1. Souheyla BENAHCOUR[1], 2. Omar BENDJEGHABA[2]

M'hamed Bougara University, LREEI, Boumerdes, Algeria (1)(2)

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Optimal Sizing and Localization of Multiple Distributed Generations in Distribution Systems Using an Improved Grey Wolf Optimization Algorithm

***Abstract**. This study investigates the impact of the localization and sizing of distributed generations in distribution systems using a combined approach of improved grey wolf optimizer (IGWO) and Newton-Raphson load flow algorithms. The suggested method optimizes the size and position of distributed generation generating both real and reactive power while ensuring power system constraints are not violated. The suggested algorithm optimizes the location and sizing of dis-tributed generations. Nevertheless, investigations show that the proposed method outperforms the PSO optimizer and takes less calculation time. Moreover, in contrast with other meta-heuristic algorithms such as JAYA, PSO, SFO, BO, SMA, GA, and GJO, the proposed approach produces a better voltage profile of the distribution system with smaller distributed generator sizes. To demonstrate the advantages of the suggested approach, the IEEE-13, IEEE-37, and IEEE-123 bus distribution systems are used as test cases, and the outcomes are contrasted with those of other meta-heuristic methods. According to simulation data, IGWO outperforms other meta-heuristic algorithms when it comes to the quality of the solution while satisfying all system constraints.*

***Streszczenie.** W tym badaniu zbadano wpływ lokalizacji i rozmiaru generacji rozproszonych w systemach dystrybucyjnych przy użyciu połączonego podejścia ulepszonego optymalizatora szarego wilka (IGWO) i algorytmów przepływu obciążenia Newtona-Raphsona. Zaproponowana metoda optymalizuje wielkość i położenie generacji rozproszonej generującej zarówno moc czynną, jak i bierną, przy jednoczesnym zapewnieniu nienaruszania ograniczeń systemu elektroenergetycznego. Zaproponowany algorytm optymalizuje lokalizację i wielkość generacji rozproszonych. Niemniej jednak badania pokazują, że proponowana metoda przewyższa optymalizator PSO i zajmuje mniej czasu obliczeniowego. Co więcej, w przeciwieństwie do innych algorytmów metaheurystycznych, takich jak JAYA, PSO, SFO, BO, SMA, GA i GJO, proponowane podejście zapewnia lepszy profil napięcia systemu dystrybucyjnego przy mniejszych rozmiarach generatorów rozproszonych. Aby zademonstrować zalety sugerowanego podejścia, jako przypadki testowe wykorzystano systemy dystrybucji magistrali IEEE-13, IEEE-37 i IEEE-123, a wyniki porównano z wynikami innych metod metaheurystycznych. Jak wynika z danych symulacyjnych, IGWO przewyższa inne algorytmy metaheurystyczne pod względem jakości rozwiązania przy jednoczesnym spełnieniu wszystkich ograniczeń systemowych. (**Optymalny rozmiar i lokalizacja wielu rozproszonych generacji w systemach dystrybucyjnych przy użyciu ulepszonego algorytmu optymalizacji Szarego Wilka**)*

Keywords: distributed generator (DG); improved grey wolf algorithm; power losses; voltage improvement.
Słowa kluczowe: generator rozproszony (DG); ulepszony algorytm szarego wilka; straty mocy; poprawa napięcia.

Introduction

Integrating renewable energy sources into the electricity grid is a key research challenge for power system engineers. Solar photovoltaic systems are one of the main renewable energy systems for power generation in electrical infrastructures. Electrical energy plays an essential role in people's daily life and growth. It is transmitted from generation units to the distribution network via high-voltage transmission lines before being converted to a useful level. Since distribution systems transport electrical energy to clients, they are considered to be the most crucial of the generation, transmission, and distribution divisions. The dependability of electricity is mostly determined by the distribution system's efficiency. Distribution systems account for around 70% of electricity losses, whereas only 30% of losses occur in transmission and generation [1].

The problem of optimal generator location is A challenging issue with nonlinear objective functions and nonlinear constraints. The most suitable locations and capacities for DGs have been determined using a variety of methodologies [2]. Many methods have been proposed and discussed to enhance the use of dispersed generation in the distribution system. [3] provided an analytical method for determining the ideal location and capacity of distributed generators in a radial distribution. The GA method was utilized by [4] to reduce the voltage profile, MVA capacity, and both the reactive and active power loss index. [5] proposed a new approach combining GA and PSO to iden-tify the ideal placement and dimension of distributed generation in radial distribution networks. [6] The flow direction algorithm (FDA), which employed the PSOS-CGSA method for the optimal location and size of distributed generation by considering the power factor of distributed generation per unit, was proposed as a new optimization approach for tackling optimization problems. 8] investigated the optimal position and size of DG units when different types of DG were considered. GWO was previously used to identify and determine the capacity of distributed generation units. [10,11] shows the optimal capacity and position of distributed generation in a radial distribution system for loss minimization using cuckoo search. The better Grey Wolf Optimizer (IGWO) has been utilized to determine the best reactive power source sizing for better power system performance [12].

The grey wolf technique (GWO) is a traditional swarm intelligence technique in the optimization literature, although it has some drawbacks, including a sluggish convergence time and the inability to reach the local optimum for some situations. The experimental findings reveal that the enhanced Grey Wolf optimization technique im-proves accuracy and convergence speed, and the optimization effect is superior.

While reviewing the published material, it is clear that practically all analyses made use of a co-simulation platform. Two distinct software applications were interfaced in order to examine the situation. MATLAB was used to implement a set of metaheuristic algorithms. The open-source program OpenDSS from the Electric Power Research Institute (EPRI) was used to solve the imbalanced power load flow analysis. [13,14,15], is a simulator created mainly for simulating electrical power distribution systems. OpenDSS supports the majority of power distribution design analyses involved with the connecting of distributed generation (DG) to utility networks. It also supports a variety of other frequency domain circuit models. These are frequently carried out on utility power distribution networks. Compared to many other tools, including commercial solutions, it represents unbalance conditions, stochastic processes and other features of electrical distribution networks and equipment in much greater detail. Through COM and scripting interfaces, other programs can use OpenDSS to run highly customised simulations, Monte Carlo analyses, etc. through automatic procedures, scripts, or dynamic links [16]. Simulation of the DG allocation and optimization of the sizing This study is carried out in the OpenDSS software, driven by the MATLAB environment.

The paper has been organized into four parts. The first section presents an over-view of IGWO. The overall function formulation for the issue is presented in the second section. Minimizing active power and reactive power losses, optimizing voltage profile, and establishing system constraints are each aspect of this. This section also includes a detailed description of the operation of the suggested algorithm. The materials and procedures section covers all the necessary information related to the problem formulation and the algorithm. The third section of the paper presents the simulation results and discussions. Finally, the conclusion section summarizes the main findings of the study.

Brief overview of IGWO

1) GWO algorithm overview

The GWO algorithm was originally proposed in [17] and is on the basis of the grey wolf's hunting behavior. There are four groups in the grey wolf social hierarchy: Alpha, Beta, Delta, and Omega. an alpha group is a group of leaders who give the other groups hunting orders. The beta and delta groups assist the leaders. The omega group has the lowest ranking [18]. The mathematical modelling of the grey wolf hunt process consists of the following phases:

1.1) Social stratification

The best solution in the population is labelled "a" while the second and third best options are labelled "ß" and "d" respectively. The population's remaining solutions are classified as "o" The "a," "ß," and "d" wolves guide the optimization process (hunting), while the "o" wolves follow the "a," "ß," and "d" wolves' lead.

1.2) Encircling prey

Once the wolf pack has located its prey, they surround it. This encircling behavior can be described in mathematical terms as follows [17]:

(1) $$D = \left| C.X_p(t) - X(t) \right|$$

(2) $$X_{(t+1)} = X_p(t) - A.D$$

While: t: represent the current iteration, A and C are the vectors of coefficients,
Coefficient vectors "A" and "C" can be expressed as follow [17]:

(3) $$A = 2a.rand_1 - a$$

(4) $$C = 2.rand_2$$

While: $rand_1$ and $rand_2$ are arbitrary vectors that are random with values ranging from 0 to 1, and the vector's components are reduced linearly from 2 to 0 throughout the iterations course.

1.3) hunting process

In the mathematical model of the hunting process, it is assumed that the alpha, beta, and delta wolves have a superior grasp of the location of the prey. The remaining wolves then randomly change their positions surrounding the prey according to the positions of the alpha, beta, and delta wolves, as shown below [17]:

(5) $$D_\alpha = \left| C_\alpha . X_\alpha - X \right|, \quad D_\beta = \left| C_\beta . X_\beta - X \right|, \quad D_\delta = \left| C_\delta . X_\delta - X \right|$$

(6) $$X_1 = (X_\alpha - A_\alpha . D_\alpha, \quad X_2 = (X_\beta - A_\beta . D_\beta, \quad X_3 = X_\delta - A_\delta . D_\delta$$

(7) $$X_{(t+1)} = \frac{X_1 + X_2 + X_3}{3}$$

2) Improved GWO

During iterations of the basic GWO algorithm, vector elements are linearly reduced from 2 to 0. This approach encourages exploration. It may, however, have an effect on the algorithm's convergence rate. As a result, for the purpose of boosting up the GWO algorithm's exploration balance and rate of convergence, the modification provided in [17] is used in this study, as shown below:

(8) $$a = \xi \, exp(-\theta \times t)$$

In the proposed change, two control parameters, and, are used to control the behavior of the GWO algorithm's convergence characteristics across iterations k for each point. Furthermore, changing the vector "a" into a random nonlinear vector keeps the algorithm's exploratory nature while speeding up its convergence. The wolves in the traditional grey wolf optimization (GWO) algorithm adjust were placed as the mean of the three best grey wolves (alpha, beta, and delta). In convoluted and irregular optimization problems, this can lead to early convergence and poor-quality outcomes [18]. To address this, the weighted distance criterion described in [18] is used in this study to improve the performance of standard GWO, particularly in convoluted and irregular optimization situations. The equation (8) has weighting at each iteration for this reason and can be recast with the following syntax [18]:

(9) $$w_1 = A_\alpha * C_\alpha, \quad w_2 = A_\beta * C_\beta, \quad w_3 = A_\delta * C_\delta$$

(10) $$X_{(t+1)} = \frac{w_1 * X_1 + w_2 * X_2 + w_3 * X_3}{w_1 + w_2 + w_3}$$

Proposed algorithm for DG allocation and sizing

1) Problem description

The goal of the problem formulation is to use multi-objective functions to determine the optimal dimensions and position of the distributed generators (DGs) while ensuring that the provided operating constraints are respected.

1.1) Objective function

First and foremost, this involves identifying the optimal dimensions and position of distributed generator units (DG) that can be connected to the distribution system. Losses in the distribution system are a major component influencing distribution costs and network technical issues. System losses must be kept to a minimum, and voltage constraints must be followed by DG units linked to feeders. The problem can be expressed in the following way:

(11) $$F = min \, f\left(x,u\right)$$

relying on:

(12) $$g\left(x,u\right) = 0$$

(13) $$h\left(x,u\right) \le 0$$

The statement describes an optimization problem in which *F* is the target function that should be reduced. The candidate dependent variables are represented by *x* and comprise the voltage node and the bus load. The candidate detached variable *u* mainly represents the dimensions and position of the Distributed Generators. The equality constraints are represented by *g*, and they correspond to the load flow equations that ensure power flows in the network are balanced. The system operating constraints, such as the allowable sizes of DGs and voltage stability limits, are represented by *h*.

(14) $$x = [V_{1,.....,}V_n, P_L, Q_L]$$

(15) $$u = [P_{DG1},...., P_{DGn}, Q_{DG1},...., Q_{DGn}, DG_{loc_1},...., DG_{loc_n}]$$

This study aims at improving the stability of imbalanced multiphase distribution networks and reducing power loss through the identification of optimal sizing and location of Distributed Generators (DGs). To achieve this, our study employs three objective functions. The first two functions represent the total power losses, including both active and reactive losses. The presence of DGs can cause excessive active power injection, which can lead to a voltage rise above the allowable limits. For that reason, the third goal function is the Cumulative Voltage Deviation, which measures the deviation of the voltage from the allowable limits. The three objective functions used in this study are as follows:

(16) $$f_1 = \sum_{i=1}^{N} P_{L_i}$$

(17) $$f_2 = \sum_{i=1}^{N} Q_{L_i}$$

(18) $$f_3 = CVD = \sum_{i=1}^{N} \left| V_i - V_{rated} \right| / N$$

To make the method and algorithm less complex, a Quadratic Penalty Factor (*QPF*) is introduced directly into the equation as a constraining factor. This factor is represented by the equation (19), and its minimization serves as the fourth objective.

(19) $$f_4 = QPF = \sum_{i=1}^{N} \begin{cases} (V_i - V_{min})^2; V_i \le V_{min} \\ 0; V_{min} \prec V_i \prec V_{max} \\ (V_i - V_{min})^2; V_i \ge V_{min} \end{cases}$$

While: In the equation, the symbol P_{L_i} reveals the active power losses on the i^{th} line, while the symbol Q_{L_i} indicates the reactive power losses on an identical line. The variable the entire number of lines in the distribution network is represented by *N*. The symbol V_i represents the i^{th} node's voltage. Finally, V_{rated} it represents the set voltage of the distribution network, which is typically 1 per unit (pu) to maintain good power quality and improve the voltage profile, as suggested by previous research [19].

(20) $$f = min \sum_{i=1}^{N} (\omega_1 f_1 + \omega_2 f_2 + \omega_3 f_3 + \omega_4 f_4)$$

The factor *ω* in the equation represents a weight factor with different weights assigned to each objective. The sum of all weights is equal to 1. In this study, the weights assigned are as follows: 0.5 for the active power losses (*PL*), 0.1 for the reactive power losses (*QL*), 0.2 for the Cumulative Voltage Deviation factor (*CVD*), and 0.2 for the Quadratic Penalty Factor related to voltage constraints. By adjusting the weights in the fitness function, it is possible achieve enhanced results by changing the profile of voltage or prioritizing loss reduction.

1.2) System Constraints

It is important to ensure that all constraints used in the algorithm are within the allowable limits. The inequality constraints in this study include bus voltage and power output from the DGs. These constraints must be satisfied to ensure that the system operates within acceptable limits.

I. Voltage Rating limits

The allowed bus voltage range for each bus in a power system is typically set by the equation (21)

(21) $$V^{min} \le V_i \le V^{max}, i = 1,..... n$$

While: V^{min} , V^{max} : are the lowest and highest voltage ranges at each node of the system.

II. Power Rating Limits

Equations (22) and (23) define the constraints for the active power and reactive power results of the distributed generators units.

(22) $$P_{DG}^{min} \le P_{DG_i} \le P_{DG}^{max}, ... DG_{units}.$$

(23) $$Q_{DG}^{min} \le Q_{DG_i} \le Q_{DG}^{max}, ... DG_{units}.$$

In equations (22) and (23) P_{DG}^{min} and P_{DG}^{max} correspond to the minimum and maximum active power output of each DG unit. Similarly, Q_{DG}^{min} and Q_{DG}^{max} indicate the minimum and maximum limits for the reactive power output of each DG unit. These limits are particular to each DG unit and must be met to guarantee that the system operates within the permissible power limits.

Proposed Algorithm Procedure

The objective of the application of the improved grey wolf Optimization (IGWO) algorithm in this study is the identification of the optimal capacity and placement of distributed generator units in the distribution system. For this purpose, the IGWO algorithm has been integrated with the Newton-Raphson power flow approach.

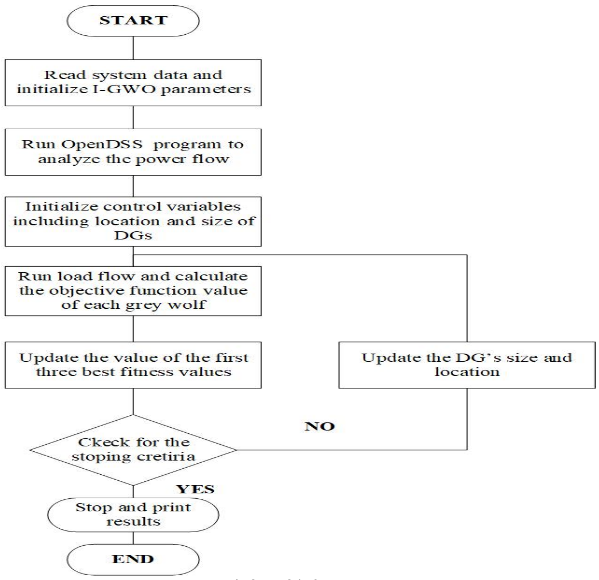

Fig.1. Proposed algorithm (IGWO) flowchart.

Figure 1, which outlines the procedures used to identify the optimal placement and capacity of distributed generator units in the radial distribution system illustrates the steps of the suggested algorithm.

Results and Analysis

The key objective of this study is to implement the IGWO method to estimate the appropriate distributed generator unit's allocation and size, taking into account the power factor. Testing of the proposed algorithm will be carried out on three different test systems, namely IEEE13-bus, IEEE37, and IEEE123, which have been selected due to their different levels of the complexity and the large number of calculations that are required for the allocation of multiple distributed generators units. The fitness function is designed to be a minimizer of active power and reactive power losses, and an enhancer of the voltage profile. The implementation of the IGWO algorithm is in MATLAB and the simulation of the test systems is in OpenDSS. The MATLAB script results are compared to the results from previous research projects and the IEEE-PES data, and the comparison is addressed in Sections 1, 2, and 3 of the paper.

MATLAB was used to implement the proposed technique. Bidirectional data communication is required between MATLAB, which implements the IGWO algorithm, and the OpenDSS simulation engine, which performs power flow analysis in the distribution system model. Figure 1 demonstrates the comprehensive process. To develop a co-simulation environment with OpenDSS, the recommended approach is implemented in MATLAB utilizing the COM interface. For the simulation testing, a deterministic curve for DG production and load demand was assumed. The assumption is that all distributed generation units have the same profile and that their load demand profile for all system loads is the same in all circumstances. Simulated on a PC with a 2.50GHz Intel(R) Core (TM) i5 7500U CPU and 4.00GB of RAM, the IGWO algorithm has been established with a population size of 30, maximum iteration sets to 200, and parameter settings of θ = 0.9 and ζ = 2.1.

IEEE-13 feeder distribution system

The analysis carried out in this study uses an IEEE13 bus system as shown in Figure 2. This test feeder is small, but highly loaded. Voltage regulators, shunt capacitor banks, aerial and underground electrical lines, and imbalanced loads are among the most typical features seen in real systems. The test supply includes 3-phase overhead and underground lines, 1-phase, 2-phase, and 3-phase branches, two 3-phase distribution transformers, local loads and a distributed load, two shunt capacitor banks, and a regulator connected in a star configuration. This feeder was chosen as a starting point for investigating power flow convergence concerns in an unbalanced system. [20] contains a thorough description of the feeder.

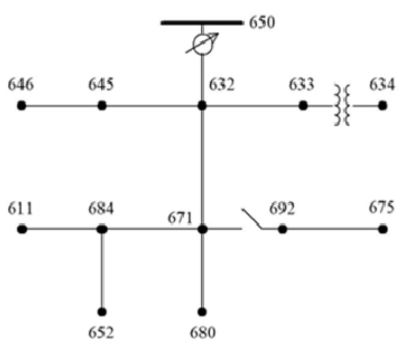

Fig .2. Diagram of the IEEE-13 bus system.

For validation of the suggested algorithm, the IEEE 13 bus test system will be used, and a comparative study will be carried out. Three cases are considered for the system. The first is the base case, which does not involve integrating any DG units. Second case involves feeding in two distributed generator (DG) units with unity reactive power. The third case is the insertion of 2 distributed generation units with the use of the IGWO algorithm for the determination of the optimal size and placement of the distributed generation (DG) units. For each case, the active power and reactive power losses and the minimum system voltage, are shown in Table 2.

Table.2 Optimal size, location, power loss and minimum voltage for the IEEE13-bus system.

METHOD	BUS NUMBER	DG SIZE (MW)	ACTIVE POWER LOSSES (kW)	REACTIVE POWER LOSSES (Kvar)	LOSS REDUCTION (%)	Min voltage (pu)
Base case [20]	-	-	117.05	339.08	-	0.9649
Case 1	680,671	1.50 , 1.50	70.74	187.73	39.56	0.9729
Case 2	675,671	0.99 , 0.96	66.85	179.67	42.89	0.9729

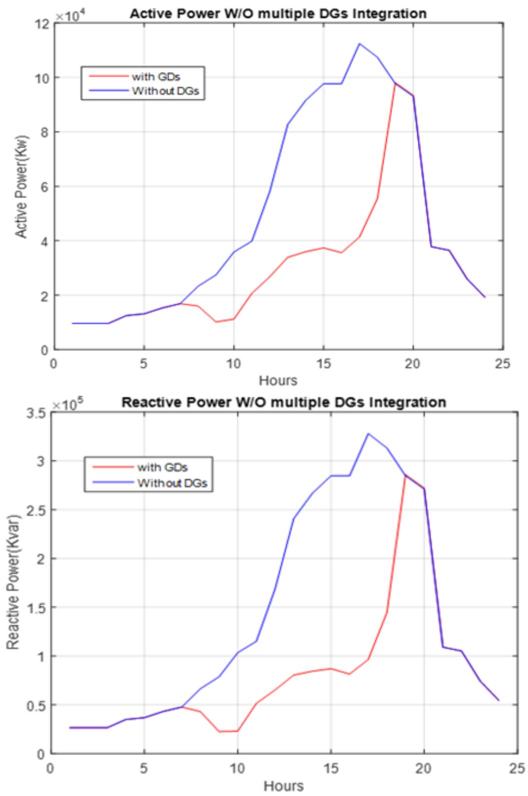

Fig.3. Active power and reactive power of the IEEE-13 bus test system.

In the distribution feeder of IEEE 13 bus, the DG units have been installed on the 675 and 671 buses. It is established total active power losses are decreased to 66.85 kW and total reactive power losses are reduced to 179.67 Kvar.

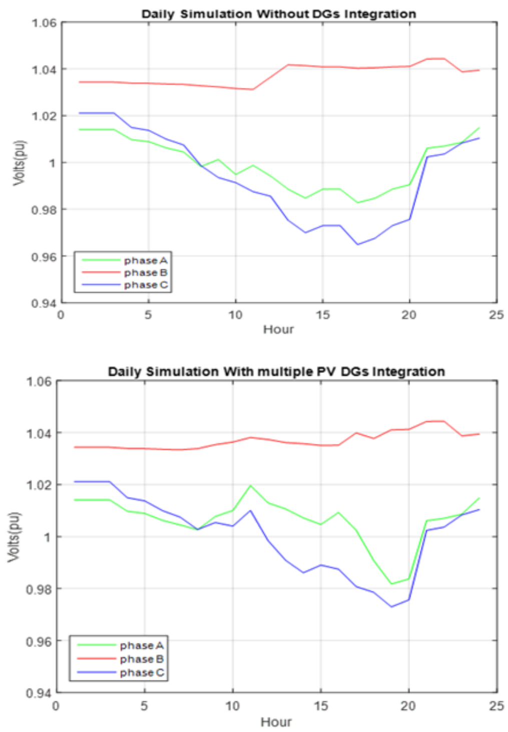

Fig.4. Voltage magnitude profile of the IEEE-13 bus system.

2) IEEE-37 Bus system

Figure 5 depicts the IEEE 37 bus system, which was used as the second test system in this study. the suggested approach was tested using an unbalanced 37-node IEEE distribution test feeder. A more detailed description of the distribution test feeder can be found in [20]. For each OpenDSS-derived power flow solution, the fitness function used for minimization with the GWO and IGWO algorithms is calculated. The suggested algorithm is tested on this system to minimize active power losses and enhance the voltage profile in the system by determining the optimal allocation and size of DG units.

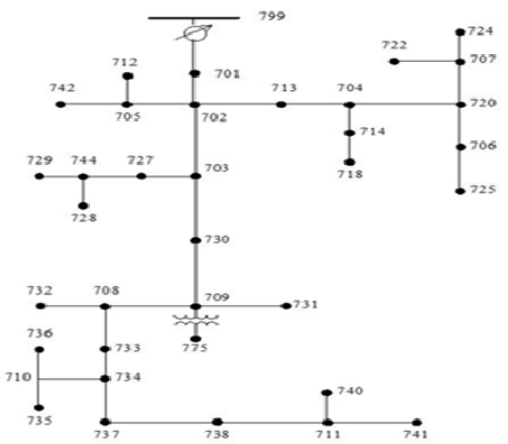

Fig.5. Diagram of the IEEE-37 bus system.

The desired quantity power to be supplied by the distributed generation units and the optimal buses for injection are calculated in this study by computing the objective value function (20) for a specific period, according to the related constraints (21) to (23). The simulation run, which is based on the IGWO algorithm, finds the ideal location and size of the distributed generation units. Table 2 displays the results received from the proposed approach. They are compared to GWO algorithm findings and previously published research. The results show that the proposed algorithm is effective in determining the appropriate position and size of DG units, resulting in considerable reductions in power losses and improvements in distribution system voltage profiles.

Table 3: Optimal placement and size for IEEE-37 bus system.

METHOD	BUS NUMBER	DG SIZE (MW)	ACTIVE POWER LOSSES (kW)	LOSS REDUCTION (%)
Base case [20]	-	-	60.56	–
GA [21]	703, 734, 711, 714	0.35, 0.99, 0.43,0.59	12.48	79.39
PSO [25]	707, 701, 737, 728	0.25, 1.63, 0.59, 0.11	14.87	75.44
GWO	703.711,704, 705	1.10, 0.44, 0.73, 0.10	11.96	80.25
IGWO	702,720, 722, 711	1.29, 0.50, 0. 07, 0.82	11.71	80.66

The comparative study carried out in this research aims to evaluate the performance of the suggested algorithm applied to the IEEE37 system, as well as to compare it with other algorithms, the GWO algorithm, and others found in the literature. The suggested algorithm is applied with the integration of four DG units. Results show that the suggested algorithm performs way better than the other algorithms in terms of a number of key performance metrics. Compared to other reviewed literature, the proposed algorithm (IGWO) leads to high efficiency in terms of active power losses.

Specifically, the results achieved by the suggested algorithm for the IEEE-37 system are as follows: The total reactive losses are significantly diminished compared to the base system, and the system's total active losses have been decreased from 60.56 kW to 11.71 kW, which is equivalent to an 80.66% loss decrease after the installation of appropriate DG units. The loss reduction achieved by the IGWO algorithm is the smallest compared to other methods. Furthermore, total reactive losses decreased from 46.45 Kvar in the base case to 7.06 Kvar. These results indicate that the suggested algorithm is effective in the identification of the optimal allocation and size of distributed generation units, this has an important effect on power loss minimization and voltage profile enhancement in the distribution system.

Fig.6. Comparison of system losses in different cases for IEEE-37 bus system.

3) IEEE-123 test system

In this study, the OpenDSS power flow solver, which takes into consideration the whole distribution network configuration, was utilized to compute the objective function. The execution of the power flow considers variations in time and increases in load into consideration. The global outcome provides the best bus places, distributed generator size and power factor for each of the four distributed generation (DGs) units once the termination criteria for the IGWO algorithm are satisfied. Figure 1 illustrates the algorithm developed to test the proposed algorithm. The algorithm involves a bidirectional data exchange between MATLAB and OpenDSS to identify the optimal size and allocation of distributed generation units (DGs) in the distribution system. The reduction of power losses and the improvement of the voltage profile in the distribution network are achieved by the suggested algorithm.

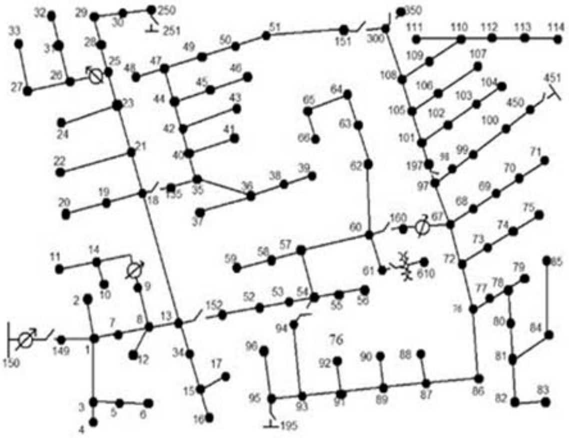

Fig.7. IEEE-123 bus system single line diagram.

Power loss is a major factor that has a profound impact on the evaluation of the quality of the system and the economic advantages. Therefore, the reduction of trans-mission line losses is a necessary issue. It should be carefully studied. Taking into con-sideration the load voltage and branch current constraints, this study considers and minimizes total power losses. The goal is to minimize power losses as considerably as possible.

Tables 3 and 4 demonstrate the results to ensure the objectivity of the proposed approach and the comparison approaches. In these tables, the performance of the sug-gested algorithm is compared to that of other algorithms examined in the literature. The findings show that the suggested algorithm is effective in terms of decreasing power losses and enhancing the voltage profile in the power distribution network. These results are an indication that the proposed method could be implemented in real-world sce-narios for the improvement of power distribution system performance.

Table 3 provides a summary of the simulation results at the unity power factor, incorporating four DG units. In this scenario, the IGWO algorithm's ideal locations and sizes reduced active power losses from 95.61 kW to 18.53 kW and reactive power losses to 27.71 Kvar, the active power loss and reactive power loss in the system have dropped significantly to 18.53kW, and 27.71Kvar corresponding to 80.62%, for IGWO, while these values are 18.60kW (corresponding to 80.54%) and 32.15Kvar for GWO, respectively. Thereby, the improvement in IGWO is more efficient than the original GWO. The pro-posed method is also better than other implemented methods such as PSO, GWO, and GJO. Like the obtained results, the solution of IGWO is better than others from 61.96% to 80.54% in the power loss. In short, IGWO is effective in maximizing economic and technical welfare.

Table 4 shows a summarized view of the simulation results at a unity power factor, with the insertion of 4 DG units. A significant reduction in active power losses, down to 18.15 kW, resulted from the optimal bus locations and sizes obtained by the IGWO algorithm. This indicates that the suggested algorithm is highly effective in determining the most suitable location and capacity for distributed generator (DG) units, as a result, power losses are significantly reduced, and the voltage profile in the distribution system is improved.

Table .4 Optimal sizing and allocation of 4 DGs for the IEEE-123 system.

METHOD	BUS NUMBER	DG SIZE (MW)	ACTIVE POWER LOSSES (kW)	REACTIVE POWER LOSSES (Kvar)	LOSS REDUCTION (%)
Base case	-	-	95.61	193.72	-
PSO [22]	67, 72, 47, 114	0.25, 1.63, 0.59, 0.11	19.6	-	79.50
GJO	72, 90,74, 83	2.04, 0.53, 0. 01, 1.82	36.37	69.08	61.96
GWO	40, 85, 72, 106	1.73, 1.83, 1.76, 0.13	18.60	32.15	80.54
IGWO	68,72, 75, 100	1.29, 0.50, 0. 07, 0.82	18.53	27.71	80.62

Table .4 Optimal allocation and size of 3 DGs for the IEEE123-bus system.

METHOD	BUS NUMBER	DG SIZE (MW)	Total capacity (kW)	ACTIVE POWER LOSSES (kW)	LOSS REDUCTION (%)
JAYA [23]	44,64,86	1.31, 0.58,1.11	3000.0	22.47	76.50
Based LII [24]	28,47,67	0.20, 0.88, 2.38	2460.0	22.06	76.93
PSO [25]	47,67,72	0.54,1.08, 1.32	2940.0	29.59	69.05
SFO [26]	47,60,76	0.77, 0.66, 1.19	2620.0	21.72	77.28
BO [26]	47,65,76	0.93, 0.37,1.50	2800.0	20.24	78.83
SMA [26]	47,65,72	0.90, 0.32, 1.59	2810.0	20.24	78.83
ISMA [26]	47,65,72	0.91, 0.34, 1.56	2810.0	20.22	78.25
GWO	86,42,76	0.29, 1.22, 1.55	3060.0	18.19	80.97
IGWO	76,46,28	2.07, 0.71, 0.05	2830.0	18.15	81.02

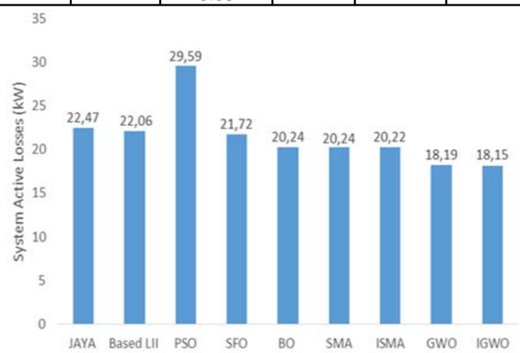

Fig .9. Comparison of system losses in different cases for IEEE-123 system.

Based on the results, it can be concluded that the suggested algorithm is highly significant in reducing both active and reactive power losses when compared to the

GWO method and other algorithms discovered in the literature for various instances. This suggests that the proposed algorithm could be a feasible option for optimizing the allocation and size of DG units in power distribution systems. As shown previously, the study has significant contributions to unbalanced distribution systems for loss reduction, voltage improvement; however, there are still serious problems existing in the unbalanced distribution systems such as surplus power of DGs based on renewable energies for the cases of low load demand and a high deviation between real and estimated wind speed and solar radiation. So, the placement of the battery energy store system (BESS), smart inverters and FACTS devices in the system can be the upcoming directions of the study. the electric components can be located at the most suitable nodes by using the proposed IGWO or a newly developed algorithm with higher performance.

Conclusion

This study introduces a new concept called improved grey wolf optimizer (IGWO); The objective of this concept is to address the issue of the most effective dispersed generation capacity and allocation of improving power system operation installation of DG appropriately aims to improve system conditions by minimizing power losses and improving the bus voltage profile. Two modifications have been made to address the drawbacks of the original GWO. Firstly, the interaction within both exploration and extraction has been adjusted with the aim to increase the velocity of convergence, and secondly, the weighted distance strategy has been implemented. The suggested method's efficacy has been assessed using three test systems and compared with other previously indicated algorithms. Simulation results have shown that the suggested algorithm outperforms all other approaches for all tested cases, indicating its ability to locate the optimally distributed generators' sizing and placement problems, IGWO algorithm has been able to reduce power losses and bus voltage deviation compared to the system without DG. Compared to other indicated algorithms, The effectiveness of the algorithm is shown by its ability to converge faster and more optimal results with the combined fitness value of power loss and minimum voltage deviation. Future work will focus on the optimal placement of FACTS devices using the suggested IGWO method to improve power system operation. In addition, the problem of optimal FACTS device allocation with renewable energy sources will also be addressed.

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