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Application of Gravitational Search Algorithm for Planning Distribution Networks with Multiple Dg Units Based On Their Real and Reactive Power Delivering Capability

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Abstract*— One of the major developments in the Current Distribution Network is the integration of Distributed Generation (DG). Planning the distribution systems without considering the site and size of multiple DG units could result in constraining the network, unpredictable network flows and greater variations in voltage. This paper focuses on planning the distribution network by determining the optimal placements and estimation of multiple DG capacities based on their real and reactive power delivering capability for grid support. For this study, Gravitational Search (GSA) algorithm is applied for optimization. To validate the proposed approach, simulations are performed on IEEE 34 bus radial distribution system. Comparisons are made in terms of Active Power loss deviations, Reactive Power loss deviations and the voltage deviations for all considered four types of DGs. The simulation result obtained indicates that by optimal location and size of Type C DG (delivering both real and reactive power) using GSA minimizes the network losses and voltage deviations than the other three types of DG. To conclude, for enhancing the grid support for the given radial distribution network, Optimal placement of DG with the capability of delivering real and reactive power by using GSA will be more effective.
Keywords*— Distributed Generation (DG), Gravitational Search Algorithm (GSA)

I. INTRODUCTION

In the last decade, the penetration of DG resources has increased worldwide in order to reduce greenhouse gas emissions and alleviate global warming. DGs are implemented in power systems mainly for grid strengthening, reducing network power losses (active and reactive), peak load shaving, improving voltage profiles and load factors, reducing for system upgrade investments, improving system security, dependability and efficacy [1]. Though DGs has the potential to solve the above network problems, in most cases, the Distribution System Operators has no control over the location and size of DG below a certain limit. When DG is not properly planned and operated, it can have a negative impact in distribution networks such as increase system losses and network capital and operating costs. On the contrary, Optimal DG placement can improve network performance in terms of voltage profile, reduce flows and system losses, and improve power quality and reliability of supply [2]. Hence, several researchers have the interest in determining the optimal DG location and sizing for various cases and with multiple DG units considering the different configurations which are listed in the literature below. Researchers have developed many interesting algorithms and solutions. The solution algorithms for optimal sizing and sitting of DG can be broadly classified in three categories: (i) Analytical methods, (ii) Numerical methods (iii) Intelligent search based methods (Genetic Algorithm (GA), Particle Swarm Optimization (PSO), etc.) [3]. In [4], analysis of optimal size and bus location for placing DG using power loss and energy loss minimization in a networked system based on bus admittance, generation information and load distribution of the system was performed using GA. In [5], optimal DG location and size are determined through Maximum Power Stability Index (MPSI) with PSO to improve power system stability and reduce active power losses. Optimal locations and sizes are obtained by integrating Sequential Quadratic Programming (SQP) and Branch and Bound (BAB) algorithm for MINLP formulation for loss minimization [6]. Artificial Neural Networks (ANN) based optimal DG placement and size approach was used to minimize total power losses including uncertainties of the load [7]. In [8], GA was used to determine the optimal size and location of multiple DG units to minimize the system losses and power supply by the main grid, considering the voltage limits at each bus of the system. In [9], a method is presented to locate DGs by maximizing Voltage Stability Margin (VSM), Network losses and generator reactive limits are involved in the optimization procedure. Based on energy resources, DGs are classified as two types, namely conventional and non-conventional energy resources. Integration of renewable energy based distributed generation units provide potential benefits when compared to conventional sources. Among many renewable energy resources such as biomass, wind, solar, hydropower and geothermal, Wind is mostly preferred for power generation as it is a relatively cheap form of

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energy resource and readily available with low environmental impact. In this paper, three Wind turbines are considered which is characterized by its active and reactive power. Reviewing the previous references, optimal location and sizing of DG using various methods, studies have done in minimizing the network losses, maximizing the profit, and minimizing the cost. But there are fewer studies regarding the Voltage improvement and minimizing the voltage deviations in the networks. In addition, there were a few works considering the multiple DG units and categories of DG units based on their real and reactive power delivering capability for the distribution planning. Hence, a method which provides the quality solutions for distribution planning with the consideration of various categories of multiple DG units is required. In this study, Optimal location and sizing of multiple DG units is determined by using Gravitational Search Algorithm (GSA) with the objective of minimizing the Network losses (Active and Reactive) and the Voltage deviations, improving the voltage profile of the radial distribution network. The four categories of the DG units are also modelled and the results are compared in terms of Active Power loss deviations, Reactive Power loss deviations and the voltage deviations for all four types of DGs. The effectiveness of the proposed methodology is tested on Standard IEEE 34 bus radial distribution system.

II. PROBLEM FORMULATION

A. Objective Function

In this paper, location and size of three DG units are determined in such way to minimize the Network losses and Voltage deviations in the given radial distribution network. Thus the objective function consists of two terms namely, Network loss deviations and Voltage deviations. The objective function can be formulated as follows:

$$Obj = \sum_{k} L_k (P_{loss} + Q_{loss}) + \sum_{i} D_i (V_i - V_{ref}) \quad (1)$$

Where,

L_k	-	Weighting Factor for the Network losses in branch k
P_{loss}	-	Active Power losses in the network
Q_{loss}	-	Reactive Power losses in the network
D_i	-	Weighting Factor for the Voltage deviations in the bus i
V_i	-	Voltage magnitude at the bus i
V_{ref}	-	Voltage reference
i	-	Index for bus
k	-	Index for the branch

The values of the weighting factors for the Network losses and Voltage deviations are 0.5 each, so as to provide equal importance for the both the network losses and voltage deviations in the objective function.

B. Constraints

The constraints in the optimization process in the proposed work are:
Active power losses constraints
Reactive power losses constraints
Voltage Constraints

1) *Active Power Losses Constraint:* The active power losses after installing DG in power grid should be less than or equal to the losses before installing DGs.

$$P_{\text{loss with DG}} \leq P_{\text{loss without DG}} \quad (2)$$

2) *Reactive Power Losses Constraint:* The Reactive Power losses after installing DG in power grid should be less than or equal to the losses before installing DGs.

$$Q_{\text{loss with DG}} \leq Q_{\text{loss without DG}} \quad (3)$$

3) *Voltage Constraint:* To ensure the voltage at any bus should be within predefined limits the following constraint is considered:

$$V_i^{\min} \leq V_i \leq V_i^{\max} \quad (4)$$

Where,

V_i	-	bus voltage magnitude
$V_i^{\max}$	-	maximum bus voltage magnitude
$V_i^{\min}$	-	minimum bus voltage magnitude

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DGs can be categorized into four types based on their terminal characteristics in terms of real and reactive power delivering capability as follows [10]:

Type A: DG capable of injecting *P* only.

Type B: DG capable of injecting *Q* only.

Type C: DG capable of injecting both *P* and *Q*.

Type D: DG capable of injecting *P* but consuming *Q*.

Photovoltaic, micro turbines, fuel cells, which are integrated to the main grid with the help of converters/ inverters, are good examples of Type A. Type B could be synchronous compensators such as gas turbines. DG units that are based on synchronous machine (cogeneration, gas turbine, etc.) fall in Type C. Type D is mainly induction generators that are used in wind farms [10].

III. GRAVITATIONAL SEARCH ALGORITHM

Gravitational search algorithm is based on Newton's law of gravity. In this algorithm, possible solutions of the problem in hand are considered as objects whose performance (quality) is determined by their masses. All these objects attract each other by the gravity force that causes a global movement of the objects towards the objects with heavier masses representing possible solutions to a problem. The heavy masses, which represent best solutions, move more slowly than lighter ones and this represents the exploitation of the algorithm. The problem iterates by changing the positions based on its velocity and acceleration that gets updated in every iteration which depends on fitness function [12]. The flowchart of Gravitational search algorithm is given Fig. 1.

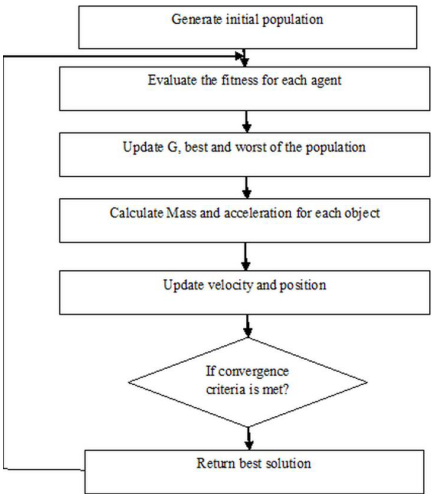


Fig. 1 Flowchart of GSA [11]

IV. CASE STUDY

A. *Test System*

The proposed work is tested on IEEE 34 bus radial distribution system as shown in the Fig. 2. The data for the system are on 100 MVA base. The network has the system voltage of 11 kV and the total real and reactive power demand of 4.636 MW and 2.873 MVAr respectively. Initially, base case load flow (without DG) analysis is done to calculate the bus voltage magnitudes and total network real power loss, reactive power loss. The bus voltage magnitude is shown in the Fig. 3 and the real power loss and reactive power loss are 223.77 kW, 170.6989 kVAr respectively.

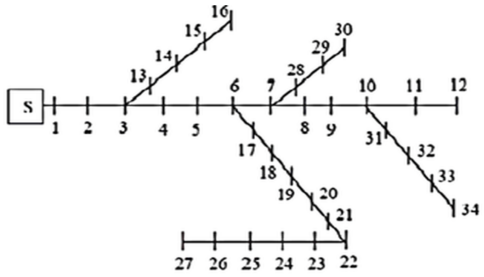


Fig. 2 IEEE 34 bus Radial Distribution System

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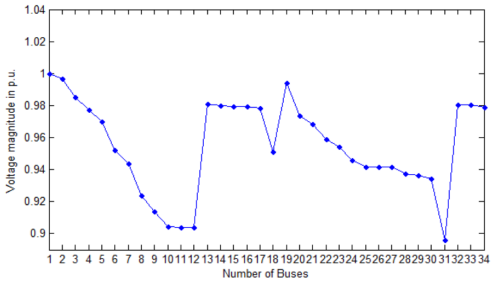


Fig. 3 Voltage Magnitude in all buses of IEEE 34 bus Radial Distribution System

The minimum and maximum limits of voltage magnitude at all buses are 1.1 p.u. and 0.9 p.u. respectively. The values of the Scaling Factor (F), Crossover Ratio (CR) for the optimization process are in the range 0.5 to 2 and 0.8 to 0.9 respectively.

B. Test Cases

In this work, to emphasis the importance of types of DG units in planning the distribution network, four cases representing the four types of DG are considered and are listed below.

Case I: With Type A DG
Case II: With Type B DG
Case III: With Type C DG
Case IV: With Type D DG

V. RESULTS AND DISCUSSION

The results of each type of DG are simulated individually and compared in terms of Active Power loss, Reactive Power loss, Voltage Deviations and the Value of Objective function. The location and size of three DG units of each type are also determined.

A. Case I: With Type A DG

TABLE I shows the optimization result for the IEEE 34 bus radial distribution system with the integration of Type A DG alone. The optimal location and sizing of three DGs attained are at buses 26, 8, 29 and 155.18 kW, 50 kW, 250 kW respectively. In this case, the Active Power loss is about 83.0856 kW and the reactive power loss is about 71.3678 kVAr. The voltage deviation in all the buses of the test system is confined to 0.00105 p.u. The fitness function value which includes the Network losses, Voltage Deviations and the Voltage constraints with corresponding weighting factors is 74.3696.

TABLE I. SIMULATION RESULT FOR CASE I

DG Parameters		Ploss (kW)	Qloss (kVAr)	Voltage Deviation (p.u.)	Value of Objective Function
Location	Size (kW)				
26	155.18	83.0856	71.3678	0.00105	74.3696
8	50				
29	250				

Fig. 4. shows the convergence characteristics of implementing DE under Case I. The result converges at 58th Generation. There is no further improvement in the value of the objective function.

Fig. 5 gives the voltage magnitude in all the buses of the networks. The value of Active Power losses and Reactive Power losses in all the 33 branches of IEEE 34 Radial Distribution System for this Case I is shown in Fig. 6-7.

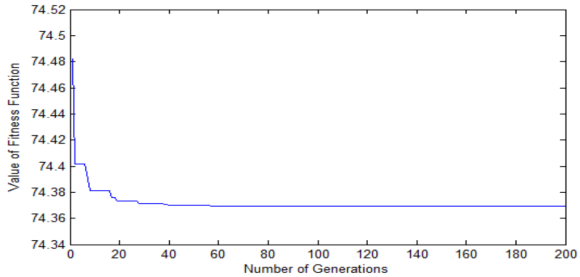


Fig. 4 Convergence Graph for the Case I

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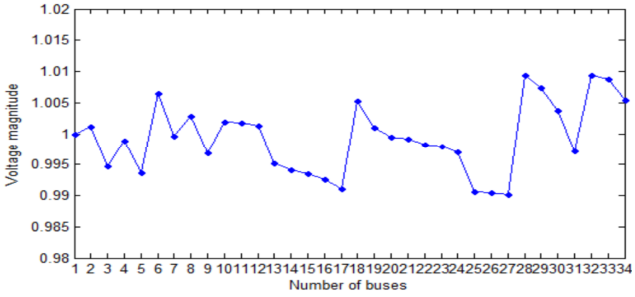


Fig. 5 Voltage Magnitude in all buses for Case I with Type A DG

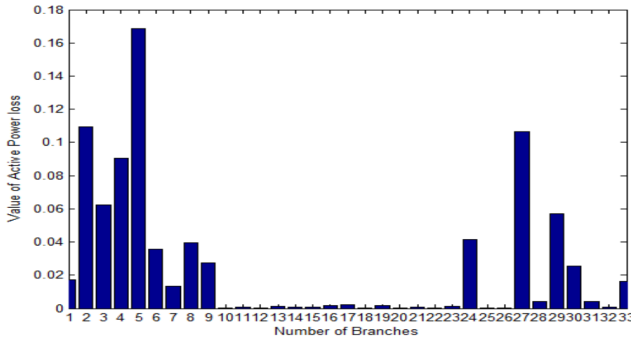


Fig. 6 Active Power losses in all branches for Case I with Type A DG

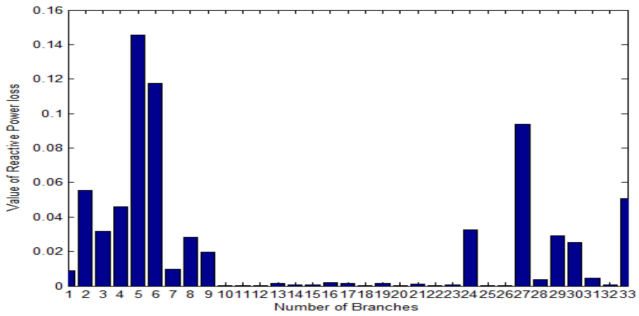


Fig. 7 Reactive Power losses in all branches for Case I with Type A DG

B. Case II: With Type B DG

In this case, Type B DG alone is considered and the results are tabulated in TABLE II. The candidate locations of three DG units are 14, 32 and 29 respectively. Their optimal sizing is 237.14 kW, 50 kW and 250 kW respectively. The Active Power loss and the Reactive Power loss for this case are 83.0412 kW and 72.1268 kVAr. The value of voltage deviations in all the buses when integrating this Type B DG is about 0.001224 p.u. The fitness function calculated by considering the network losses and the voltage deviations is 75.3846.

TABLE II. SIMULATION RESULT FOR CASE II

DG Parameters		Ploss (kW)	Qloss (kVAr)	Voltage Deviation (p.u.)	Value of Objective Function
Location	Size (kW)				
14	237.14	83.0412	72.1268	0.001224	75.3846
32	50				
29	250				

Fig. 8 shows the convergence characteristics of implementing DE in the Case II with the Type B DG. Here, after 30th Generations, the fitness function i.e., minimizing the Active and Reactive Power loss and voltage deviations is reached its maximum value 75.3846. Fig. 9 gives the voltage magnitude in all the buses of the networks. The value of Active Power losses and Reactive Power losses in all the 33 branches of IEEE 34 Radial Distribution System for this Case II are given in Fig. 10-11.

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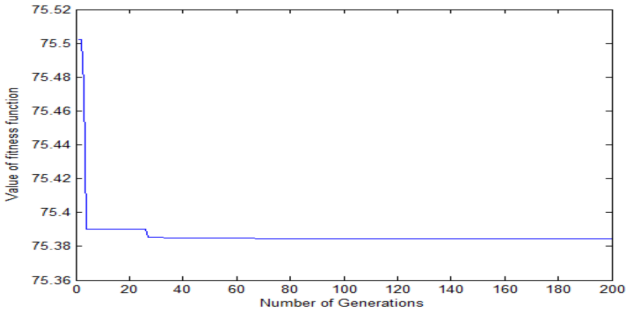


Fig. 8 Convergence Graph for the Case II

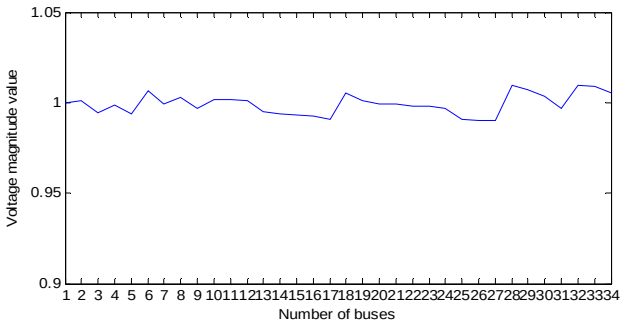


Fig. 9 Voltage Magnitude in all buses for Case II with Type B DG

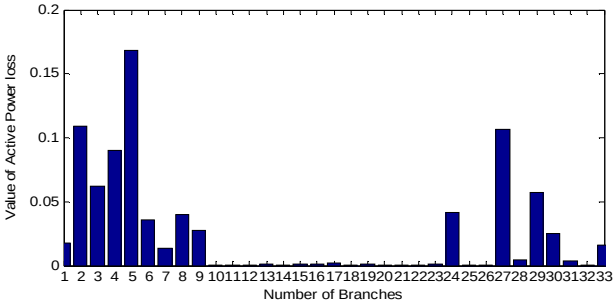


Fig. 10 Active Power losses in all branches for Case II with Type B DG

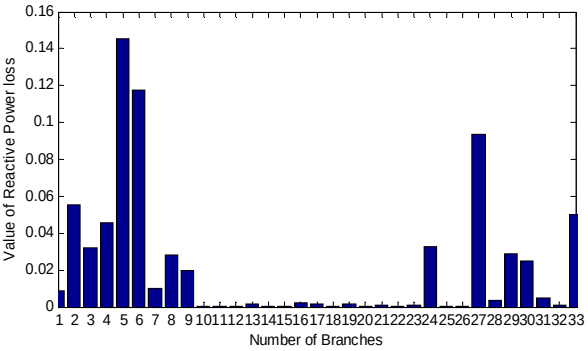


Fig. 11 Reactive Power losses in all branches for Case II with Type B DG

C. Case III: With Type C DG

Type C DG alone is considered in this case i.e, both the real and reactive power is delivered by the considered three Wind units. The results are listed in TABLE III. The optimal locations of three DG units are 28, 5 and 26 respectively. Their optimal sizing are 132.42 kW, 50 kW and 250 kW respectively. The Active Power loss and the Reactive Power loss for this case are 99.3016 kW and 86.4478 kVAr. The value of voltage deviations in all the buses when integrating this Type C DG is about 0.001287p.u. The fitness function calculated by considering the network losses and the voltage deviations is 72.5351.

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TABLE III. SIMULATION RESULT FOR CASE III

DG Parameters		Ploss (kW)	Qloss (kVAr)	Voltage Deviation (p.u.)	Value of Objective Function
Location	Size (kW)				
28	132.42	99.3016	86.4478	0.001287	72.5351
5	50				
26	250				

For this Case III, the Convergence Characteristics is given in Fig. 12. The maximum value of fitness function is 72.5351 and is reached at the 60th Generation. Fig. 13 gives the voltage magnitude in all the buses of the networks. The value of Active Power losses and Reactive Power losses in all the 33 branches of IEEE 34 Radial Distribution System for this Case III are given in Fig. 14-15.

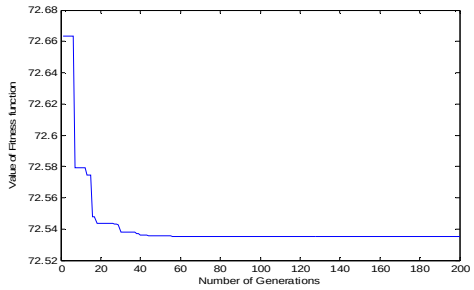


Fig. 12 Convergence Graph for the Case III

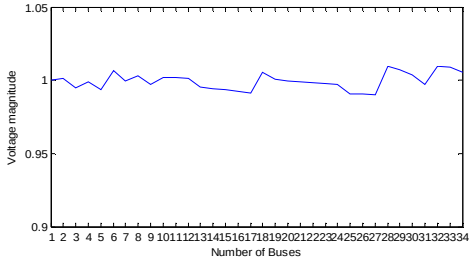


Fig. 13 Voltage Magnitude in all buses for Case III with Type C DG

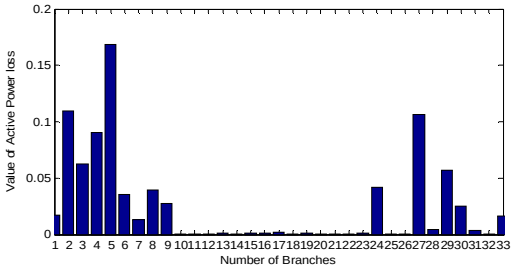


Fig. 14 Active Power losses in all branches for Case III with Type C DG

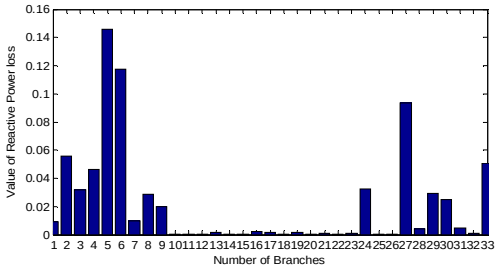


Fig. 15 Reactive Power losses in all branches for Case III with Type C DG

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D. Case IV: With Type D DG

In this case, Type D DG alone is integrated and the results are tabulated in TABLE IV. The candidate locations of three DG units are 19, 32 and 13 respectively. Their optimal sizing are 207.89 kW, 105.07 kW and 224.21 kW respectively. The Active Power loss and the Reactive Power loss for this case are 102.8696 kW and 86.3817 kVAr. The value of voltage deviations in all the buses when integrating this Type D DG is about 0.001086p.u. The fitness function calculated by considering the network losses and the voltage deviations is 76.5312.

TABLE IV. SIMULATION RESULT FOR CASE IV

DG Parameters		Ploss (kW)	Qloss (kVAr)	Voltage Deviation (p.u.)	Value of Objective Function
Location	Size (kW)				
19	207.89	102.8696	86.3817	0.001086	76.5312
32	105.07				
13	224.21				

For this Case IV, the Convergence Characteristics is given in Fig. 16. The maximum value of fitness function is 76.5312 and is reached at the 30th Generation. Fig. 17 gives the voltage magnitude in all the buses of the networks. The value of Active Power losses and Reactive Power losses in all the 33 branches of IEEE 34 Radial Distribution System for this Case III are given in Fig. 18-19.

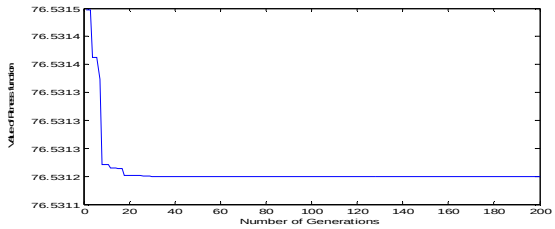


Fig. 16 Convergence Graph for the Case IV

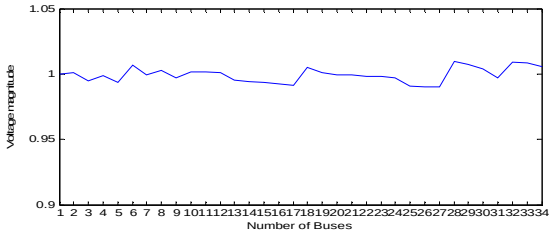


Fig. 17 Voltage Magnitude in all buses for Case IV with Type D DG

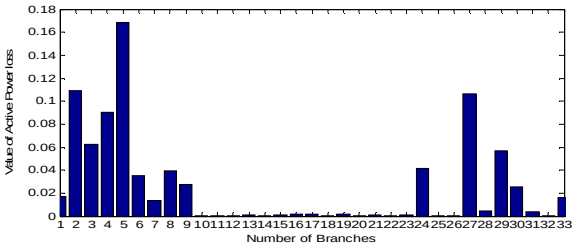


Fig. 18 Active Power losses in all branches for Case IV with Type D DG

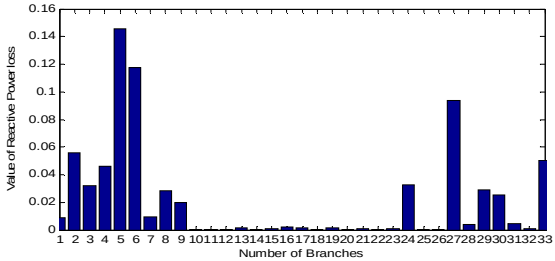


Fig. 19 Reactive Power losses in all branches for Case IV with Type D DG

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E. Comparison of All Test Cases:

The TABLE V shows the Value of objective function for all the four cases considered for the given Radial Distribution Network with three Wind units.

TABLE V. COMPARISON OF ALL TEST CASES

	Case I (TYPE A DG)	Case II (TYPE B DG)	Case III (TYPE C DG)	Case IV (TYPE D DG)
Value of Objective Function	74.3696	75.3846	72.5351	76.5312

When compared to others, Case III result is minimum which states that the Network losses including the Active and Reactive Power loss and the Voltage deviations are reduced when the three DG units are injecting both the real and reactive power to the system. To ensure a near optimal solution, for any random trial, the standard deviation should be low. From TABLE VI, the standard deviation of GSA is very low and hence GSA is robust.

TABLE VI. STATISTICAL ANALYSIS OF PERFORMANCE OF GSA WITH TYPE C DG

Compared Terms	GSA
Obj_{min}- best	72.5350645027198
Obj_{min}- worst	72.5350645019168
Average value	72.5350645020574
Standard Deviation	1.7961719642151e-10

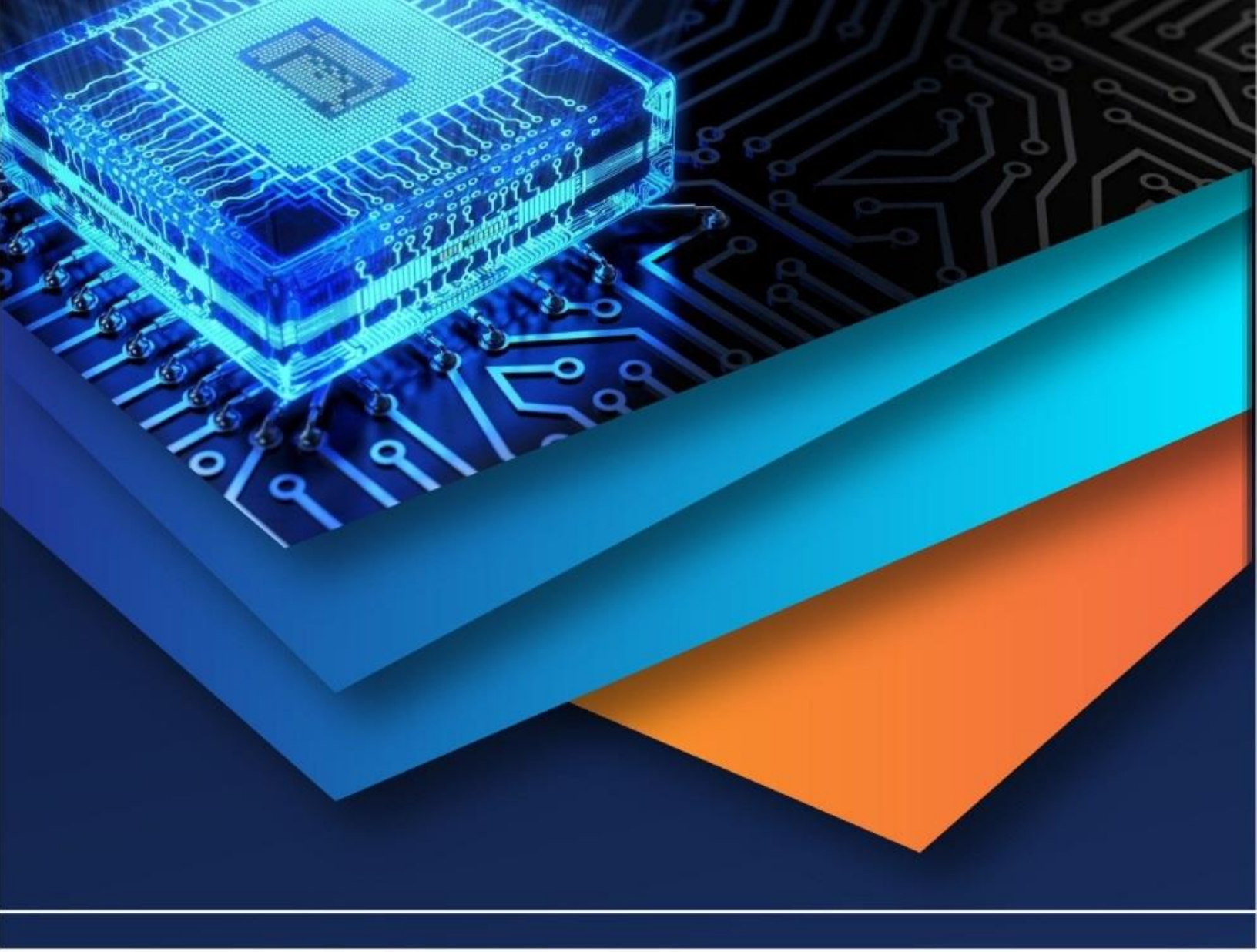
VI. CONCLUSION

Increasing the number of DG units in power system, Type of DG units and Place and size of DG units are all the important factors in planning the distribution networks and in reducing system Network loss and improve voltage profile. In this paper, Gravitational Search Algorithm is used to determine the optimal location and sizing of three DG units which efficiently minimizes the active power loss, reactive power losses, improve the voltage profile and satisfying all constraints. The proposed algorithm is so fast and efficient and at the same time so accurate in determining the size and location of DG unit(s). Results prove that among the four types of DGs, Type C DG units have better impact on system power loss reduction and system voltage profile improvement.

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