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Whale Optimization Algorithm Based Technique for Distributed Generation Installation in Distribution System

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ABSTRACT

This paper presents Whale Optimization Algorithm (WOA) Based Technique for Distributed Generation Installation in Transmission System. In this study, WOA optimization engine is developed for the installation of Distributed Generation (DG). Prior to the optimization process, a pre-developed voltage stability index termed Fast Voltage Stability Index (FVSI) was used as an indicator to identify the location for the DG to be installed in the system. Meanwhile, for sizing the DG WOA is employed to identify the optimal sizing. By installing DG in the transmission system, voltage stability and voltage profile can be improved, while power losses can be minimized. The proposed algorithm was tested on 30-bus radial distribution network. Results obtained from the EP were compared with firefly algorithm (FA); indicating better results. This highlights the strength of WOA over FA in terms of minimizing total losses.

1. INTRODUCTION

The advancement of distributed generation technology has opened a new era in the smart-grid environment. The presence of smart-grid has witnessed numerous supplies being integrated together so that they can be controlled from a common control center. This can be implemented in the current environment, where internet of things (IoT) has been in the picture recently. DG can be divided into several types, depending on the nature of the power to be injected into the system. DG can be of normal, active power source, reactive power source or combination of both the reactive and active power supplies. Several studies have been conducted in DG [1]-[11].

One of the most important work is the one conducted by N. Acharya *et al*. [1] where an analytical approach for DG allocation in primary distribution network was conducted. In this study, the contribution of DG in Denmark and the Netherlands has reached 37% and 40%, respectively. M. Shahzad *et al*. [2] and T. Gzel *et al*. [3] have addressed DG installation in the radial distribution system. In [2], Besides, there has been a dense research for investigating the technical aspects of power system with DGs including voltage profile improvement, active power loss minimization, power quality issues, reliability, protection and stability over the last two decades. Presently, voltage stability has been a concern in power system network. This phenomenon can be alleviated by the installation of DG in a power system.

Environmental pollution, increasing technical and commercial losses, growing power quality disturbance and reliability of the network are the identified factors for voltage stability in a power system network. However, environmental pollution is considered not a technical problem, rather a human factor issue or even geographical issue. Most of these researches concluded that above mentioned benefit(s) can be acquired by optimizing the size and location of the DGs in the network. Various approaches have been invented to identify the most suitable solution in addressing the optimum DG placement for minimizing the power losses in the power system. This can be listed as the classical approach: second-order algorithm method, the meta-heuristics approaches: genetic algorithm and Hereford Ranch algorithm, fuzzy-GA method, tabu search, and the analytical approaches [3].

The current scenario has witnessed instability issues in the system which are high power loss and poor voltage profiles, which also suffers of increase in power losses. Optimization techniques are substantially important since the incorrect sizing or location of DG installation would lead to over-compensation or under-compensation. Among the popular optimization methods are ant colony optimization (ACO), evolutionary programming (EP), bee colony optimization (BCO), particle swarm optimization (PSO), firefly algorithm (FA) and genetic algorithm (GA). In [4], to find the optimal placement of DG and recloses based on system reliability, ACS (Ant Colony Search Algorithm) has been implemented. For optimum placement considering the minimum electricity cost for consumers, Particle Swarm Optimization algorithm (PSO) was applied in [6]. In [7], the best location for DG with maximum profit as an objective function has been considered. In this study, dynamic based programming approach was the suitable approach. For optimal sizing and placement of DG, considering different objective functions, Genetic Algorithm (GA) based methods have been proposed in [9],[10].

From the numerous literatures, it has indicated that optimization technique is important. Meta-heuristic optimizing algorithm for DG placement and the application line of the Fast Voltage Stability Index (FVSI) is one of the studies which dealt with optimization process. A previous study by M. M. Aman *et al.* in [11] has used the continuation power flow method to determine the most voltage-sensitive bus in the distribution system which could results in voltage instability in the system. DG is placed on the identified sensitive bus and the size of DG on that bus is increased gradually till the objective function (voltage constraints) is achieved. The proposed algorithm which is Whale Optimizing Algorithm (WOA) also working on the same objective function for DG allocation. The developed index is used to identify the most critical bus in the system that can lead to system voltage instability when load increase above a certain limit. The DG is placed on the identified bus. The search algorithm is used for estimating the size of DG considering minimum network losses. Overall, this proposed method is simpler and requires less computational time for determining the optimum placement and size of DG as compared to classical search algorithms.

This paper presents a whale optimization algorithm-based technique for distributed generation installation on the distribution system. The objective of this study is to minimize the total power losses in the transmission system. This is implemented by optimizing the size of DG. The developed WOA optimization engine has been compared with respect to firefly algorithm. It is revealed that WOA outperformed FA in minimizing the total transmission loss.

2. METHODOLOGY

2.1. Proposed Method for Optimal DG Placement in Transmission System

Under normal conditions, FVSI value should be closer to zero. If the value of FVSI is higher or closer to 1, the system is unstable. Meanwhile, if the value of FVSI is closer to zero, the system is more stable. The bus with high FVSI value is more sensitive and suitable for optimal allocation DG placement. Figure 1 shows the process of FVSI in identifying the most stressful bus and suitable location for DG placement. When reactive power is injected, the line losses in the system will increase resultant to the outage. Hence, every loading condition, the program will read and interpret the bus data, and line data in the bus system. FVSI will be computed by using the load flow solution. Bus data will be sorted from highest to lowest value. After the power flow solution was applied, the next step is to determine the optimum DG placement by using FVSI. The highest value of FVSI will indicate the most suitable location of DG when the value is closer to unity which means that is the weakest bus in the system.

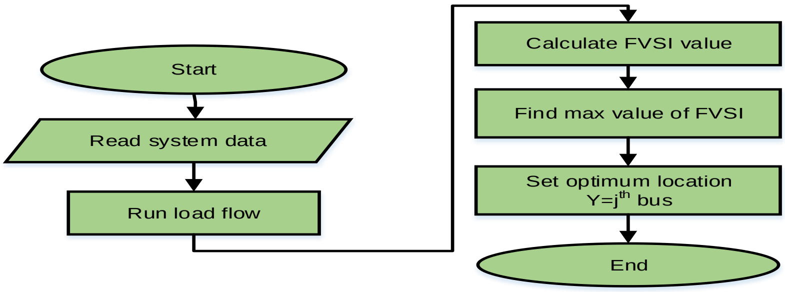

Figure 1. Flow chart of FVSI process

2.2. Problem Formulation

In this paper, there is some condition that has to be met in order to minimize the power losses by using the proposed algorithm. The algorithm as follows:

2.2.1. Encircle the Prey

To encircle the prey, humpback whales can recognize the location of prey. The WOA algorithm anticipates that the current best candidate solution is the target prey or is close to the optimum, since the position of the optimal design in the search space is not known a priori. Thus, this behavior is defined as follows:

$$\vec{D} = \left|\vec{C}.\overrightarrow{X^*}(t) - \vec{X}(t)\right| \tag{1}$$

$$\vec{X}(t+1) = \overrightarrow{X^*}(t) - \vec{A}.\vec{D} \tag{2}$$

$$\vec{A} = 2\vec{a}.\vec{r} - \vec{a} \tag{3}$$

$$\vec{C} = 2.\vec{r} \tag{4}$$

where $\vec{A}$ and $\vec{C}$ are coefficient vector, $\overrightarrow{X^*}$ is the position vector of the best solution, "." is element-by-element value, $\overrightarrow{D'}$ indicates the distance of the ith whale to the prey (best solution obtained so far), $\vec{r}$ as a random vector in [0,1] and $\vec{a}$ is known as the course of iterations when linearly decreased from 2 to 0 (in both exploitation and exploration phases).

2.2.2. Bubble-net Attacking Method (Exploitation Phase)

2.2.2.1. Shrinking Encircling Mechanism

By decreasing the value of $\vec{a}$ in the Equation 3, the behavior is achieved. Plus, the value of $\vec{A}$ will decrease $\vec{a}$ decreased. Hence, $\vec{A}$ as a random value between the interval [-a,a] and set the random values for $\vec{A}$ in [-1,1]. Figure 2(a) shows the possible positions from (X,Y) towards (X*,Y*) which is humpback whale and prey position that can be achieved by $0 \leq A \leq 1$ in a 2D space.

2.2.2.2. Spiral Updating Position

The distance between the whale and prey is calculated as shown in Figure 2(b). Then, from the figure, spiral equation is developed as follows:

$$\vec{X}(t+1) = \overrightarrow{D'}.e^{bl}.\cos 2\pi l + \vec{X}(t) \tag{5}$$

is element-by-element value, $\overrightarrow{D'}$ indicates the distance of the ith whale to the prey (best solution obtained so far), b is a constant for defining the shape of the logarithmic spiral, l is random number in [-1,1].

Note that humpback whales hunt their prey by either shrinking in circle form or spiral-shaped path simultaneously. To develop this simultaneous behavior, we should assume that there is a probability 50 percent chance that whales will hunt either use shrinking method or spiral-shaped method to update the position of whales during optimization. Below shows the mathematical model:

$$\vec{X} = \begin{cases} \overrightarrow{X^*}(t) - \vec{A}.\vec{D} & if\ p < 0.5 \\ \vec{D}.e^{bl}.\cos 2\pi l + \vec{X}(t) & if p \geq 0.5 \end{cases} \tag{6}$$

where p is a random number in [0,1].

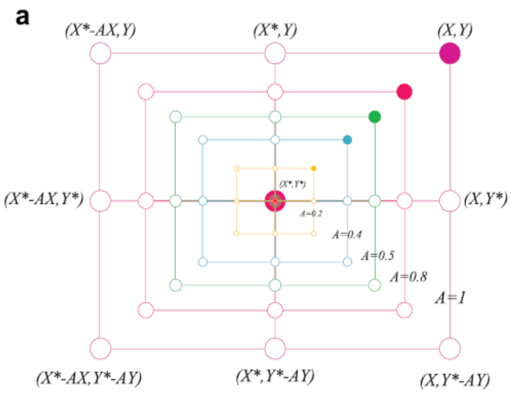

Figure 2 (a). Shrinking encircling mechanism

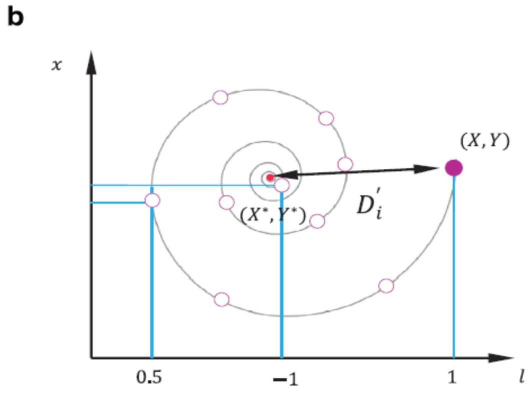

Figure 2(b). Spiral updating position

2.2.3. Search for Prey (Exploration Phase)

In this technique, the same approached is used as exploitation to utilize the prey. Hence, $\vec{A}$ is used with the random values higher or less than 1 and -1 in order to force the search agent away from reference whale or leader. If $\vec{A}$>1 will emphasize exploration and allows the WOA to perform global search. Equation 7 and 8 show the mathematical model global search:

$$\vec{D} = \left|\vec{C}.\overrightarrow{X_{rand}}(t) - \vec{X}\right| \tag{7}$$

$$\vec{X}(t+1) = \overrightarrow{X_{rand}} - \vec{A}.\vec{D} \tag{8}$$

where $\overrightarrow{X_{rand}}$ is a random position vector (a random whale) chosen from the current population. Figure 3 below shows the exploration mechanism implanted in WOA. (X* is randomly chosen search agent).

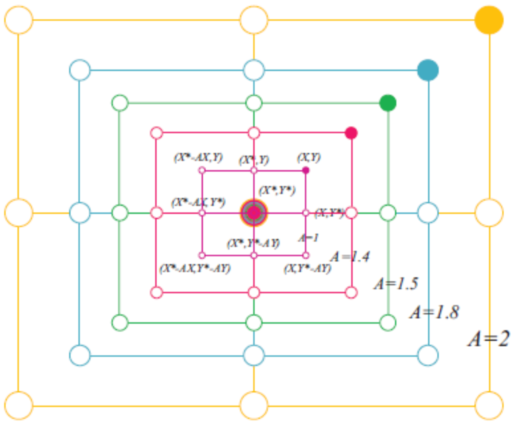

Figure 3. Exploration mechanism implanted in WOA

In addition, in order to minimize the power losses and maximize the voltage profile and stability, Figure 4 will show the steps on how it is improved.

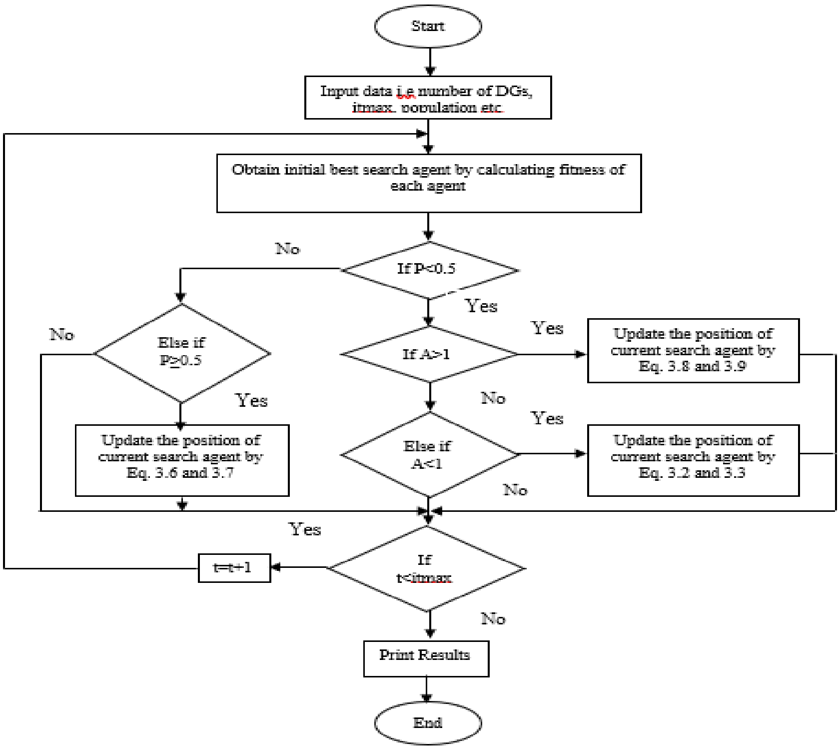

Figure 4. Flowchart of proposed algorithm

Based on the Figure 4, the input data should be initalized before excutes the algorithm. Then, the initial search agents should be obtained by calculating fitness of each agent in the bus system. After the search agents have been obtained, there are some condition that should be met in order to proceed the searching of the prey. For $p < 0.5$, the search agents, which are humpback whales in this algorithm will start their hunt by using either two methods, Bubble-Net Attacking Method (exploitation phase) which are shrinking encircling mechanism the prey or spiral-shaped updating position when $\vec{A}<1$, thus will update the position of current search agents by Equation 1 and 2. Apart from that, if $\vec{A}\geq1$, means that emphasize exploration and allow WOA algorithm to perform global search by updateing the position of current search agents by Equation 7 and 8. If random value $p \geq 0.5$, it will update their position based on Equation 5 and 6 as stated earlier. Hence, if the condition is met, it will iterate until the condition of itmax is achieved and last but not least, it will stop the process and print the results as it optimal solution have been achieved.

3. RESULTS AND DISCUSSION

In this research, 30-bus system was used to test the stability and losses in the transmission system. Optimization was conducted by considering the variance of loading load and comparison between other algorithms which is Firefly Algorithm (FA) in order to test the proposed algorithm. In this study, there are two cases to be considered, Case A and Case B.

3.1. Single Installation

Table 1 tabulates the effects of variation of loading condition, Mvar towards V_{min}, V, P_{loss} (MW) and $FVSI_{max}$ where number of search agents, N is 20, number of iterations is 200 and subjected load bus namely bus 4 and 6. Based on the Table 1, the result can be analyzed that before and after the installation of DG at selected load bus 4. The difference can be seen that after DG was installed, all the variables are optimized. The system was improved as the voltage profile and stability increased. Meanwhile the power losses in the system have been reduced significantly. This shows that, as the loading condition is varied, the losses increased while the voltage reduced significantly. By injecting DG, the problem has been optimized. Other than that, the value of $FVSI_{max}$ shows that after installation of DG, the line data become more stable rather than without DG installation. Figure 5, Figure 6 and Figure 7 would illustrate the voltage profile, real power losses and voltage stability in a system as a result of installing DG at the selected bus.

Table 1. The Effects of Variation of Loading Condition, Mvar towards V_{min}, V, P_{loss} (MW) and $FVSI_{max}$ at Bus 4

Loading Condition (Mvar)	Condition	V_{min} (V)	P_{loss}(MW)	$FVSI_{max}$	Q_{DG}
1.6	Without DG	0.9945	17.5985	0.2035	0
(Base Case)	With DG	1.0001	17.4851	0.1550	34.6240
50	Without DG	0.9863	18.2650	0.2682	0
	With DG	0.9956	17.5397	0.1936	34.6228
100	Without DG	0.9862	19.8376	0.3529	0
	With DG	0.9648	18.2788	0.2691	34.6220
150	Without DG	0.9227	22.4314	0.4160	0
	With DG	0.9756	18.8847	0.3136	34.6212
200	Without DG	0.8963	25.6642	0.4916	0
	With DG	1.0039	17.6694	0.1480	34.6241
250	Without DG	0.8691	30.1873	0.5783	0
	With DG	0.9791	18.5021	0.2911	34.6212

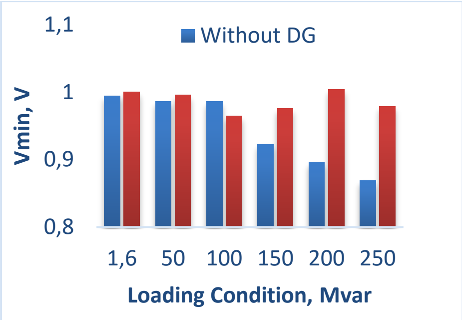

Figure 5. Voltage profile without and with DG at bus 4

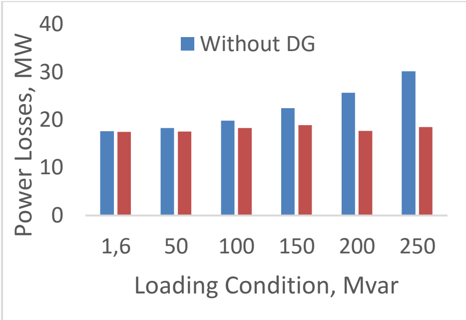

Figure 6. Real power losses without and with DG at bus 4

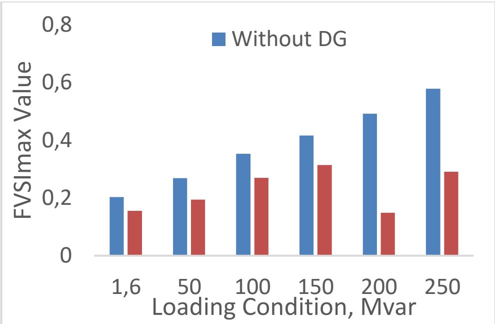

Figure 7. Voltage stability without and with DG at bus 4

Bar chart in Figure 5 illustrated that the variation of voltages in the system as a result installing DG and loading condition were varied at bus 4. The bar chart shows clearly the result of variation as the loading condition increased. Bar chart in Figure 6 illustrated that the variation of real power losses in the system as a result installing DG and loading condition were varied at bus 4. The bar chart shows clearly the result of variation as the loading condition increased. Bar chart in Figure 7 illustrated that the variation of voltage stability in the system as a result installing DG and loading condition were varied at bus 4. The bar chart shows clearly the result of variation as the loading condition increased.

Based on the Table 2, the result can be analyzed that before and after the installation of DG at selected load bus 6. The difference can be seen that after DG was installed, all the variables are optimized. The system was improved as the voltage profile and stability increased. Meanwhile the power losses in the system have been reduced significantly. This shows that, as the loading condition is varied, the losses increased while the voltage reduced significantly. By injecting DG, the problem has been optimized. Other than that, the value of $FVSI_{max}$ shows that after installation of DG, the line data become more stable rather than without DG installation.

Table 2. The Effects of Variation of Loading Condition, Mvar towards $V_{min,}$ V, P_{loss} (MW) and $FVSI_{max}$ at Bus 6

Loading Condition (Mvar)	Condition	V_{min} (V)	P_{loss} (MW)	$FVSI_{max}$	Q_{DG}
Base Case	Without DG	0.9945	17.5985	0.2035	0
	With DG	0.9894	17.7522	0.2193	23.6663
50	Without DG	0.9781	18.0165	0.2396	0
	With DG	0.9982	17.5643	0.1960	23.6651
100	Without DG	0.9502	19.1391	0.2948	0
	With DG	0.9900	17.7315	0.2179	23.6682
150	Without DG	0.9313	20.5680	0.3303	0
	With DG	1.0000	17.5757	0.1923	23.6657
200	Without DG	0.9213	22.0172	0.3577	0
	With DG	0.9806	17.9103	0.2341	23.6596
250	Without DG	0.9110	23.9601	0.3870	0
	With DG	0.9947	17.5940	0.2030	23.6638

Figure 8, Figure 9 and Figure 10 illustrate the voltage profile, real power losses and voltage stability in a system as a result of installing DG at the selected bus. Bar chart in Figure 8 illustrated that the variation of voltages in the system as a result installing DG and loading condition were varied at bus 6. The bar chart shows clearly the result of variation as the loading condition increased. Bar chart in Figure 9 illustrated that the variation of real power losses in the system as a result installing DG and loading condition were varied at bus 6. The bar chart shows clearly the result of variation as the loading condition increased. Bar chart in Figure 10 illustrated that the variation of voltage stability in the system as a result installing DG and loading condition were varied at bus 6. The bar chart shows clearly the result of variation as the loading condition increased.

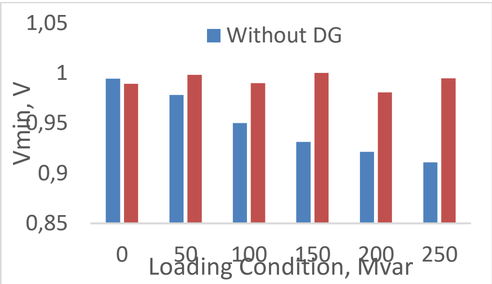

Figure 8. Voltage profile without and with DG at bus 6

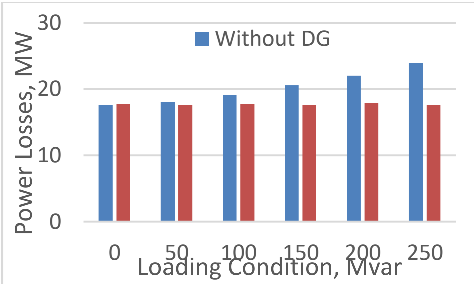

Figure 9. Real power losses without and with DG at bus 6

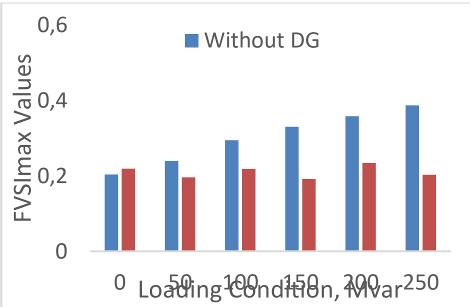

Figure 10. Voltage stability without and with DG at bus 6.

3.2. Case B: Comparison with other Algorithm which is Firefly Algorithm (FA)

To determine the optimum size of DG, the proposed algorithm is applied and the results are tabulated in Table 3 and Table 4 where number of search agents, N is 20, number of iterations is 200 and subjected load bus namely bus 29. The results were than compared with the results conducted using FA and tabulated in Table 3 and Table 4, from where it could be seen the close agreement of the proposed method with existing one.

Table 3. Application of Proposed Algorithm on Transmission Networks

Bus System	Proposed Algorithm (WOA)			
	Max FVSI Values	Bus number	Vmin	Optimum Size
30	0.3232	29	0.8799	17.5576

Table 4. Application of Firefly Algorithm on Transmission Networks

Bus System	Firefly Algorithm (FA)			
	Max FVSI Values	Bus number	Vmin	Optimum Size
30	0.3256	29	0.9111	18.7927

Based on the result from Table 3 and Table 4, the proposed WOA algorithm is better than FA. It could be observed that the proposed method results are in closes agreement with FA. Other than that, optimum size for WOA is less than FA which is better in minimizing power losses.

4. CONCLUSION

In this paper, a new proposed is proposed for DG placement and sizing. The DG placement and sizing is based on FVSI index to identify the most sensitive voltage and minimum total power losses. Plus, using new proposed algorithm has improved the voltage profile, stability and minimize power losses in the system which have been proved in result and discussion. The proposed algorithm is tested with 30-bus system radial transmission system and the results are verified with Firefly algorithm (FA). Overall findings for this research are the voltage profile has improved and the voltage stability has increased, power losses have minimized and the overall capacity system has increased.

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