Optimal Allocation of Distributed Generators in Electrical Distribution Systems Using OWOA

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Abstract - *In recent decades, energy crises due to the scarcity of fossil fuels and rely on non-renewable energy for industrial and commercial purposes increased drastically. This emerges, the concept of Distributed Generation (DG), setting up of smaller modular resources in a distributed manner closer to the point of load. Over conventional large-scale electrical transmission and distribution network, DG has efficient performances. This research intends to utilize the Opposition based Whale Optimization Algorithm (OWOA) to identify optimal DG placement in the radial distribution networks for a reduction in real power losses and enhancement in voltage profile. This research methodology executed on IEEE- 33 bus radial distributive system to evaluate the performance of employed techniques. It is evident from the investigation that the incorporation of optimization techniques reduces computational complexity rather than random trial and error DG placement. In general, OWOA achieves proficient performance in different loading conditions and loading positions. The performance of OWOA is possible through opposition strategy, which increases the chance of predicting an optimal solution*.

Key Words: IEEE-33 bus system, Distributed Generation (DG), Radial distribution networks and Opposition based Whale Optimization Algorithm (OWOA).

1.INTRODUCTION

The electric power industries have seen numerous changes in recent years [1]. The unpredictability of power system makes its activity exceptionally difficult on considering a high demand for electricity supply and load density [2]. Accordingly, this necessitated delivering electrical power over long transmission and distribution line to meet the ever increment of energy demand [3, 4]. The existing distribution frameworks are affecting towards smart distribution frameworks to accomplish bigger socio-economic and other non-tangible benefits. Distributed generations (DGs) are currently getting to be basic segments for understanding the idea of smart distribution frameworks on account of financial feasibility and severe natural laws [5]. Accordingly, future distribution networks with the high DG penetration to be arranged and worked so as to improve their proficiency [6]. The optimal allocation of DG units requires the assurance of their optimal sizing and sites to accomplish wanted targets while fulfilling a few constraints. Hence, DG optimal allocation is a nonlinear complex combinatorial constraint optimization problem and is one of the most significant and testing task towards acknowledging smart grid objectives [7]. DGs may originate from an assortment of sources and technologies. DGs from renewable sources, like wind, solar and biomass are often called as “Green energy”. Furthermore, DGs incorporates micro turbines, gas turbines, diesel engines, fuel cells, stirling engines and internal combustion reciprocating engines [8].

Optimal placement and sizing of DG utilizing NR method of load flow study at the proper bus location minimizes both the losses and the expenses all the while which aides in maximizing the potential benefits [9]. Scientists have investigated numerous strategies for optimal sizing and placement of DG in distribution networks for example analytical techniques, numerical techniques, and heuristic techniques [10]. Among the accessible techniques, heuristic techniques have demonstrated their superiority and effectiveness associated to the conventional techniques [11]. Numerous optimization tools like Genetic algorithm (GA), Particle Swarm Optimization (PSO), Whale Optimization Algorithm (WOA) and Evolutionary Algorithm (EA) are as yet utilized in the power system optimization issue to take care Different DG unit’s problem [12]. WOA has been demonstrated dependent on the unique hunting behavior of humpback whales. The WOA is utilized to decide the optimal size of DGs at various power factors to lessen the power losses of the distribution system as much as possible and enhancing the voltage profile of the framework [13].

2. Literature review

Satish Kumar Injeti [14] 2018, had planned to choose optimal sizes and locations for DGs in radial distribution systems (RDS) to minimize losses, improve voltage profile and minimize working expense. Improved Differential Search Algorithm (IDSA) was utilized to solve the optimization problem through Pareto optimal methodology by considering technical and financial benefits of DGs as goals.
Tri Phuoc Nguyen and Dieu Ngoc Vo [15] 2018, had suggested an application of a stochastic fractal search algorithm (SFSA) for settling the optimal allocation of distributed generators (OADG) issue in radial distribution systems (RDSs). The outcome correlations from the test frameworks have demonstrated that the proposed method can acquire higher quality solutions than numerous different

approaches for the considered scenarios from the test frameworks.

A. H. Ahmed and S. Hasan [16] 2018, had anticipated a particle swarm optimization (PSO) based algorithm for optimal allocation of DGs in an essential radial distribution system to minimize the difference in voltage between indicated two buses so that they could be attached to loop a part of the framework.

P.Dinakara Prasad Reddy et al. [17] 2018, had proposed a meta heuristic algorithm called whale optimization algorithm (WOA) was utilized to decide the optimal DG-unit's size. The outcomes acquired by the proposed WOA algorithm were contrasted and various sorts of DGs and other evolutionary algorithms. At the point when contrasted and different algorithms the WOA algorithm gives better outcomes.

Fahad S. Abu-Mouti and M. E. El-Hawary [18] 2011, had proposed a optimization approach that utilizes an artificial bee colony (ABC) algorithm to decide the optimal DG-unit's size, power factor, and location in order to minimize the total system real power loss. The results confirm that the ABC algorithm was efficient, robust, and capable of handling mixed integer nonlinear optimization problems.

Satish Kansal et al. [19] 2011, had proposed the utilization of Particle Swarm Optimization (PSO) method to find the optimal size and optimum location for the placement of DG in the radial distribution networks for active power compensation by decrease in real power losses and enhancement in voltage profile. The proposed method was tested on standard 33-bus test system and the got outcomes are contrasted with the exhaustive load flows.

3. Proposed methodology

The significant purpose of this research is to reduce active power loss for the optimal allocation of DG in distribution network. To initiate this process through trial and error process takes long time for computation. To resolve, this research intends to utilize optimization techniques to identify appropriate location for DG. In this work backward forward method used for load flow solution and the three loading condition such as 30% for light condition, 65% for medium condition and 100% for heavy condition are performed. Techniques involves in this process are OWOA, Whale Optimization Algorithm (WOA), Particle Swarm Optimization (PSO), Genetic Algorithm (GA), Differential Evolution (DE). Here, opposition strategy involved to enhance the performance of conventional WOA by increasing the probability of attaining optimal solution. The following section details the mathematical formulation of predicting appropriate DG placement in associate with OWOA. This work include type 'C' DG placement as a proposed method, because it is capable of delivering both real and reactive power. Figure 1 shows IEEE 33 bus system diagram and figure 2 demonstrates the flowchart for OWOA algorithm.

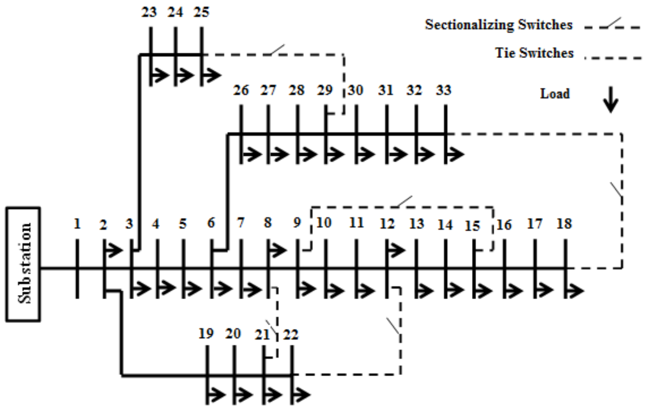

Fig -1: IEEE 33 bus system diagram

3.1 Opposition based Whale Optimization Algorithm (OWOA)

Recently a new optimization algorithm called whale optimization algorithm (Mirjalili 2016) has been acquainted with metaheuristic algorithm by Mirjalili and lewis. The whales are viewed as exceptionally highly intelligent animals with motion. The WOA is inspired by the special chasing behaviour of humpback whales. Typically the humpback whales like to chase krills or small fishes which are near the surface of sea. Humpback whales utilize an exceptional remarkable chasing technique called bubble net feeding method. In this technique they swim around the prey and make a particular bubble along a circle or 9-shaped path.

3.1.1 Initialization

This is the initial process of OWOA, which includes three-position index holding bus number ranges from 1 to 33 randomly distributes on the solutions. Along with the randomly generated initial solution, this research also includes opposition based solution expected to increase the probability of getting an optimum solution and the mathematical function expressed below. The process of generating new vectors is called initialization process and the generated vectors are called parent or target vectors ($y^k_{i,j}$) and it can be expressed as,

$$y_{i,j}^{k} = y_{min,i} + \sigma_{i,j} \cdot \left(y_{max,i} - y_{min,i}\right) \quad (1)$$

Where $i = 1, 2, ..., D$ and $j = 1, 2, ..., NP$. D and NP are the dimension of the issue and the number of population separately. k shows the iteration or generation number. $y_{min,i}$ and $y_{max,i}$ are the minimum and maximum limit of i^{th} dimension of a vector individually. The estimations of $\sigma_{i,j}$ varies randomly somewhere in the range 0 and 1.

If Y_j is j^{th} population vector in i-dimensional search space such that $Y_j=(y_{1j}, y_{2j},....y_{ij})$, where i= 1, 2,... D, j = 1, 2,...NP and $y_{ij} \in [y_{min,i}, y_{max,i}]$.

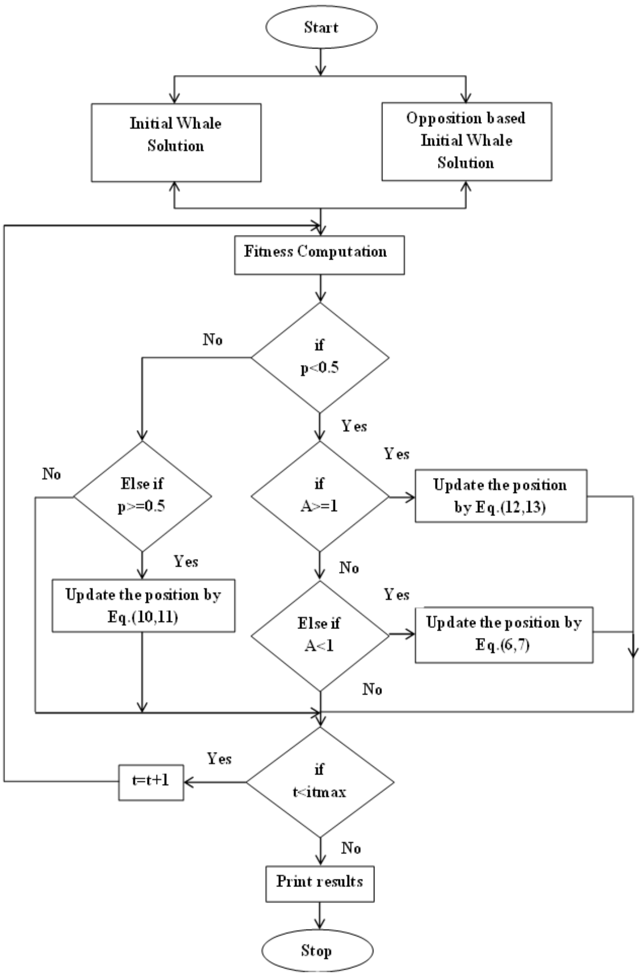

Fig -2: Flowchart for OWOA algorithm

At that point its opposite point $\tilde{Y}_j$ is characterized as $\tilde{Y}_j = (\tilde{y}_{1j}, \tilde{y}_{2j}, \ldots \tilde{y}_{3j})$, where $\tilde{y}_{ij}$ is the component of y_{ij} . Numerically it tends to be determined as $\tilde{Y}_{ij} = y_{min,i} + y_{max,i} - y_{ij}$.

3.1.2 Fitness Computation

Presently, the fitness values for both the points are calculated. In the event that the fitness value for $\tilde{Y}_j$ is better than the fitness value for Y_j then replace Y_j with $\tilde{Y}_j$; generally proceed with Y_j .

$$P_{loss} = \sum_{i=1}^{N} \sum_{j=1}^{N} \left[A_{ij} \left(T_i T_j + R_i R_j \right) + B_{ij} \left(R_i T_j - T_i R_j \right) \right] \quad (2)$$

Where,

$$A_{ij} = \frac{L_{ij}}{|V_i||V_j|} \cos(\delta_i - \delta_j)$$

$$B_{ij} = \frac{L_{ij}}{|V_i||V_j|} \sin(\delta_i - \delta_j)$$

T_i and R_i are total active and reactive power injection correspondingly in the i^{th} bus. L_{ij} is the line resistance between bus i and j. $|V_i|$ and δ_i are the magnitude and angle individually of i^{th} bus voltage.

In its simplified form, the total active power loss in a distribution system with 'n' number of branches can likewise be planned as:

$$P_{loss} = \sum_{i=1}^{n} I_i^2 L_i \quad (3)$$

Where, I_i and L_i are the current and resistance of branch i individually. Eq. (3) can be further rewritten in the form of loss happened due to active (I_{ai}) and reactive (I_{ri}) component of current I_i.

$$P_{loss} = \sum_{i=1}^{n} I^2 a_i \, L_i + \sum_{i=1}^{n} I^2{}_{ri} \, L_i \quad (4)$$

Eq. (4) can be additionally rearranged as:

$$P_{loss} = \sum_{i=1}^{n} \frac{T^2{}_{bi} + R^2{}_{bi}}{|V_i|^2} L_i \quad (5)$$

Where, T_{bi} and R_{bi} are the total active and reactive power flow through the branch i. utilizing these equations, total active power loss of the entire branch can be calculated which is to be minimized after penetration with DG.

3.1.3 Updating process

The mathematical model of WOA is portrayed in the accompanying sections

1. Encircling prey.
2. Bubble net hunting method.
3. Search the prey.

Encircling prey

WOA expects that the present best candidate solution is the objective prey. Others attempt to update their positions toward best search agent. The behaviour modelled is as

$$\vec{Z}(t+1) = \vec{Z}(t) - \vec{A} \cdot D \quad (6)$$

$$D = \left| \vec{c} \cdot \vec{Z}(t) - \vec{Z}(t) \right| \quad (7)$$

$$\vec{A} = 2\vec{a}\vec{r} - \vec{a} \quad (8)$$

$$\vec{c} = 2\vec{r} \quad (9)$$

Current iteration is indicated by t. $\vec{A}$, $\vec{c}$ are coefficient vectors. $\vec{a}$ is directly lessened from 2 to 0. $\vec{r}$ is a random vector [0, 1].

Bubble net hunting method

In this hunting technique two methodologies are there.

Shrinking encircling prey

Here $\vec{A}$ ϵ[−a, a], where $\vec{A}$ is diminished from 2 to 0. Here $\vec{A}$ position is setting down at random values in between [−1, 1].

The new position of $\vec{A}$ is gotten between original position and position of the current best agent.

Spiral position updating

To imitate helix-shaped movement spiral equation is utilized.

$$\vec{Z}'(t+1) = \vec{D}' e^{bl} \cos\,(2\pi l) + \vec{Z}(t) \quad (10)$$

In hunting whales swim around the prey in above two paths at the same time. To update whale's positions 50% probability is taken for over two techniques.

$$\vec{Z}(t+1) = \begin{cases} \vec{Z}(t) - \vec{A}\vec{D} & if \quad p < 0.5 \\ \vec{D}' e^{bl} \cos(2\pi l) + \vec{Z}(t) & if \quad p \geq 0.5 \end{cases} \quad (11)$$

Search for prey

To get the global optimum values updating has finished with randomly chosen search agent rather than the best agent.

$$D = \left| \vec{c} \cdot \overrightarrow{Z_{rand}(t)} - \vec{Z}(t) \right| \quad (12)$$

$$\vec{Z}(t+1) = \overrightarrow{Z_{rand}(t)} - \vec{A} \cdot D \quad (13)$$

Z_{rand} is the random whales in current iteration. The symbol || signifies the absolute values.

4. Result and discussion

This research investigation intends to identify optimal positioning and sizing of DG's with minimum power loss in IEEE 33 bus systems. Computing these process through manual take a long time and complex, to resolve employing optimization techniques is an appropriate course of action. The primary mode of research includes two-set of operation (i) without DG systems and considering 3-DG systems. While considering 3-DG systems, the investigation consists of three-cases by positioning the load on different (9, 16, and 27) buses. This research also includes the performance of OWOA on heavy, medium, and light load conditions, respectively. It is evident, the incorporation of optimization techniques certainly eradicate the computational complexity. Especially, OWOA attains superior performance over other comparative methods, which is possible because of opposition strategy. IEEE 33 bus system for line and load data, which includes sending and receiving bus numbers, resistance, reactance, load at receiving end bus (real and reactive power). [22] Table.1 exhibits the performance of employed techniques on optimal DG placement, DG's sizing, average bus voltage profile (pu), and real power loss while load applied on the 27th bus. The results from OWOA shows actual power loss as 112.8651 kW, which is 8.7238 kW better than WOA, 11.5332 kW is better than PSO, 19.9449 kW lower than GA, 37.4358 kW lesser than DE. In general, the real power loss from optimization techniques is far better when compared with not considering the DG system. It seems that all voltages are within the desired limits (Vmin = 0.91 pu and Vmax = 1.01 pu).

Case-1, Optimal DG placement for 27th bus loading

Table -2. Technique-wise comparison for optimal DG placement- loading on 27th bus

No. of DG's	Techniques	DG Location (Bus.No)	DG Size (kW)	Average Bus Voltage (pu)	Real power loss (kW)
0	Nil			0.9039	210.016
3	OWOA	19	817	0.9923	112.8651
		4	1088		
		13	1060		
	WOA	2	875	0.9896	121.5889
		26	1110		
		25	1037		
	PSO [16]	20	863	0.9941	124.3983
		3	1203		
		33	1095		
	GA [20]	21	923	0.9916	132.8100
		19	1199		
		28	1117		
	DE [21]	19	925	0.9945	150.3009
		24	1182		
		4	1132		

The following Fig. 3 to 7 exhibits the technique-wise performance of light load (30kW) voltage profile comparison for with and without DG's system.

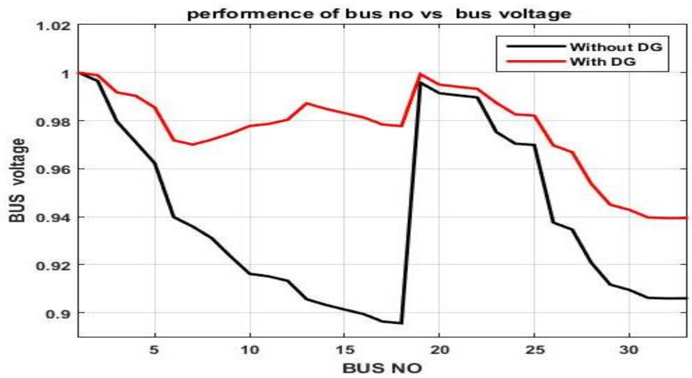

Fig -3. Bus Voltage profile from OWOA for light load

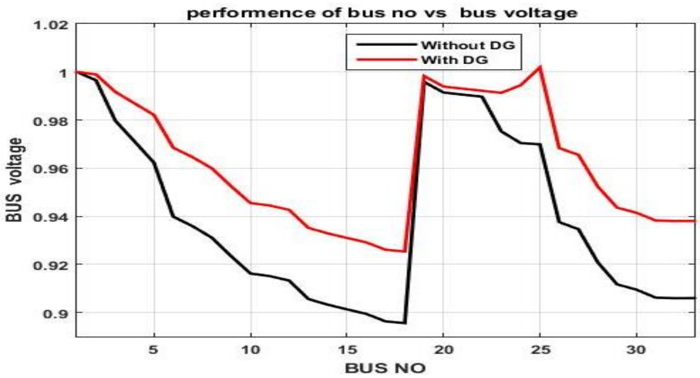

Fig -4. Bus Voltage profile from WOA for light load

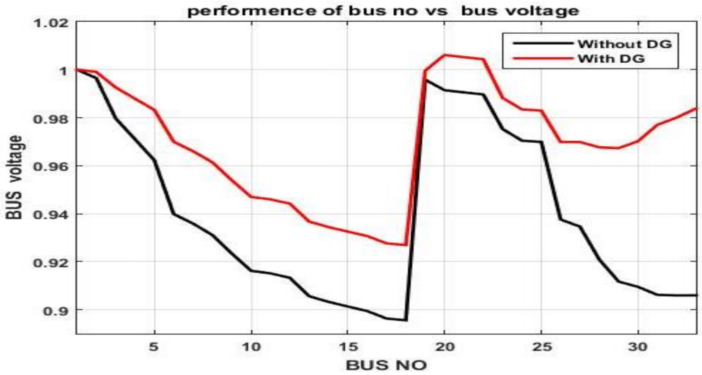

Fig -5. Bus Voltage profile from PSO for light load

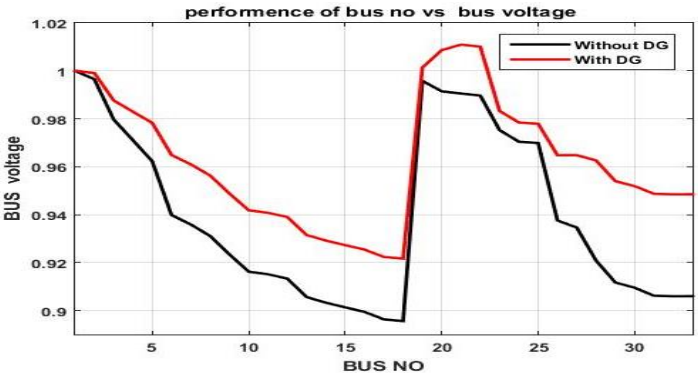

Fig.-6. Bus Voltage profile from GA for light load

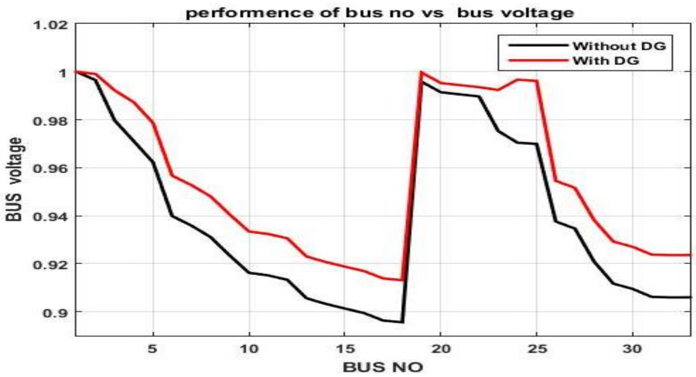

Fig.-7. Bus Voltage profile from DE for light load

The following Fig.8 exhibits the converging performance of employed optimization techniques concerning power loss and iterations. The graph apparent the performance of OWOA in converging the fitness value (power loss: 112.8651kW) by predicting appropriate DG location (19, 4, and 13). OWOA converged at 400th iteration, which is earlier saturation than comparative techniques. OWOA attains superior performance and earlier convergence because of incorporating opposition strategy, which increases the chance of converging.

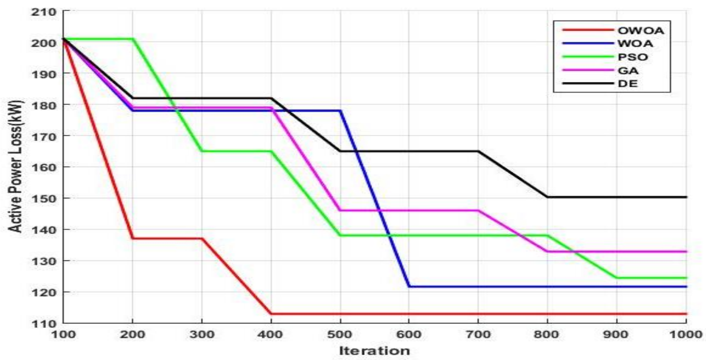

Fig.-8. Techniques-wise convergence performance for light loading on 27th bus

Case-2, Optimal DG placement for 16th bus loading.

Table -2. Technique-wise comparison for optimal DG placement- loading on 16th bus

No. of DG's	Techniques	DG Location (Bus.No)	DG Size (kW)	Average Bus Voltage (pu)	Real power loss (kW)
0	Nil			0.9039	210.016
3	OWOA	23	915	0.9895	104.8028
		3	1045		
		30	1173		
	WOA	21	825	0.9939	119.9052
		23	1187		
		32	1119		
	PSO [16]	23	890	0.9904	120.1393
		20	1058		
		12	1008		
	GA [20]	25	800	0.9948	165.8404
		2	1221		
		3	1059		
	DE [21]	22	832	0.9904	182.5090
		19	1000		
		23	1227		

Table.2 exhibits the techniques-wise optimal DG placement concerning real power loss, along with DG's sizing and average bus voltage profile (pu) while load applied on the 16th bus. The OWOA unveils real-power loss as 104.8028 kW, which is 15.1024 kW lesser than WOA, 15.3365 kW is lower than PSO, 61.0376 kW better than GA and 77.7062 kW superior to DE. This case also proved that employing DG on an appropriate location reduces real power loss significantly over without a DG system. The following figure 9 to 13 exhibits the technique-wise performance of light load (30kW) voltage profile comparison for with and without DG's system. It seems that all voltages are within the desired limits (Vmin = 0.91 pu and Vmax = 1.01 pu).

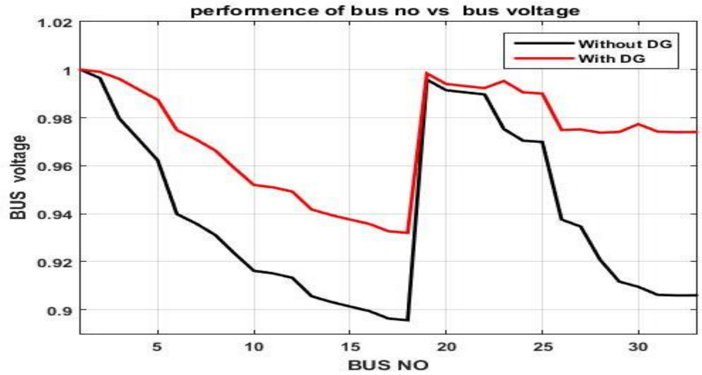

Fig.-9. Bus Voltage profile from OWOA for light load

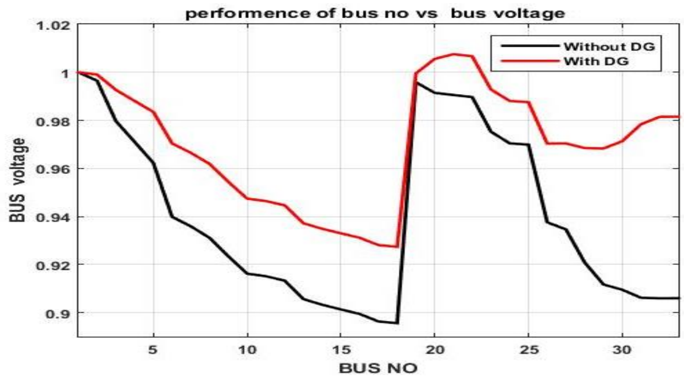

Fig.-10. Bus Voltage profile from WOA for light load

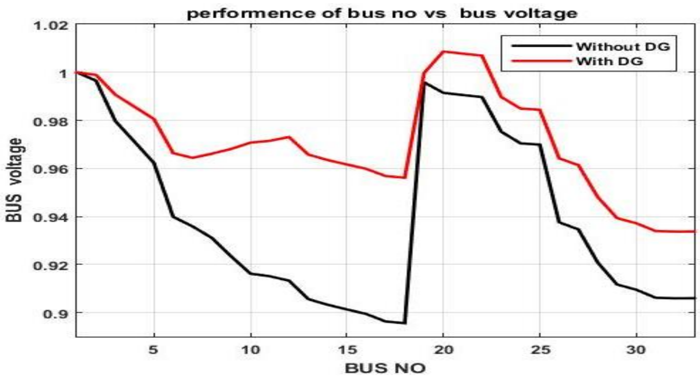

Fig.-11, Bus Voltage profile from PSO for light load

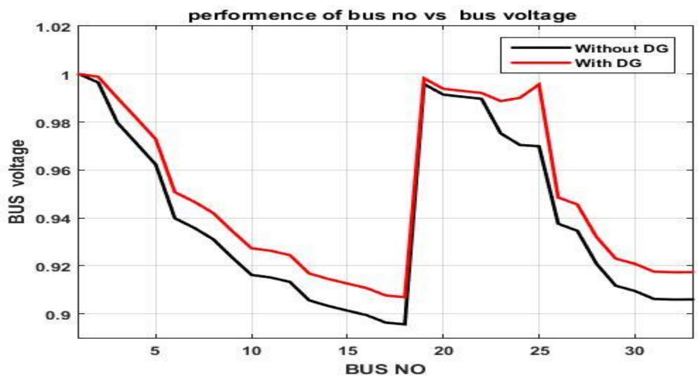

Fig -12. Bus Voltage profile from GA for light load

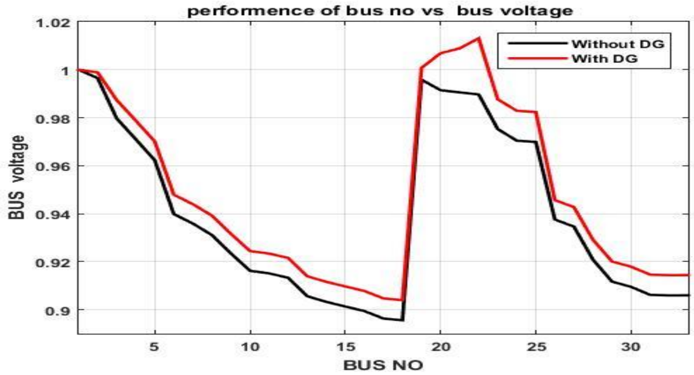

Fig -13. Bus Voltage profile from DE for light load

The following figure.14 displays the converging performance of employed optimization techniques for power loss and iterations. The graph apparent the performance of OWOA in converging the fitness value (power loss: 104.8028kW) by predicting appropriate DG location (23, 3, and 30). OWOA converged at 300th iteration, which is earlier saturation than comparative techniques. OWOA attains superior performance and earlier convergence because of incorporating opposition strategy, which raises the probability of getting an optimal solution at the earliest.

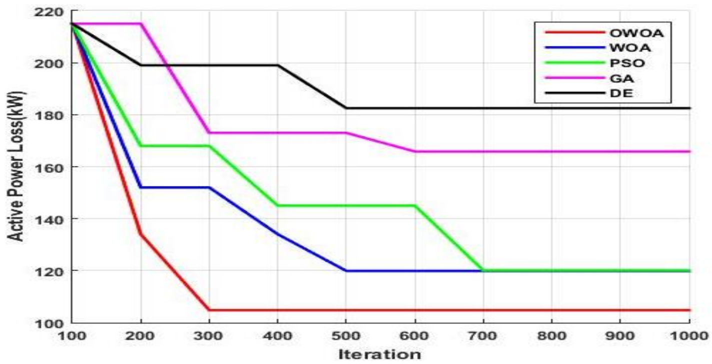

Fig -14. Techniques-wise convergence performance for light loading on 16th bus

Case-3, Optimal DG placement for 09th bus loading

Table -3 Technique-wise comparison for optimal DG placement- loading on 9th bus

No. of DG's	Techniques	DG Location (Bus.No)	DG Size (kW)	Average Bus Voltage (pu)	Real power loss (kW)
0	Nil			0.9039	210.016
3	OWOA	19	878	0.9902	102.0953
		7	1044		
		30	1152		
	WOA	3	809	0.9881	108.2661
		27	1024		
		5	1092		
	PSO [16]	4	892	0.9853	115.8737
		2	1109		
		27	1020		
	GA [20]	21	829	0.9904	117.6709

		5	1132		
		26	1037		
	DE [21]	2	943	0.9964	125.4577
		25	1090		
		32	1210		

Table.4 shows the techniques-wise optimal DG placement to real power loss, along with DG's sizing and average bus voltage profile (pu) while load applied on the 9th bus. The OWOA unveils real power loss as 102.0953 kW, which is 6.1708 kW lesser than WOA, 13.7784 kW lower than PSO, 15.5756 kW better than GA and 23.3624 kW superior to DE. Similarly, this case also proved that employing DG on an appropriate location reduces real power loss significantly over without a DG system.

The following figure 15 to 19 exhibits the technique-wise performance of light load (30kW) voltage profile comparison for with and without DG's system. It seems that all voltages are within the desired limits (Vmin = 0.92 pu and Vmax = 1.01 pu).

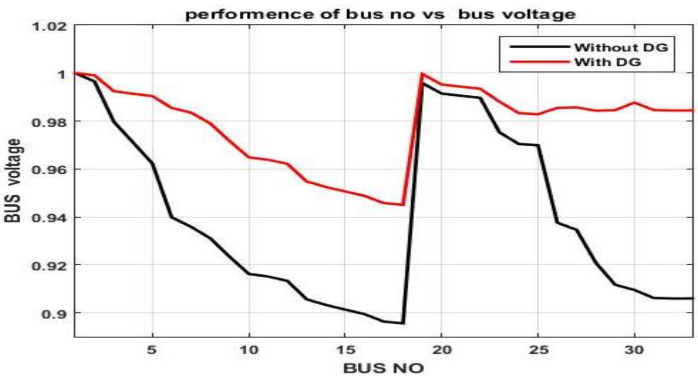

Fig -15. Bus Voltage profile from OWOA for light load

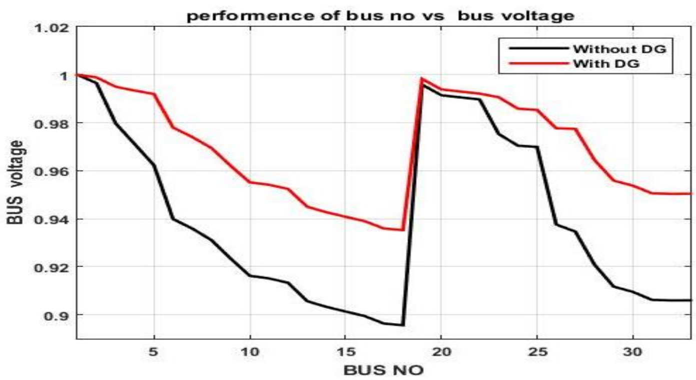

Fig.-16. Bus Voltage profile from WOA for light load

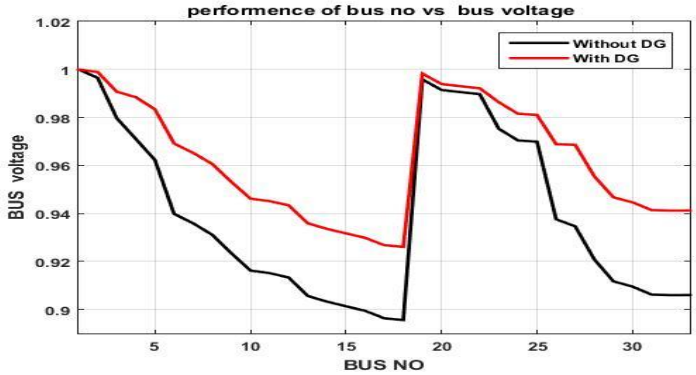

Fig.-17. Bus Voltage profile from PSO for light load

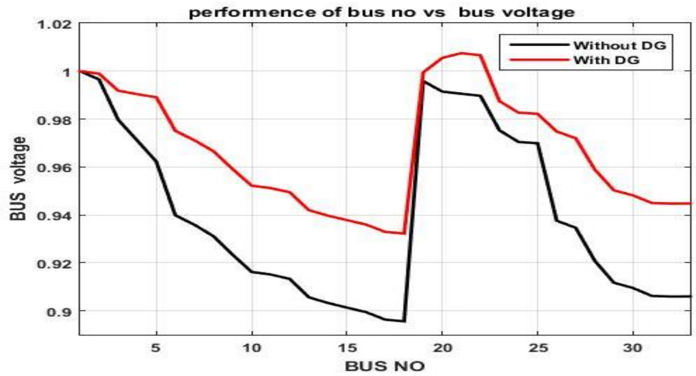

Fig.-18. Bus Voltage profile from GA for light load

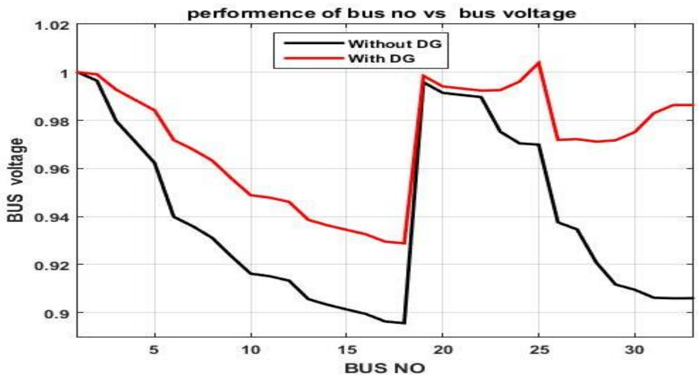

Fig -19. Bus Voltage profile from DE for light load

The following figure.20 shows the converging performance of employed optimization techniques concerning power loss and iterations. The graph apparent the performance of OWOA in converging the fitness value (power loss: 102.0953kW) by predicting appropriate DG location (19, 7, and 30). OWOA converged at 400th iteration, which is earlier saturation than comparative techniques. OWOA attains superior performance and earlier convergence because of incorporating opposition strategy, which increases the probability of getting an appropriate solution.

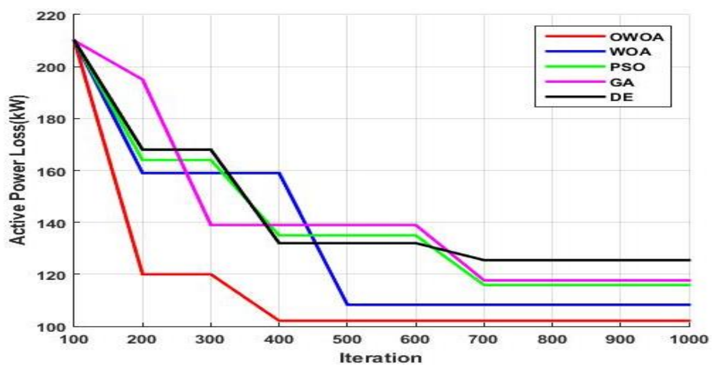

Fig-20. Techniques-wise convergence performance for light loading on 9th bus

Case-4. Optimal DG placement for medium loading condition

Table -4. optimal DG location from OWOA for medium loading condition

No.of DG's	Loading-Location (Bus.No)	DG Location (Bus.No)	DG Size (kW)	Average Bus Voltage (pu)	Real power loss (kW)
3	27	20	944	0.9897	109.6986
		5	1211		
		29	1095		
	16	3	902	0.9892	111.8742
		6	1146		
		23	1228		
	9	19	866	0.9897	106.4776
		26	1012		
		7	1247		

Table.4 illustrates the performance of OWOA in 70kW-medium loading conditions to identify appropriate DG location with respect to different loading bus-position 27, 16, and 9. This table also includes the corresponding DG size for predicted DG's, average bus voltage, and real power loss.

The following figure 21 to 23 evident the difference considering DG over without considering for different loading bus-location. For OWOA, It seems that all voltages are within the desired limits (Vmin = 0.93 pu and Vmax = 1.01 pu).

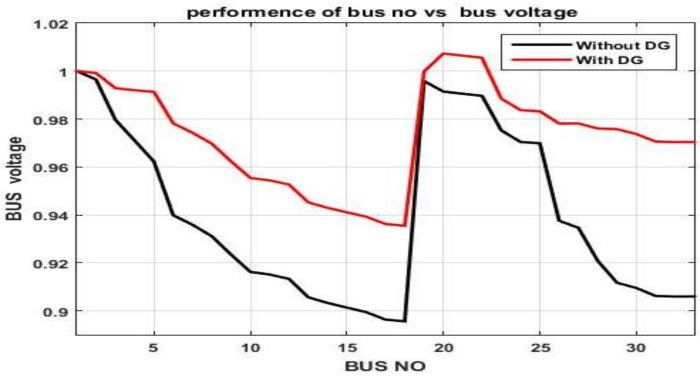

Fig -21. Bus Voltage profile from OWOA for medium loading on 27th bus

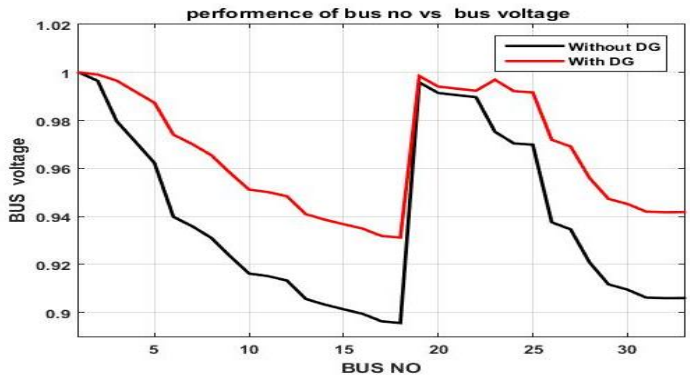

Fig -22. Bus Voltage profile from OWOA for medium loading on 16th bus

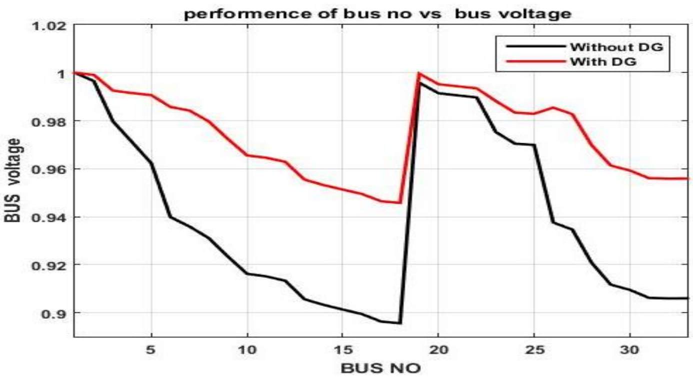

Fig -23. Bus Voltage profile from OWOA for medium loading on 9th bus

Case-5 Optimal DG placement for heavy loading condition

Table -5. optimal DG location from OWOA for heavy loading condition

No.of DG's	Loading-Location (Bus.No)	DG Location (Bus.No)	DG Size (kW)	Average Bus Voltage (pu)	Real power loss (kW)
3	27	24	909	0.9990	115.0565
		9	1176		
		3	1179		
	16	26	882	1	109.4071
		16	1081		
		24	1145		
	9	24	909	0.9913	107.0944
		9	1176		
		3	1179		

Table.5 illustrates the performance of OWOA in 155kW-heavy loading conditions to identify appropriate DG locations for different loading bus-position 27, 16, and 9. This table also includes the corresponding DG size for predicted DG's, average bus voltage, and real power loss.

The following figure 24 to 26 evident the difference considering DG over without considering to different loading bus-location. For OWOA, It seems that all voltages are within the desired limits (Vmin = 0.94 pu and Vmax = 1.01 pu).

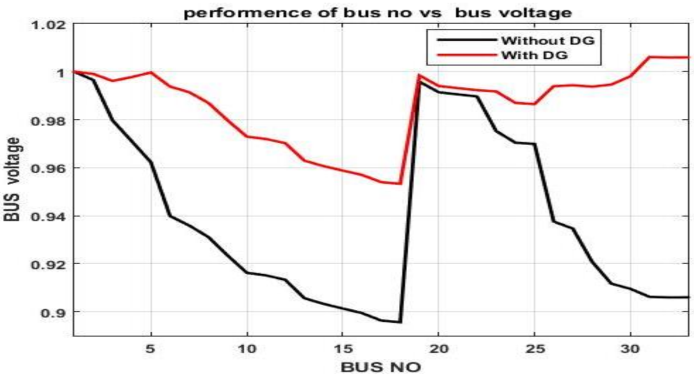

Fig -24. Bus Voltage profile from OWOA for heavy loading on 27th bus

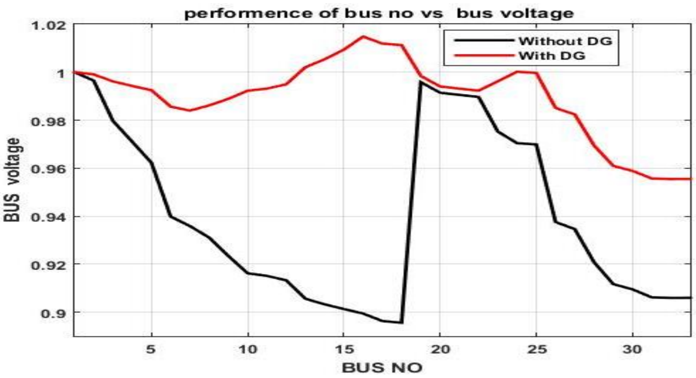

Fig -25. Bus Voltage profile from OWOA for heavy loading on 16th bus

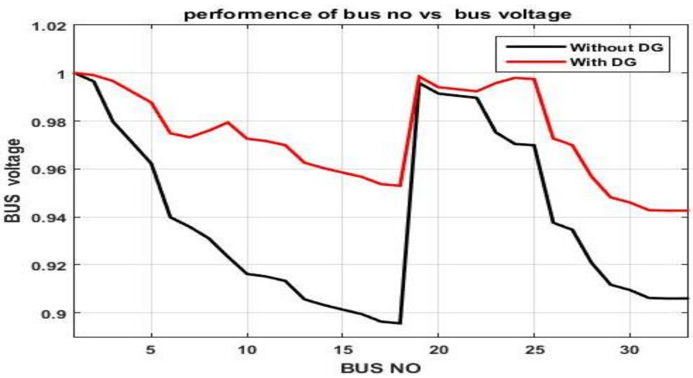

Fig.-26. Bus Voltage profile from OWOA for heavy loading on 9th bus

3. CONCLUSIONS

The purpose of this investigation executes successfully with OWOA by predicting appropriate DG placement in the IEEE-33 BUS system. Incorporation of optimization techniques over trial and error reduces the computational complexity in terms of time and processing. The oppositional strategy includes in conventional WOA certainly increases the probability of finding an optimal solution. The proposed OWOA appropriate bus location positioning DG systems unveils lower real power loss over comparative techniques and attains proficient performance over without the DG system. In case of varying loading condition like light, medium, and heavy and varying loading bus location; the proposed OWOA achieve superior performance over contest techniques.

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