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Binary Gravitational Search Based Algorithm for Optimal DG and Capacitor Allocation Along with Network Reconfiguration in Radial Distribution Systems

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ABSTRACT- The Binary Gravitational Search Algorithm (BGSA) is a multi-purpose optimization technique presented in this research that may be used to identify the best capacity, position DG modules and capacitor groups, and reconfigure networks in distribution systems. The objective function has six performance indices: section load ability, voltage deviation, voltage stability index, dynamic and sensitive losses, and balancing current index. The optimization problem's objective function takes into account both the relevance of each indication and its combination. The suggested BGSA method was assessed on an IEEE 33 and 69 bus system and related to three other well-known algorithms: the Grey Wolf Optimizer (GWO), Particle Swarm Optimization (PSO), Genetic Algorithm (GA), and Gravitational Search Algorithm (GSA). The simulation results demonstrate how the BGSA algorithm can adjust the capacity and position of capacitor banks and DG sources in a variety of operating circumstances, boosting system performance and lowering active network losses.

Keywords: Network Reconfiguration (NR), Binary Gravitational Search Algorithm (BGSA) Grey Wolf Optimizer (GWO), Genetic Algorithm (GA), Particle Swarm Optimization (PSO).

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1. INTRODUCTION

When energy is transferred across long feeders to meet system demands, transmission and distribution losses grow. Large-scale distribution systems experience higher losses. When the integrated power system's distribution system is the last phase that supplies electricity to large loads like residential, commercial, and industrial buildings. Improving the performance of distribution networks based on technical and financial goals is difficult today due to the diverse operational characteristics of electrical loads, their rapid expansion, the integration of renewable energy sources (RES), the long-range radial structure, and the high resistance-to-reactance (R/X) ratio of distribution lines. The numerous operational characteristics of electrical loads, their rapid spread, the incorporation of renewable energy sources (RES), the long-range radial structure, and the high R/X ratio of distribution lines all contribute to the difficulty of improving distribution network act built on technical and financial objectives today. Technically and monetarily, these issues can be addressed by adding more active and reactive power to system buses via distributed generation (DG) and shunt capacitors. Consequently, it is possible to describe the ideal positioning of capacitors and DGs as a limited optimization issue. It is essential that he look for an optimization strategy capable of handling such a challenging issue. To determine the best location for DGs, various optimization approaches were applied. Sultana and Roy [1] determined the optimal location for two distinct types of DGs using the krill herd algorithm (KHA) in an effort to lower total actual power losses. Adaptive quantum-inspired evolutionary algorithm (AQiEA) was employed by Manikanta et al. [2] to find optimal distributed generation (DG) locations and sizes that minimize overall real power losses while taking into consideration various models of voltage-dependent loads. Karunarathne together with others. So as to lessen complete real power loss, [3] used an improved PSO-based methodology to identify the ideal position and dimension of distributed generators (DGs) in a functioning distribution network with multiple soft open points (SOPs). But just one OF was taken into account. Tan et al. [4] optimized the position and size of distributed generators (DGs) in centrifugal distribution networks by using the Swarm Moth Flame Optimization Method (SMFO), which takes

voltage profile, combined power losses, and effluence emissions into consideration. But only one kind of DG was looked into. Distribution grids (DGs) placement was determined using a two-step process by Esmaili et al. [5].
A systematic method based on correspondent current inoculation and LSFs was used by Gozel and Hocaoglu [6] to identify the best position and DG dimension for lowering entire power losses in distribution networks. To minimize total true power losses, However, the optimal solution was found only at a unity power factor. Genetic algorithm (GA) was used by Biswas et al. [8] to optimize voltage sag, DG cost, and total real power losses in order to minimize multi-factor of failure (OF) and find the best location for distributed generators (DGs) at a power factor of unity The flower pollination technique (FPT) was then used to calculate the proper dimensions of 3 distinct types of DGs in an effort to decrease overall losses. To lower power losses and increase load capacity, an analytical technique was developed by Hung and Mithulananthan [10] to control the optimal DG size and power factors. Al-Ammar et al. [12] employed multilayer particle swarm optimization (MLPSO) to determine the ideal DG sites and dimensions for lessening overall active power losses. But individual one OF with a single class of DGs was taken into account. An extensive analysis centered on the best arrangement of DGs from several angles and perspectives, including goals, limitations, techniques, and algorithms, was provided by Ehsan and Yang [13].

According to [14], distribution system losses account for 70% of all power losses. In contrast, the cost of power generation is directly proportional to power system losses. Resampling as a method for reducing losses in power networks has been the subject of a great deal of recent research. In contrast, the higher reliability of the power system is due to the configuration change, which also reduces losses and improves the voltage profile [17-19]. Using distributed generation sources is another technique to reduce power system losses [20–21]. Installing distributed generation (DG) units near customers reduces power system losses, both overall and line losses [20-23]. Dispersed producing sources typically have a capacity of less than 10 megawatts [24-25]. As a result, the amount of electricity produced by distributed production sources is increasing daily [26]. Another way to reduce power system losses is to use capacitive banks to regulate the voltage [27-30]. To reduce losses, distributed generating sources and capacitors were installed simultaneously [31-33]. The foundation of the distribution system rearrangement in [34] was the Cuckoo search algorithm. The IEEE 33, 69, and 118 bus structures are compared in order to validate the suggested methodology. Ref [35] uses a prohibited pursuit strategy to reorganize the system with the goal of improving voltage stability and reducing losses. The IEEE 33 and 69 systems, in addition to Ahwaz's distribution system, are examined in [36] when reorganizing based on the learning method. In this reference, lowering losses while raising the voltage profile is the intended function.

The six performance indices that are used to achieve this are section load ability, voltage stability index, active losses, voltage deviation, reactive losses, and segment balancing current index. Network performance is maximized with the application of a multi-objective Binary Gravitational Search Algorithm (BGSA). The IEEE 33 and 69 bus systems are used to illustrate the effectiveness of the suggested approach.

The issues listed below will be addressed in the next section: The second section discusses the objective function, indices, and a problem summary. The final section discusses the Binary Gravitational Search Algorithm (BGSA) technique to address the optimization problem. The fourth unit displays the simulation findings. The BGSA method's results were compared to genetic and particle swarm optimization methods, as well as cross-referenced with other sources. Finally, the final section presents the conclusions.

2. PROBLEM FORMULATION

The purpose of this section is to discuss how to choose the best placement, size, and configuration for DG and capacitor banks while taking network configuration into account. Reducing losses, voltage deviations, and improving the voltage stability index and system current balance are the goals of the unbiased function. As a result, the purposeful function that has been developed here combines power losses, sectional currents, voltage stability index, voltage deviation index, line limitations, and optimization problem restrictions.

2.1. Power Loss Calculation

There are two approaches for reducing distribution system real power losses: lowering line resistance and lowering current. Modifications to the system's topology may affect network section resistance. Additionally, the current flowing over the wires is decreased by carefully placing capacitors and scattered producing sources throughout the network. The decrease in real network power loss is known as the active loss index.

$$P_{LI} = \frac{P_L^a}{P_L^b} \quad (1)$$

In a similar vein, the decrease in reactive network power loss defines the reactive power loss index.

$$Q_{LI} = \frac{Q_L^a}{Q_L^b} \quad (2)$$

In the event of a power outage, the objective function is written as:

$$\min OF_1 = X_1 P_{LI} + Y_1 Q_{LI} \quad (3)$$

X_1&Y_1 values are taken as 0.8 and 0.2 respectively.

2.2. Voltage Deviation Index

One security metric is bus voltage, and quality of power is critical to the structure's functionality. The electrical system operates poorly when the voltage is adjusted. Equation (4) describes the voltage variations in network buses.

$$VI = \sum_{k=1}^{N_b} \frac{V_B - V_k}{V_B} \quad (4)$$

2.3. Voltage Stability Index

By raising the voltage constancy index, one may determine the appropriate stability margin for every bus. In line with [30], Equation (5) is used to determine a bus's voltage stability factor.

One can compute the voltage stability index within a bus by applying the subsequent formula:

$$V_{SI,N2} = |V_{N2}|^4 - 4(P_{N2}X_{kk} - Q_{N2}R_{kk}) + 4(P_{N2}R_{kk} + Q_{N2}X_{kk})|V_{N1}|^2 \quad (5)$$

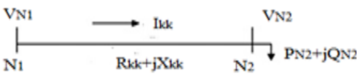

Figure 1. Simple Branch of the Network

The following is the expression of the goal function incorporating voltage deviation and voltage stability indices:

$$\min OF_2 = X_2 VI + Y_2 \frac{1}{V_{SI}} \quad (6)$$

The values of $X_2 \& Y_2$ are taken as 0.5 and 0.5 respectively.

2.4. Section Balancing Currents Index (SBCI)

Existence of producing units, both active and reactive, in close proximity to the loads affects the current flow in different network segments. The network's capacity to manage increasing loads is increased by lowering this index. The formula (7) is used to define the index.

$$SBCI = \frac{\sum_{s=1}^{Ns} \left| \frac{I_{sb} - I_{sa}}{max(I_{sa}, I_{sb})} \right|}{Ns} \quad (7)$$

The objective function with section load index and section balancing currents index is expressed as:

$$\min OF_3 = X_3 \times SLI + Y_2 \times SBCI \quad (8)$$

The values of are taken as 0.5 and 0.5 respectively.

2.5. Limits and Constraints

Equations (9) through (12) specify the optimum real and imaginary power produced by DG modules and bank of capacitors, as well as the voltage and temperature limitations of network lines, which constrain the optimization problem.
Bus Voltage limit is written as:

$$0.9 \leq V_k \leq 1.1 \quad ; k = 1,2 \ldots \ldots .. NB \quad (9)$$

Section current limit is written as:

$$|I_{k,k+1}| \leq |I_{k,k+1,max}| \,; k = 1,2 \ldots \ldots .. Ns \quad (10)$$

The distributed generation units are supposed to be restricted to generating active electricity. Equation (11) calculates the sources' power production capacity. With 20 capacitors per bank, each capacitor bank has a 50 kV capacity, allowing for 21 distinct levels of power to be generated from the reactive capacitor bank.

The DG and Capacitor bank constraints can be written as:

$$P_{DG}^{min} \leq P_{DG}^{k} \leq P_{DG}^{max} \quad (11)$$

$$Q_{C}^{min} \leq Q_{C}^{k} \leq Q_{C}^{max} \quad (12)$$

The power balance constraints or equality constraints are written as:

$$P_{G,NB} + \sum_{k=1}^{N_{DG}} P_{k,NB}^{DG} = P_{Load,NB} + P_{L,NB} \quad (13)$$

$$Q_{G,NB} + \sum_{k=1}^{N_C} Q_{k,NB}^{C} = Q_{Load,NB} + Q_{L,NB} \quad (14)$$

2.6. Multi Objective Function

Three components make up the suggested multi-objective function, as shown by equation (15). The homogenous indexes of both reactive and active power losses were displayed using functions f_1 and f_2, the voltage variance indexes and enhancements in voltage stability were displayed using function f_2, and the line current capability limit and current balance indexes were displayed using function f_3. These functions are combined with the function of objective and weighted to create the optimization problem.

$$OF = X_T \times OF_1 + Y_T \times OF_2 + Z_T \times OF_3 \quad (15)$$

The values of are taken as 0.4, 0.3 and 0.3 respectively.

3. BINARY GRAVITATIONAL SEARCH ALGORITHM

Inspired by the laws of motion and gravity, the Binary Gravitational Search technique (BGSA) is a metaheuristic optimization technique. It is frequently applied to the resolution of optimization issues. Finding the best places to install distributed generation (DG) units and capacitors in the power distribution network in order to reduce losses, improve voltage profile, and improve overall system performance is the aim when it comes to optimal location of DG and capacitors seeing network reconfiguration in electrical power systems.

Step 1: Initialization Set the population of solutions to zero. Every possible arrangement of DG units and capacitors inside the network is represented by each solution. Generate binary strings at random to indicate if DG units and capacitors are present or absent at each network node.

Step 2: Fitness Evaluation Determine each solution's fitness. Goals including cutting down on power losses, enhancing voltage profile, and other pertinent performance measures should be taken into account by the fitness function. For every solution configuration, simulate the power flow over the network and get the relevant fitness values.

Step 3: Gravitational Search Calculate the gravitational force acting on each solution based on its fitness value. Solutions with higher fitness values experience stronger gravitational forces. Update the positions of solutions based on the gravitational forces acting on them. Solutions with higher fitness values are attracted towards better regions of the search space.

Step 4: Binary Gravitational Movement Apply binary gravitational movement to update the binary strings representing the presence or absence of DG units and capacitors. Use binary operations such as crossover and mutation to create new solutions based on the gravitational forces and the current positions of solutions.

Step 5: Local Search Optionally, apply local search techniques to explore the neighborhood of promising solutions and improve solution quality. Local search methods such as hill climbing or simulated annealing can be used to fine-tune the solutions obtained from the gravitational search process.

Step 6: Termination For a set number of iterations or until the convergence requirements are satisfied, repeat steps 2 through 5 again. Terminate the algorithm and output the best solution found during the optimization process.

Step 7: Post-processing Examine the final solution that the optimization process produced. Validate the solution by simulating its performance under various operating conditions and comparing it with alternative configurations.

3.1. Implementation Considerations
Design appropriate data structures to represent the network topology, solution configurations, and other relevant parameters. Implement efficient algorithms for simulating power flow and evaluating fitness values.

Tune algorithm parameters such as population size, gravitational constants, and mutation rates to balance exploration and exploitation. Utilize parallel computing techniques to speed up the optimization process, especially for large-scale networks.

4. SIMULATION RESULTS
Case A: IEEE 33 bus system

In this work, an optimization problem is solved using the BSGA algorithm. In order to find the optimal configuration for the system and to maximize various network metrics like voltage stability, line capacity, current equilibrium, active and reactive loss reduction, and voltage deviation, the system's performance has been assessed. Additionally, the location of sources of disseminated generation and capacitor banks are determined. By running the software on an IEEE 33 bus distribution system.

There are 37 branches, 32 sectionalizing switches, and 5 tie switches in the IEEE 33-bus distribution system. This system's line and load information are shown in [34]. Furthermore, according to load flow, the true and imaginary power losses in the first scenario are 210.679 kW and 143.14 kVAR. The loads on this network have a combined active and reactive power of 3.715 MW and 2.3 MVAr. In Figure 2, the network diagram is shown.

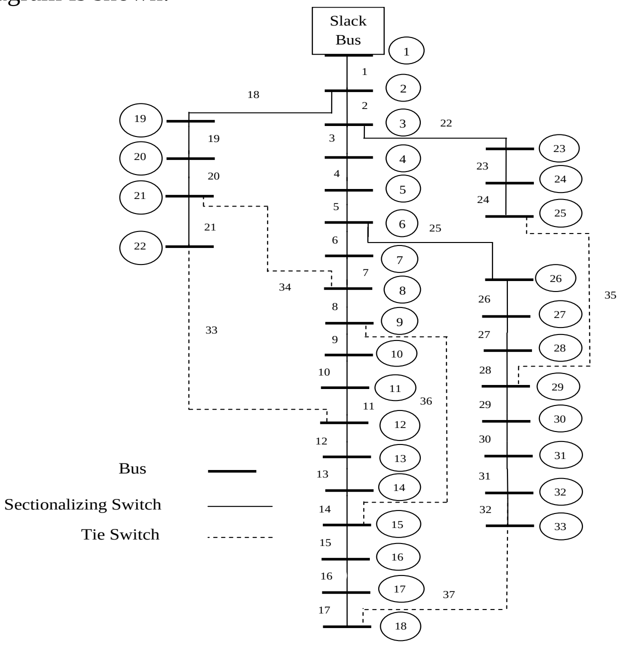

Figure 2. IEEE 33 bus system with sensationalizing switches

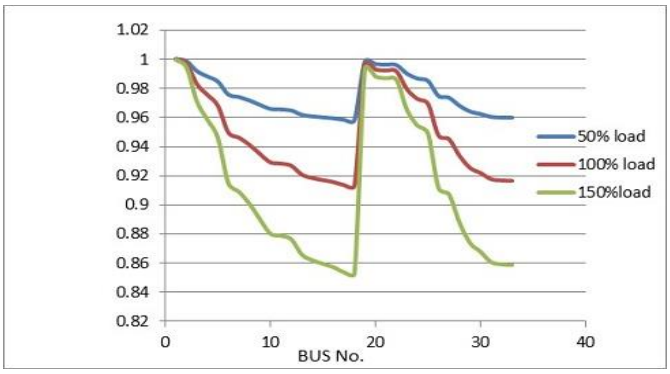

Figure 3. Voltage deviations at different loading conditions before optimal placement of DG, Capacitor bank and Network Configuration

Table 1. IEEE 33 bus system base values

Active Power Loss (kW)	211
Reactive Power Loss (kVAR)	143
Voltage Deviation	1.8
Voltage Stability Margin	0.67
Maximum Line Loadability (A)	4.61
Maximum Line current (A)	4.62

This system's lowest voltage on bus 18 is 0.90 per unit at base load. The indices for the elementary status of system are displayed in Table 1. Neither dispersed producing sources nor are capacitor banks present in this scenario. This system has a low voltage stability limit of 0.67, which strains the buses. As a result, network losses can be reduced by restructuring the

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network and using distributed production sources and capacitive banks to reduce bus stress.

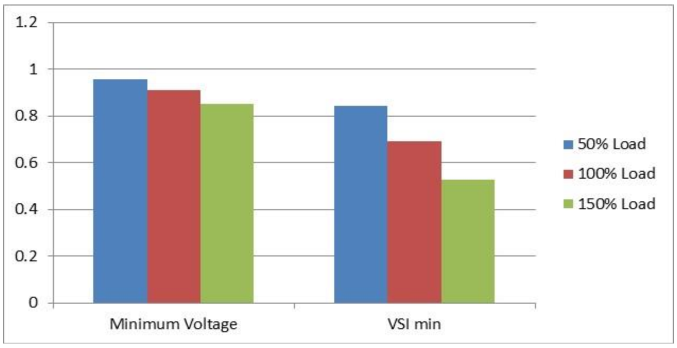

Figure 4. Minimum Voltage and Voltage Stability Index at different loading conditions before optimal placement of DG, Capacitor bank and Network Configuration

Fig.3 and 4 depict the voltage deviations, minimum voltage and voltage stability index at different loading conditions before optimal placement of DG, Capacitor bank and Network Configuration respectively.

Table 2. IEEE 33 bus system values without and with BGSA algorithm

Parameter	Without	With BGSA
Real Power Loss (kW)	211	172.02
Imaginary Power Loss (kVAR)	143	117.02
Voltage Deviation	1.8	1.0
Voltage Stability Margin	0.67	0.91
Maximum Line Load ability (A)	4.61	1.1
Maximum Line current (A)	4.62	1.21

Table 3. IEEE 33 bus system voltage and VSI values with BGSA algorithm

Bus No.	Voltage Scale (p.u)	VSI
1	1	1
2	0.99706	0.988242
3	0.98312	0.925985
4	0.97792	0.894814
5	0.97291	0.894347
6	0.9611	0.850729
7	0.95768	0.835604
8	0.95293	0.820669
9	0.94679	0.797003
10	0.94342	0.782525
11	0.94298	0.790388
12	0.94226	0.78781
13	0.93962	0.776594
14	0.93881	0.775523
15	0.94201	0.794617
16	0.94068	0.781878
17	0.9387	0.773952
18	0.93811	0.773281
19	0.99653	0.987773
20	0.99295	0.967329
21	0.99225	0.967978
22	0.99161	0.964378
23	0.97646	0.932884
24	0.96321	0.857001
25	0.95338	0.81367
26	0.9604	0.804814
27	0.95977	0.805925
28	0.95912	0.793759
29	0.94925	0.778767
30	0.94653	0.759449
31	0.93962	0.849427
32	0.93734	0.845962
33	0.93476	0.826286

The six goal function indices in the basic scenario are shown in *figure 5*, along with the configuration before DG and capacitors are installed. Section load ability, voltage deviation, voltage stability, active & reactive power loss, along with the index of balancing current across sections are the indices.

With the network adjusted using the BGSA approach, the capacitor bank and DG positioned properly, the lowest voltage on bus 33 for this system is 0.93476 per unit at base load. *Table 1* shows the numerical values of the parameters for the system's fundamental state. Neither dispersed producing sources nor are capacitor banks present in this scenario. This system has a low voltage stability high-limit limit of 0.98, which strains the buses. *Table 2* compares the parameters both with and without the BGSA algorithm.

From the table; it is perceived that after source node the maximum voltage and minimum voltages recorded as 0.997 and 0.934 on buses 2 and 33 respectively. The extreme and least voltage stability limits are 0.988 and 0.773 on buses 2 and 18 respectively.

Table 4 shows the simulation results obtained after applying multiple optimization strategies to simultaneously place the DG and capacitors in a 33-bus system and rearrange the network. The open switches that comprise the final segment of the 33-bus structure, after employing the BGSA algorithm, are 6, 11, 25, 31, and 35. Looking at the results, it is clear that, when compared to the GA, PSO, GWO and GSA strategies, the proposed BGSA strategy is better suited to handling the optimization problem.

The active and reactive losses obtained using the BGSA approach are less than those obtained using the GA, PSO, GWO and GSA algorithms. The suggested BSGA method yields a voltage constancy index that is superior to that of the voltage deviation index achieved *via* the use of GA, PSO, GWO and GSA approaches, but the voltage deviation index produced through these methods is roughly equal. In contrast to the values provided by the GA, PSO, GWO and GSA approaches, Lower results were observed for section load capabilities and the catalog of matching current of segments using the BGSA methodology.

Table 4. shows each bus voltage and voltage stability index

	GA	PSO	GWO	GSA	BGSA
Open Switches	5,7,8,11,12	5,8,9,25, 31	7,10,13,27,32	7, 8, 9, 10, 32	6, 11, 25, 31, 32
DG Placement & (optimal Capacity (MW))	1.155@bus 18 1.500@bus 29	1.500@bus 13 1.254@bus 29	0.426@bus 32 1.202@bus 29	1.51@bus 29 1.24@bus 13	1.447@bus 25 1.521@bus 15
Capacitor placement & (optimal Capacity (MVar)	0.650@bus 6 1.000@bus 18	0.700@bus 16 0.900@bus 30	0.713@bus 18 0.65@bus 27	0.715@bus 16 0.810@bus 15	0.955@bus 30 0.710@bus 15
True power losses (kW) (Ploss)	27.82	24.51	22.03	20.30	17.20
Imaginary power losses (kVar) (Qloss)	26.51	23.32	20.22	19.50	11.70
Voltage Deviations Index (VI)	0.008	0.005	0.004	0.0037	0.003
Voltage stability index (VSI)	0.9	0.91	0.93	0.935	0.95
Section Balancing Current Index (SBCI)	0.3	0.28	0.26	0.258	0.25

GWO and GSA algorithms. The suggested BSGA method yields a voltage constancy index that is superior to that of the voltage deviation index achieved via the use of GA, PSO, GWO and GSA approaches, but the voltage deviation index produced through these methods is roughly equal. In contrast to the values provided by the GA, PSO, GWO and GSA approaches, Lower results were observed for section load capabilities and the catalog of matching current of segments using the BGSA methodology.

Case B: IEEE 69 bus system

The IEEE 69 bus test system fig 5 shows the test system with sectionalizing switches and Tie line switches the performance comparison table is shown in table 5. In base case 69,70, 71, 72 and 73 switches are opened. In this base case, power loss and minimum volt.

After applying GA algorithm for best location and dimensions of DGs and banks of Capacitor considering network configuration are: three DGs with 0.4 MW, 0.4 MW and 0.4 MW are located at 58, 61 and 65 respectively; three capacitor banks with ratings 0.5 MVAR, 0.47 MVAR and 0.7 MVAR located at 7, 13 and 61 respectively.

After applying PSO algorithm for best location, DGs dimensions and bank of Capacitors considering network configuration are: three DGs with 0.35 MW, 0.62 MW and 1.164 MW are located at 11, 18 and 62 respectively; three capacitor banks with ratings 0.2 MVAR, 0.4 MVAR and 0.47 MVAR located at 21, 62 and 64 respectively.
ages are 225kW and 0.9092 p.u.

Following the use of the GWO algorithm, the best locations and sizes for DG and capacitor banks are determined by taking network configuration into three DGs with 0.614 MW, 1.82 MW and 0.6 MW are located at 37, 61 and 22 respectively; three capacitor banks with ratings 0.29 MVAR, 0.926 MVAR and 0.3 MVAR located at 25, 62 and 28 respectively.

Following the use of the GSA algorithm, the best locations and sizes for DG and capacitor banks are determined by taking network configuration into: three DGs with 0.1 MW, 0.2 MW, 0.3 MW and 0.4 MW are located at 46, 35, 14 and 53 respectively; three capacitor banks with ratings 0.1 MVAR, 0.2 MVAR, 0.3 MVAR and 0.4 MVAR located at 24, 45, 49 and 61 respectively.

Table 5. Comparison performance IEEE 69 bus system.

	GA	PSO	GWO	GSA	BGSA
Open Switches	20, 37, 43, 57, 60	13, 17, 47, 49, 69	9,70, 17, 26, 54	26, 42, 44, 59	20, 70, 26, 43, 69
DG Placement (optimal Capacity (MW)	0.4@bus 58 0.4@bus 61 0.4@bus 65	0.35@bus 11 0.62@bus 18 1.164@bus 62	0.614@bus 37 1.82@bus 61 0.6@bus 22	0.1@bus 46 0.2@bus 35 0.3@bus 14 0.4@bus 53	0.71@bus 36 1.91@bus 62 0.7@bus 22
Capacitor location and (optimal Capacity (MVar)	0.5@bus 7 0.47@bus 13 0.7@bus 61	0.2@bus 21 0.4@bus 62 0.47@bus 64	0.29@bus 25 0.926@bus 62 0.3@bus 28	0.1@bus 24 0.2@bus 45 0.3@bus 49 0.4@bus 61	0.31@bus 27 0.94@bus 62 0.45@bus 25
Active power losses (kW) (Ploss)	34.27	32.21	10.45	10.15	9.75
Reactive power losses (kVar) (Qloss)	32.25	30.09	9.55	9.25	8.35
Voltage Deviations Index (VI)	0.01	0.007	0.002	0.0019	0.001
Voltage stability index (VSI)	0.92	0.94	0.96	0.959	0.965
Section Balancing Current Index (SBCI)	0.32	0.29	0.27	0.261	0.252

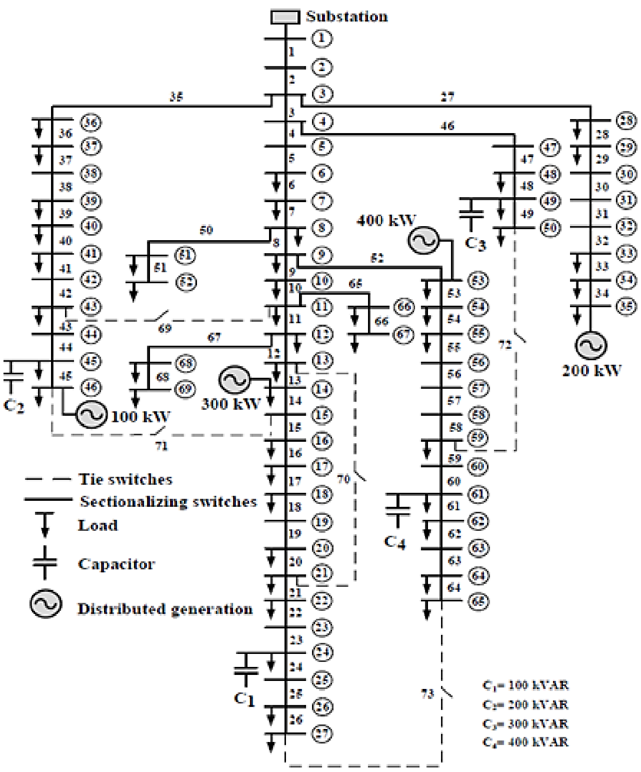

Figure 5. IEEE 69 bus system with sensationalizing and tie switches

Following the use of the BGSA algorithm, the best positions and dimensions for DG and banks of capacitors are determined by taking network configuration into three DGs with 0.71 MW, 1.91 MW and 0.7 MW are located at 36, 62 and 22 respectively; three capacitor banks with ratings 0.31 MVAR, 0.94 MVAR and 0.45 MVAR located at 27, 62 and 25 respectively. Table 5 explains the comparison Performance comparison (IEEE 69 bus).

5. CONCLUSION

The BGSA method was presented in this research as the best location, sizing, and consideration for network reconfiguration when placing numerous DGs and capacitor banks. The suggested approach is used in the MATLAB/Simulink environment on IEEE 33 and 69 bus systems, and its performance is contrasted with that of GA, PSO, GWO, and GSA. From the findings, initially GSA performance was better for best location of DG & bank of capacitors with network reconfiguration as compared with GA, PSO & GWO algorithms. Finally, from the findings, it is clear that all the performance indices were achieved effectively by using BGSA algorithms as compared with GA, PSO, GWO and GSA algorithms.

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