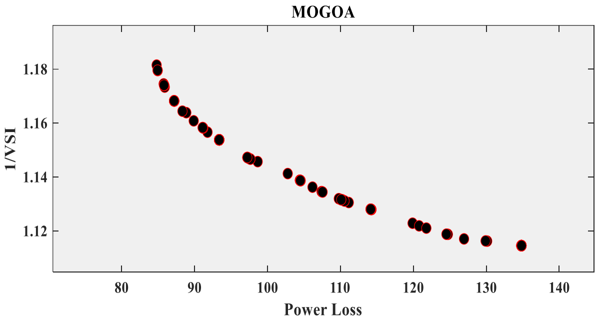

Fig. 6. The best Pareto optimal solution obtained by MOGOA for three DG

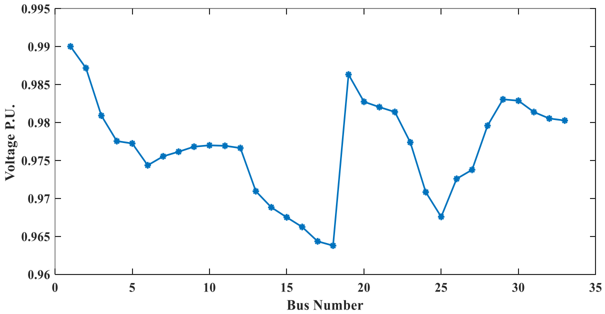

Fig 7. The bus voltage for three DG

A comparison between buses' voltage magnitudes for the case studies of scenario 1 is illustrated in Fig. 8. As observed from the figure, most of the bus voltages have been improved dramatically with increasing the DG numbers. The minimum bus voltage is improved from 0.9038 to 0.9638 p.u. through these cases.

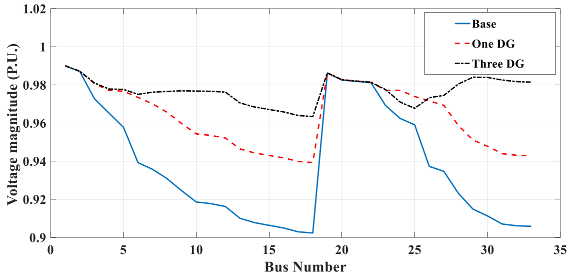

Fig. 8. Bus voltage of DN for DGs connections in scenario 1

B. Scenario 2: Install DSTATCOMs only

Scenario #2 contains two cases of connecting the DSTATCOMs to the test system. These cases are; connect one DSTATCOM and connect three DSTATCOMs. In each case study, the proposed method will be applied according to the flowchart illustrated in Fig. 1 to find the optimum size and location of the DSTATCOMs.

TABLE 1
RESULT ANALYSIS OF THE PROPOSED MOGOA METHOD IN CASE OF DG

Case	**Base Case**	**Single DG**		**Three DGs**	
Method	-	MOGOA	PSO [2]	MOGOA	Backtracking Search [15]
DG size	-	2343.6	2589.6	123.4 2369.2 241.1	632 487 550
DG Bus		6	6	12 28 31	12 28 31
P_{loss}*(kW)*	210.97	109.5041	110.99	84.85	89.05
ΔTPL %	-	48	47.30	59.78	57.79
V_{min}*(p.u.)*	0.9038	0.9441	0.9428	0.9638	0.949
VSI_{min} *(p.u.)*	0.661	0.78125	N/A	0.8465	0.8051
ΔVSI %	-	18	N/A	28	21.80

1) Case# 1: Integrating only one DSTATCOM

In this case, one DSTATCOM unit is installed at the test system. The LSF is employed to specify the optimal busbar to install the DSTATCOM. The bus, which has the largest values of the LSF according to the reactive power, is bus 30. Then the proposed MOGOA method is applied to find the optimal size and compare the values of ΔTPL and ΔVSI with the results of the Immune Algorithm [21]. By applying the MOGOA, the optimal reactive power generated from the DSTATCOM is 1147.87 kVAR (26.2% of total power). The system's TPLs are minimized to 155.6 kW. Also, the value of the VSI is increased to 0.6992 pu as illustrated in Fig. 9. Table 2 illustrates that the proposed MOGOA method can decrease and improve the amount of the ΔTPL and the ΔVSI by 26.2% and 0.5% than the Immune Algorithm [21], respectively. The minimum value of voltage is 0.9145 pu at bus 18 as illustrated in Fig. 10. All buses' voltage is between the limits of 0.9145 and 0.995 p.u.

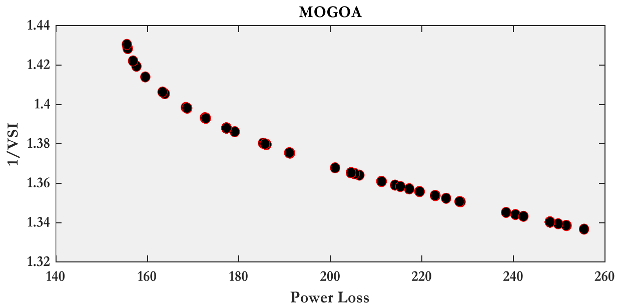

Fig. 9. The best Pareto optimal solution obtained by MOGOA for one DSTATCOM

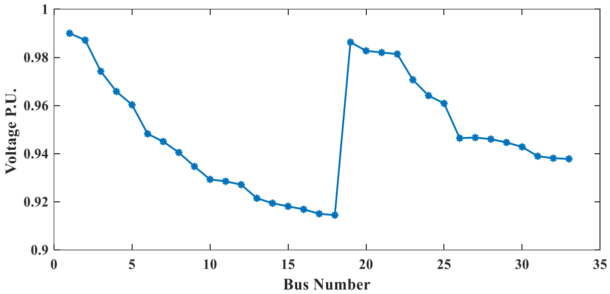

Fig. 10. The bus voltage for one DSTATCOM

2) Case#2: Integrating three DSTATCOMs

In this case, the DSTATCOMs of optimal rating 246.25, 606, and 711.19 kVAR are installed at the optimal places 11, 24, and 30, respectively. The TPLs are minimized to 130.37 kW, and the minimum VSI is 0.7714 pu as illustrated in Fig. 11. The minimum value of voltage is 0.9327 pu at bus 18, as illustrated in Fig. 12. The proposed MOGOA method can decrease and improve the amount of the ΔTPL and the ΔVSI by 38.2% and 16.7% than Sine Cosine Algorithm [38] as illustrated in Table 2.

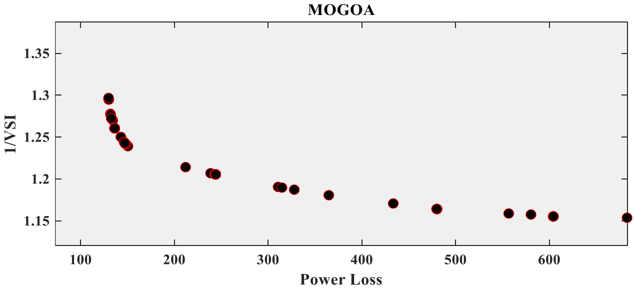

Fig. 11. The best Pareto optimal solution obtained by MOGOA for multiple DSTATCOM

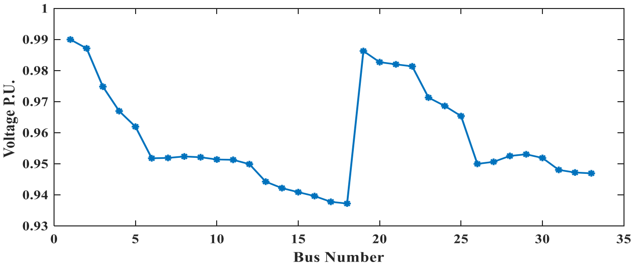

Fig. 12. The bus voltage for multiple DSTATCOM

A comparison between buses' voltage magnitudes for the case studies of scenario 2 is illustrated in Fig. 13. The voltage magnitude is improved to 0.9376 while increasing the number of DSTATCOM units from one to three units.

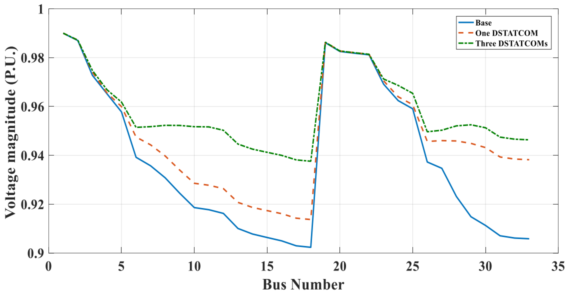

Fig.13. Bus voltage of the DN for DSTATCOMs connections in scenario 2

C. Scenario # 3: Install DGs and DSTATCOMs

Scenario #3 contains two cases of connecting a combination between DGs and DSTATCOMs to the test system. These cases are; connect single DG and DSTATCOM and connect three DGs and DSTATCOMs. In each case study, the proposed method will be implemented according to the flowchart in Fig. 1 to obtain the optimal sizes and locations of the DGs and DSTATCOMs.

TABLE 2
RESULT ANALYSIS OF THE PROPOSED MOGOA METHOD IN THE CASE OF DSTATCOMS.

Case	**Single DSTATCOM**		**Three DSTATCOM**	
Method	Proposed MOGOA	Immune Algorithm [21]	Proposed MOGOA	Sine Cosine Algorithm [38]
DSTATCOM size, (kVAR)	1147.87	962.49	246.25 606 711.19	771.3 993.3 425.1
DSTATCOM Bus	30	12	11 24 30	30 4 11
P_{loss} (kW)	155.6	171.81	130.37	135.2
ΔTPL %	26.24%	18.50%	38.20%	39.61%
V_{min} (p.u.)	0.9145	N/A	0.9327	0.9420
VSI_{min} (p.u.)	0.6992	N/A	0.7714	0.7874
ΔVSI %	0.50%	N/A	16.70%	17.04%

1) Case# 1: Integrating only one DG& DSTATCOM

In the first case study, the single device of DSTATCOM and DG are optimally located at bus 30 with a size of 2679.28 kW and 1057.38 kVAR, respectively. The TPLs are minimized to 64.320 kW from 210.97 kW (base case), the minimum VSI is improved to 0.8071 pu as illustrated in Fig. 14. The minimum value of voltage is 0.9478 pu at bus 18, as illustrated in Fig. 15. The proposed MOGOA method decreased and improved the amount of the ΔTPL and the ΔVSI by 69.5% and 22.1% as illustrated in table 3.

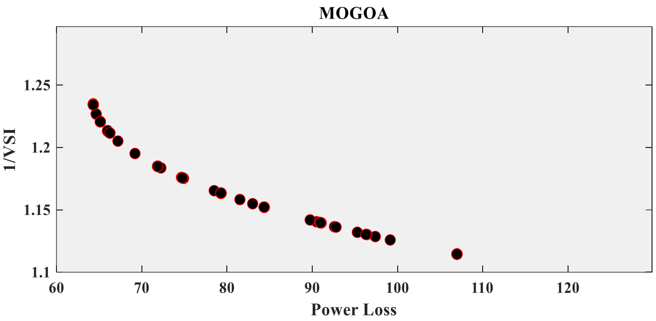

Fig. 14. The best Pareto optimal solution obtained by MOGOA for only one DG& DSTATCOM

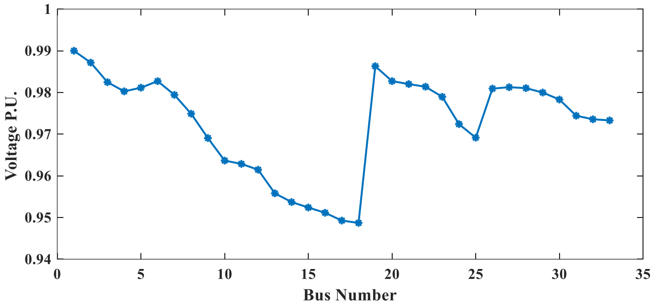

Fig. 15. The buses voltage for only one DG& DSTATCOM

2) Case#2: Integrating three DGs& DSTATCOMs

In the second case study, three DGs& DSTATCOMs are installed at the same time at different optimal places employing LSF. The sizing of the DGs & DSTATCOMs can be done by applying MOGOA. The TPLs are minimized to 38.9763 kW from 210.97 kW (base case) while the VSI is improved to 0.8645 pu as illustrated in Fig. 16. The minimum value of voltage is 0.9734 pu, as shown in Fig. 17.

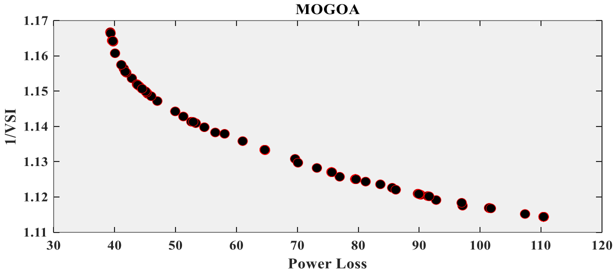

Fig. 16. The best Pareto optimal solution obtained by MOGOA for three DGs& DSTATCOMs

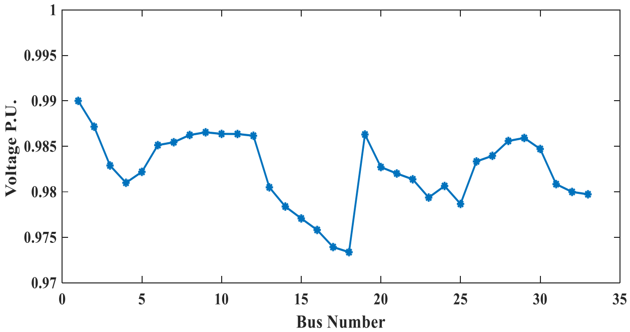

Fig. 17. The buses voltage of the DN for three DGs& DSTATCOMs

A comparison between buses' voltage magnitudes for the case studies of this scenario is illustrated in Fig. 18. There is a reasonable increase in bus voltages for all cases compared to the base case. For this scenario, the minimum bus voltage is improved from 0.9478 p.u. for a single DG/DSTATCOM to 0.9734 p.u. for three DGs/DSTATCOMs. Generally, increasing the number of DG/DSTATCOM decreases power loss, improves VSI, and the voltage becomes flatter.

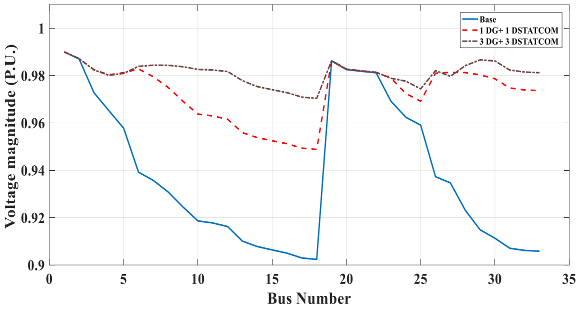

Fig. 18. Bus voltage for DG/DSTATCOM connections

MOGOA method decreased and improved the amount of the ΔTPL and the ΔVSI by 81.5% and 30.7% than Bacterial Foraging Optimization Algorithm (BFOA) [39] as illustrated in Table 3. Among the previously illustrated scenarios, scenario#3 provides better minimization of the TPLs and VSI, and improvement of voltage profile compared to the other studied scenarios.

TABLE 3
RESULT ANALYSIS OF THE PROPOSED MOGOA METHOD IN THE CASE OF DG & DSTATCOM

Case	**Single DG& DSTATCOM**	**Single DG& DSTATCOM**	**Three DGs& DSTATCOMs**	
Method	Proposed MOGOA	lightning search algorithm [22]	Proposed MOGOA	(BFOA) [39]
DG size, (kw)	2679.28	1000	166.5 410.5 2086.5	0.5424 0.1604 0.8955
DG Bus	30	30	12 25 30	17 18 33
DSTATCOM size, (kVAR)	1057.38	1500	257 454 766.5	0.1632 0.5410 0.3384
DSTATCOM Bus	30	30	12 25 30	18 30 33
P_{loss} *(kW)*	64.32	86.26	38.97	41.41
ΔTPL %	69.50%	59%	81.50%	80.37%
V_{min} *(p.u.)*	0.9478	0.9503	0.9734	0.9783
VSI_{min} *(p.u.)*	0.8071	N/A	0.8645	N/A
ΔVSI %	22.10%	N/A	30.70%	N/A

VII. CONCLUSION

A novel proposed algorithm was used for determining the optimal placement and penetration of DGs/DSTATCOMs in the DNs. The effectiveness of the proposed MOGOA was investigated for the optimization procedure to attain the optimal size and locations of the DGs and DSTATCOMs to reduce the

TPLs of the RDS, improve the value of VSI and enhance the voltage profile. In the proposed method, the LSF was used to investigate the DG&DSTATCOM pre-optimal placement. Then, the optimal DG/DSTATCOM penetration can be found by employing MOGOA in different scenarios. The results proved that the reduction in the TPLs and improvement in the VSI were 69.5% and 22.1%, respectively at case 1 scenario 3 which combined single DG and DSTATCOM. Also, the results achieved more improvement and became 81.5% and 30.7%, respectively at case 2 in scenario 3, which combined multi DGs and DSTATCOMs for the modified IEEE 33-bus test system.

The outcomes of MOGOA were compared with different available methods. The obtained results illustrated that the proposed MOGOA has a precise view of this very important effective problem and a balance between both exploration and exploitation. The algorithm can be used as a support tool to address the technical challenges of engineering problems.

AUTHORS CONTRIBUTION

M. Frahat performed writing – original draft, software and conceptualization.

A. Hatata performed Investigation, methodology, and project administration.

M. M. Saadawi and S. S. Kaddah, performed supervision, critical revision of the article, and approved the final version to be published

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DECLARATION OF CONFLICTING INTERESTS STATEMENT

The author declared that there are no potential conflicts of interest with respect to the research authorship or publication of this article

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Title Arabic:

الحجم الأمثل المعتمد على خوارزمية أسراب الجراد لمصادر الطاقة المتجددة وأجهزة التعويض الموزعة في شبكات التوزيع

ARABIC ABSTRACT:

تتبنى هذه الورقة البحثية تطبيق تقنية التحسين للوصول إلى الحجم الأمثل والموقع الأمثل لأجهزة التعويض الموزعة والمولدات الموزعة في شبكة التوزيع الكهربائية. وتستند هذه التقنية إلى محاكاة سلوك أسراب الجراد وتسمى خوارزمية الجراد المثالي. إن الهدف من الطريقة المقترحة التي استخدمت هو الحصول على أفضل حجم وأفضل موقع لأجهزة التعويض الموزعة والمولدات الموزعة والتى يتم دمجها من أجل الحد من مفاقيد القدرة الكهربية الفعالة وتحسين مؤشر استقرار الجهد الكهربى، الذي يقوم بدوره بإكتشاف الخطوط الضعيفة في شبكة التوزيع. حيث يتم أولاً التعرف على المواقع المثلى لأجهزة التعويض الموزعة باستخدام عامل حساسية الفقد، وبعد ذلك يتم تطبيق طريقة المحاكاة المتعددة الأهداف المقترحة للحصول على أفضل حجم لها فى شبكة التوزيع. وللتأكد من فعالية المنهجية المقترحة فقد تم اختبارها على نظام 33 قضيب توزيع من خلال تطبيق عدة سيناريوهات مختلفة. وأثبتت النتائج أن الانخفاض في إجمالي فقد الطاقة والتحسن في مؤشرات ثبات الجهد وصلت لنسب 81.5٪ و 30.7٪ على التوالي في حالة الجمع بين مصادر الطاقة المتجددة الموزعة وأجهزة التعويض الموزعة لنظام اختبار 33 قضيب توزيع. وتم مقارنة الطريقة المقترحة بعدة خوارزميات سبق نشرها وتشمل خوارزمية حركة اسراب الطيور، خوارزمية البحث التراجعية، خوارزمية المناعة، خوارزمية جيب التمام الجيبى، خوارزمية بحث البرق، خوارزمية تحسين البحث البكتيرى. وأكدت النتائج أن المنهجية المقترحة تعطى نتائج أفضل.