International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-12, October 2019

Voltage Control and Power Loss Reduction in Distribution Networks using Distributed Generation

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Abstract*: Distributed generation (DG) units can provide many benefits when they are incorporated along the distribution network/system. These benefits are more if DG units are connected at suitable nodes with appropriate rating otherwise, they may cause to increased power loss and poor voltage profile. In this work, optimal allocation (both location and size) problem is solved by considering power loss minimization as an objective function. An analytical method "index vector method (IVM)" is applied to find DG location. A new optimization algorithm "Whale Optimization Algorithm (WOA)" is employed to determine the DG rating. Two popularly known test systems "IEEE 33 & IEEE 69"bus systems are used to evaluate the efficacy of IVM and WOA.

Keywords: **Distributed generation, Distribution system, Index vector method, Power loss reduction, Whale optimization algorithm.**

I. INTRODUCTION

Distribution network/system is an integral part of power system that joins high voltage sub-transmission system to the low voltage consumers. With ever increasing demand for electrical energy, distribution network needs continuous expansion to meet the increasing load demand. According to Indian records 20% of total power generation is wasting at distribution level. Distributed Generation (DG) is the main and one of the alternatives to meet ever increasing load demand and decrease power loss at distribution level. Integration of DG units into the distribution network can provide numerous environmental, technical and economic benefits to the consumers as well as distribution companies. Many studies proved that the above said benefits can be achieved only if the DG units are placed at optimal locations with optimal size otherwise DG leads to negative impacts.

Revised Manuscript Received on October 30, 2019.
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DGs are categorized as follows [1]:

Type-1 DG: These DGs can inject only P (active power) into the system.

Type-2 DG: These DGs can inject only Q (reactive power) into the system.

Type-3 DG: These can inject P in to the system and consume Q from the system.

Type-4 DG: These can inject P as well as Qin to the system.

So in this work optimal sitting and sizing problem in distribution network is solved by taking power loss reduction as main objective function. This paper is organized as follows: section one gives the introduction about distribution network, DG and also presents literature survey. Section two presents the analytical method called index vector method used to identify the optimal DG locations. Section three explains and models the whale optimization algorithm used to find the optimal rating of DG unit. Section four presents the simulation results and finally section five gives the final conclusions.

II. INDEX VECTOR METHOD

In this work, optimal DG locations (bus or node) in a given distribution network are found by using index vector method [1]. Index vector values at each bus excluding reference bus of a system are found by using equation (1). The normalized voltages calculated by the given equation (2) at each and every bus of a network are also considered to select the optimal DG locations. The bus with the highest index value and normalized voltage less than 1.01 will be on top priority to place DG. The index vector of a given system can be calculated as follows:

$$\text{Index Vector}(n)=\frac{1}{V(n)^2}+\frac{I_q(k)}{I_p(k)}+\frac{Q_{eff}(n)}{Q_{total}} \quad (1)$$

Normalized voltages are determined as follows:

$$\text{Normalized voltage, } V_{nor}(n)=\frac{V(n)}{0.95} \quad (2)$$

Where

Index vector (n) = index value at bus 'n'

V(n) = voltage magnitude of bus 'n'

Ip(k) = Real component of current flowing through branch 'k'

Iq(k) = Imaginary component of current flowing through branch 'k'

Qeff(n) = Effective reactive load at bus ‘n’
Qtotal = Sum of reactive loads of system

III. WHALE OPTIMIZATION ALGORITHM

Whale optimization algorithm (WOA) [2] is a new bio inspired, population based optimization technique developed in 2016 by the scientists namely S. Mirjalili and Lewis. Whales are the biggest mammals in the planet and they will not move fast enough to follow and catch a school fish during hunting. Therefore, they exhibit a unique hunting method called “bubble net hunting technique” to catch a school of fish or pray. In this method, humpback whales generate air bubbles around the prey or a school of fish along the circular or spiral shaped path. As it can be viewed in “Fig. 1” [3], the radius of the bubble net continuously decreases towards the water surface. The humpback whales forces or directs a school of fish towards the surface of the water and attacks them when they are close to the surface of water. Therefore, this unique technique simplifies the hunting process. The bubble net hunting technique has been simulated in WOA.

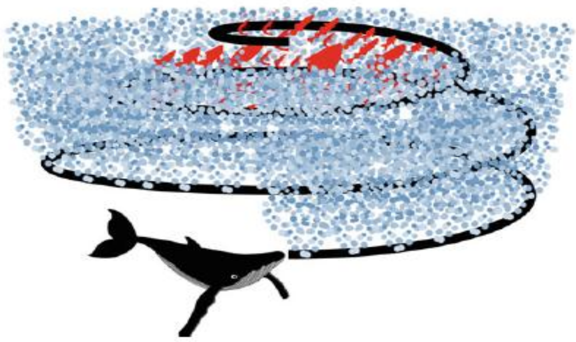

Fig.1. Bubble net feeding technique

The hunting behavior of humpback whales can be explained and modeled in three sections as follows:

A. Encircling Prey

Humpback whales can predict the location of prey and encircle them. At starting, humpback whales assume the current best candidate solution as the location of prey and the remaining whales update their position towards the best solution. This behavior is modeled as follows:

$$\vec{D}=|\vec{C}.\vec{X}^*(t)-\vec{X}(t)| \quad (3)$$

$$\vec{X}(t+1)=\vec{X}^*(t)-\vec{A}.\vec{D} \quad (4)$$

The values of vectors ‘$\vec{A}$’ and ‘$\vec{C}$’ are determined using equations (36) and (37)

$$\vec{A}=2.\vec{a}.\vec{r}-\vec{a} \quad (5)$$

$$\vec{C}=2.\vec{r} \quad (6)$$

Where‘t’ denotes the current iteration ‘$\vec{A}$’ and ‘$\vec{C}$’ represents coefficient vectors X $^{\rightarrow}$* is position vector of the prey or best solution ‘$\vec{X}$’ is current position. Where ‘$\vec{a}$’ value linearly decreases from 2 to 0 over the succeeding iterations and ‘$\vec{r}$’ is a random vector in [0,1].

B. Bubble net attacking method

In this phase, humpback whales (search agents) moves closer to the prey (best solution agent). The bubble net attacking technique can be mathematically modeled using the following two approaches:

1) Shrinking encircling mechanism

This SEM presented in “Fig.2” is achieved by decreasing the value of ‘$\vec{a}$’ in expression (5) and hence the value of ‘$\vec{A}$’ also decreases by ‘$\vec{a}$’. Now, the next position of a search agent (whale) can be assigned anywhere in between the original position of the search agent and the position of the existing best agent by assigning random values for ‘$\vec{A}$’ in [−1,1].

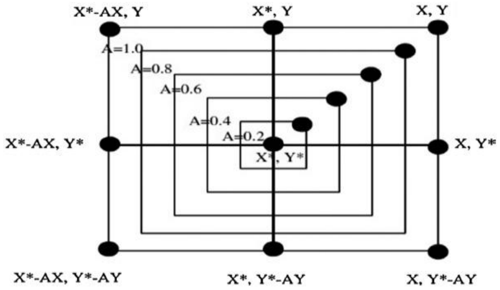

Fig.2. Shrinking encircling mechanism

2) Spiral updating position

In this phase presented in “Fig.3”, the distance between the (X, Y) (whale position) and (X*, Y*) (prey position) is calculated and then a spiral equation is formed using expression (7).

$$\vec{X}(t+1)=D'.e^{bl}.\cos(2\pi l)+\vec{X}^* \quad (7)$$

Where ‘$D'=|\vec{X}^*-\vec{X}(t)|$’ represents the distance between the (X, Y) and (X*, Y*) and variable ‘l’ is a random number between -1 and 1.

During hunting process, humpback whales moves in spiral shaped as well as shrinking circle path simultaneously and hence we consider 50% probability between both shrinking circling and spiral model. Now the updated position is determined using the below equation (8).

$$\vec{X}(t+1)=\begin{cases}\vec{X}^*(t)-\vec{A}.\vec{D} & \text{if } P<0.5\\ D'.e^{bl}.\cos(2\pi l)+\vec{X}^* & \text{if } p\geq 0.5\end{cases} \quad (8)$$

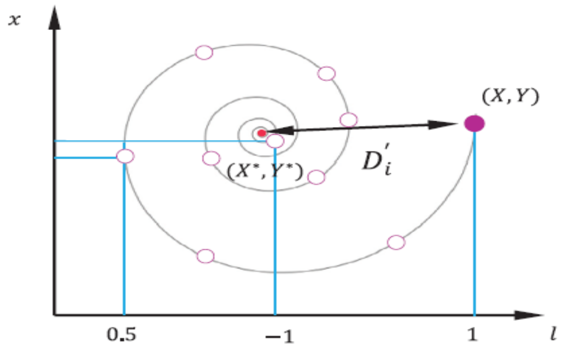

Fig.3. Spiral updating position mechanism

C. Search for Prey

To make the algorithm global optimizer when less than one or greater than one the search agent (whale) is updates its position according to a randomly selected search agent instead of the best search agent.

$$\vec{D} = |\vec{C}.\vec{X}rand - \vec{X}| \quad (9)$$

$$\vec{X}(t+1) = \vec{X}rand - \vec{A}.\vec{D} \quad (10)$$

IV. RESULTS AND ANALYSIS

Two popularly used test systems in the literature are used to test and evaluate the efficacy of proposed techniques.

Test system#1: A popularly known IEEE 33-bus system is considered as test system 1. The data including branch and load data are taken from [1]. It consists of one feeder, 33 nodes/buses, 32 lines/braches and operates at 12.66 KV. The sum of real and reactive loads of system is 3.715 MW and 2.3 MVAr, respectively. Without any compensation, the real and reactive losses are 210.99 KW and 143.03 KVAr. Index vector values of this test system are graphically presented in "Fig.4". As it can be viewed from "Fig.4", the bus 30 is having the highest index value and its normalized voltage in "Fig.5 is also less than 1.01 and hence it is selected as candidate node/bus to connect DG.

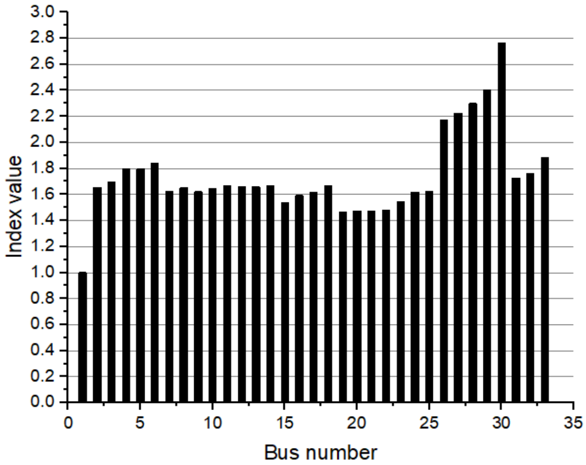

Fig.4. Index vector profile for IEEE 33-bus system

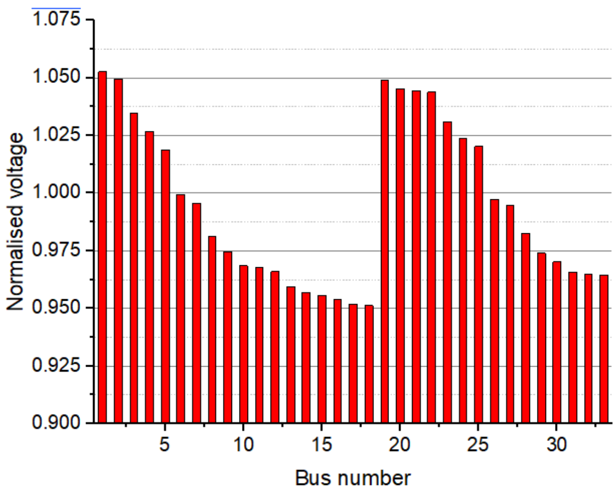

Fig.5. Normalised voltage profile of IEEE 33-bus system

The optimized results of IEEE 33-bus system with the proposed WOA algorithm are recorded in "Table-I". The results include DG size in kilowatts, real power loss (Ploss), reactive power loss (Qloss), minimum voltage level (Vmin) and total voltage deviation (Vdevi). From the results it is clear that the power losses after the placement of type-4 DG is very less when compared to other types of DGs. Power losses are very less with type-4 DG because it injects active power as well as reactive power at connected bus. The actual reduction in real power loss after the placement of type-1, 2, 3 and 4 DGs are 40.67%, 28.25%, 7.18% and 65.12%, respectively. The minimum voltage level at bus 18 is greatly improved with type-4 DG when compared to other DG types. The reduction in total voltage deviation is also superior with type-4 DG unit. Figure 6 shows the graphical representation of voltage profile of IEEE 33-bus system with and without DG.

Table-I: Results of IEEE 33-bus system

	Without DG	With DG			
		Type-1	Type-2	Type-3	Type-4
DG location	NA	30	30	30	30
DG size	NA	1542.67 KW	1257.99 KVAr	631.83 KVA	1976.20 KVA
P_{loss}(KW)	210.99	125.16	151.37	195.84	73.59
Q_{loss}(KVAr)	143.03	89.28	103.81	134.00	55.68
Vmin (p.u)	0.9038	0.92723	0.91648	0.9086	0.93941
Vdevi	1.8051	1.1137	1.4263	1.6637	0.74551

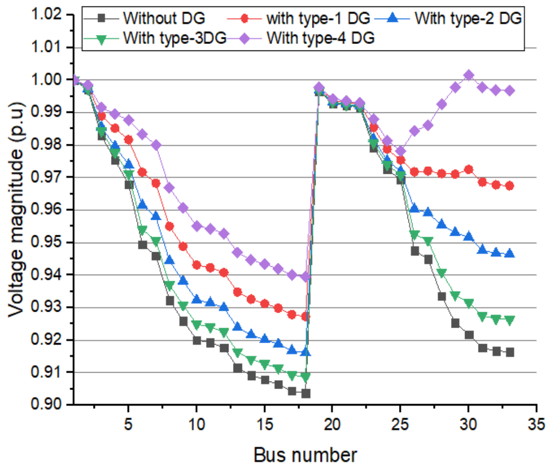

Fig.6. Voltageprofile of IEEE 33-bus system

"Fig.7" visualizes the convergence curves of a WOA when applied for test system 1. From the convergence curves it is clear that the proposed WOA can converge in very less number of iterations.

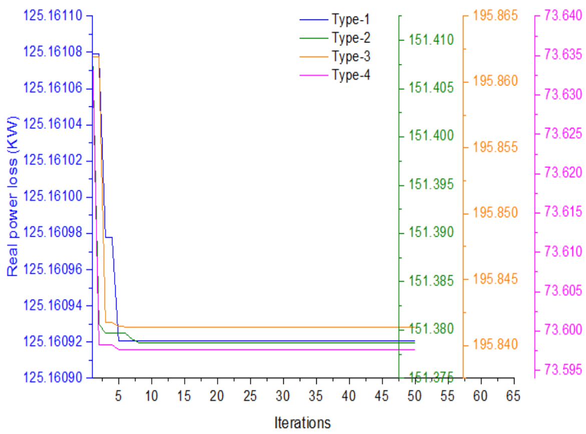

Fig.7. Convergence characteristics of WOA for IEEE 33-bus system

Test system#2: IEEE 69-bus system is taken as second test system. The system data including line/branch data and load/bus data is obtained from [1]. It consists of 69 nodes/buses, 68 branches/lines and operates with 12.66 KV. Total network loads are 3802.19 KW and 2694.6 KVAr. "Fig. 8" and "Fig. 9" represents index vector profile and normalized voltage profile of a IEEE 69-bus system. From the index vector profile it is very clear that bus 61 is having highest index value and from normalized voltage profiles its normalized voltage is also less than 1.01. Hence, bus 61 is selected to place DG units.

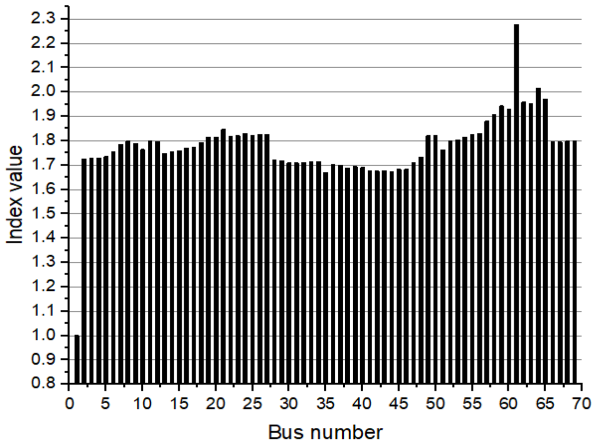

Fig.8. Index vector profile for IEEE 69-bus system

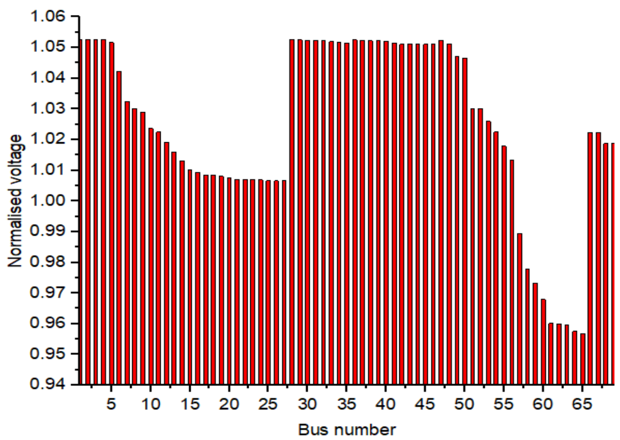

Fig.9. Normalized voltage for IEEE 69-bus system

The optimized results of IEEE 69-bus system with the proposed WOA algorithm are recorded in "Table-II". The results include DG size in kilowatts, real power loss (Ploss), reactive power loss (Qloss), minimum voltage level (Vmin) and total voltage deviation (Vdevi). From the results it is clear that the power losses after the placement of type-4 DG is very less when compared to other types of DGs. Power losses are very less with type-4 DG because it injects active power as well as reactive power at connected bus. The actual reduction in real power loss after the placement of type-1, 2,3 and 4 DGs are 63.01%, 32.42%, 12.43% and 89.70%, respectively. The minimum voltage level at bus 65 is greatly improved with type-4 DG when compared to other DG types. The reduction in total voltage deviation is also superior with type-4 DG unit. "Fig. 10" shows the graphical representation of voltage profile of IEEE 69-bus system with and without DG.

Table-II: Results of IEEE 69-bus system

	Without DG	With DG			
		Type-1	Type-2	Type-3	Type-4
DG location	NA	61	61	61	61
DG size	NA	1872.70 KW	1329.99 KVAr	813.41 KVA	2223.86 KVA
P_{loss}(KW)	225	83.22	152.04	197.63	23.16
Q_{loss}(KVAr)	102.17	40.52	70.49	90.28	14.37
Vmin (p.u)	0.90918	0.96831	0.93072	0.92598	0.97247
Vdevi	1.8388	0.8822	1.5093	1.6147	0.5867

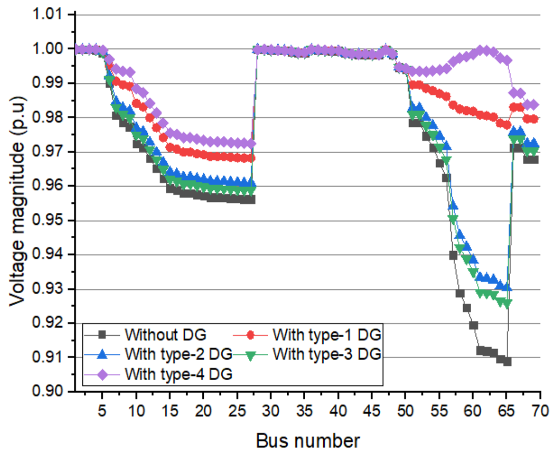

Fig.10. Voltage profile of IEEE 69-bus system

"Fig. 11" visualizes the convergence curves of a WOA when applied for test system 2. From the convergence curves it is clear that the proposed WOA can converge in very less number of iterations.

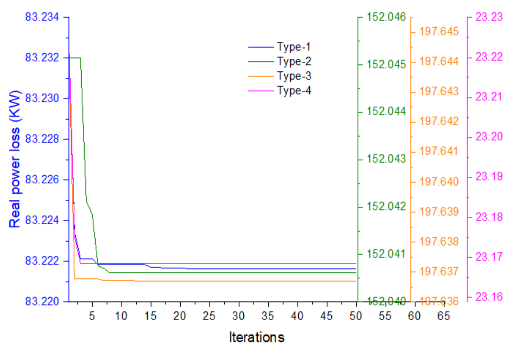

Fig.11. Convergence characteristics of WOA for IEEE 69-bus system

V. CONCLUSION

Power loss reduction and voltage control are considered as main objectives in this work. This objectives are reached by optimal placement and sizing of different types of DG units. Optimal DG locations are found by using analytical method called index vector method (IVM) and optimal rating are found by optimization technique called 'whale optimization algorithm' (WOA). The proposed IVM and WOA are tested on two popularly used test systems namely IEEE 33 & 69 bus systems. Finally, it is observed from the results that type-4 DG performs well as compared to other types of DGs in view of power loss reduction and voltage profile improvement.

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Sabarinath.G received his B.Tech and M.Tech degrees in Electrical and Electronics Engineering from JNT University Anantapuramu, India. Currently, he is pursuing his full-time Ph.D in electrical engineering in S.V.University, tirupathi. His research areas include power electronics, electrical drives, power quality issues in distribution systems, distributed generation and soft computing techniques.

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