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Optimal placement of different DG units type in distribution networks based on voltage stability maximization and minimization of power losses

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Abstract—**In recent years, distributed generation units became attractive due to its technical, economic and environmental benefits. This paper dealt with the optimal placement and sizing of DG units in radial distribution networks. For this purpose, three kinds of this latest have been employed (injection of active power, injection of reactive power and injection of both powers together). Then, a new optimization technique known as: Bat Algorithm is employed using the Total Active Power Losses as a performance index. Investigation was carried out on the standard 33, 69 buses test feeders. Simulation results demonstrate the effectiveness and the robustness of the proposed methodology. Obtained results are compared with recently published work.**

Keywords—Distributed Generation (DG); Bat algorithm (BA); Power losses; Voltage stability index.

I. INTRODUCTION

Distributed Generations (DGs), a term generally used for small-scale power generation (1 kW to 50 MW) connected to local distribution systems, but they can have a significant impact on system performance and quality of power supply for customers and electricity suppliers [1]. However, DG unit inauguration in distribution systems requires a proper placement and size. Thus, optimal location plays a major role in minimizing the losses through appropriate installation and sizing which can be achieved by using optimization techniques.

Recently, the DG has been exploited by many researchers in the distributed radial network due to its efficiency in power losses reduction, power system reliability enhancement and its low costs [2]. Different attempts were made up in the literature for its corresponding location and sizing based on traditional and meth-heuristics techniques. The authors in [3] have employed an analytical approach for the optimum DG unit location for minimizing active power losses. Further, the authors in [4] have developed a new analytical method for the voltage profile enhancement and compensation of active power losses. Optimal siting and sizing of capacitor for real power loss reduction in distribution feeder systems, using 2/3 rule has been presented in [5]. In Ref. [6] the authors determine the optimal allocation of DG and capacitor by the applications of Grid search technique to reduce the real power loss. The authors in [7] have proposed a meta-heuristic called Ant bee colony (ABT) algorithm for reducing the active power losses in radial power network. In [8], the authors presented mixed-PSO for optimal allocation of distributed generation in distribution networks considering different loading conditions. Other prepositions in [9] based on the installation of the capacitor bank to minimize the total power losses and net saving maximization using a novel optimization algorithm. Furthermore, the authors in [10] have proposed a multi-objective optimization problem for improving the transient stability using a hybrid evolutionary algorithm. The practical swarm optimization (PSO) and non-dominated sorting genetic algorithms II (NSGA-II) techniques have been demonstrated in [11–12] to find the optimal size and location of DG to minimize the total active power losses and enhancement in voltage stability index.

In fact, different types of the DG's can also be categorized on the basis of their terminal characteristics into four major types as follows [4]:

Type-1: DG units capable of injecting active power only (P), such as fuel cells, photovoltaic cells etc.

Type-2: DG units capable of injecting reactive power only (Q), such as synchronous compensator and capacitors

Type-3: DG units capable of injecting both active and reactive power (P&Q), such as Voltage Source Convertor (VSC) based DG unit and synchronous machine based DGs are in this group.

Type-4: DG units capable of injecting active power (P) but consuming reactive power (Q), such as induction generators used in wind farms.

In this paper, we assume that integrate type-1, type-2 and type-3 DG units in the distribution network.

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The present study describes the employment of new metaheuristic called Bat algorithm (BA) for the optimal location and sizing of various types of DG units in radial distribution networks. For this purpose, the BA has been employed to compensate the total active power losses. The algorithm is recently developed which has simple implementation and less parameters setting to be tuned as compared to other heuristic algorithms. The investigated algorithm has been carried out on 33 and 69 bus radial systems.

The remainder of this paper is organized as follows: In Section 2, the methodology is presented for optimum DG placement and sizing. In Section 3, the necessary background and fundamentals of the BA and the implementation of the proposed BA are described. Section 4 presents the subject of the point estimated method, modeling wind and load uncertainty in power systems. Finally, Section 5 the proposed algorithm is tested on two different test feeders. The proposed algorithm is also compared with other existing methods. All results are discussed and summarized in the same section.

II. PROBLEM FORMULATION

A. Objective functions

1) Minimization of power losses: Reducing the total power losses of distribution network is a significant goal of implementing sources, which can be formulated as follows [13]:

$$H_1 = \sum_{i=2}^{N_{bus}} P_{loss}(i) = \sum_{i=2}^{N_{bus}} r_i |I_i|^2 \tag{1}$$

where N_{bus} is the number of buses, r_i and I_i are the resistance and the current magnitude of *i th* the bus, respectively.

2) Voltage Stability Index: Under power systems planning and operation the voltage stability is one of the most important security indices. DG has a profound impacted on the voltage stability index and it will be changed by integrating DG. Chakravorty and Das in [14] proposed a stability index for finding the bus, which is most sensitive to voltage collapse in the system. The one line diagram is shown in Fig. 1. The second fitness function for voltage stability index can be defined as follows:

$$H_2 = \frac{1}{1 + SI_i} \tag{2}$$

$$SI_i = V_{i-1}^4 - 4\cdot(P_i x_i - Q_i r_i)^2 - 4\cdot(P_i r_i + Q_i x_i)^2 \cdot V_{i-1}^2 \geq 0 \tag{3}$$

where SI_i is the stability index for node *i* (*2,3,…, N_{bus}*), V_{i-1} is voltage of node *i-1*, P_i and Q_i are total active and reactive power load fed through at *i* bus, x_i is reactance of branch *i*, and r_i is resistance of branch *i*.

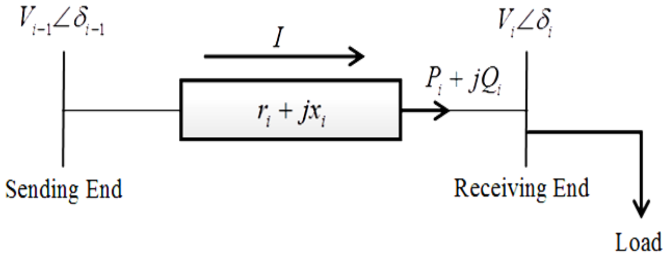

Fig. 1. A two-bus system one line diagrams.

B. Constraints

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1) Equality Constraints: For every bus, the following power flow equations must be satisfied:

$$\begin{cases} P_{Gi} - P_{Di} - V_i \cdot \sum_{j=1}^{N_{bus}} V_j \cdot Y_{ij} \cdot \cos(\theta_{ij} + \delta_j - \delta_i) = 0 \\ Q_{Gi} - Q_{Di} - V_i \cdot \sum_{j=1}^{N_{bus}} V_j \cdot Y_{ij} \cdot \sin(\theta_{ij} + \delta_j - \delta_i) = 0 \end{cases} \quad i = 1,2,3,\ldots,N_{bus} \tag{4}$$

Where P_{Gi} and Q_{Gi} are the active (resp. reactive) power generated at the each bus; P_{Di} and Q_{Di} are the active and reactive load demand at the every bus, respectively. P_i and Q_i are the active and reactive power at bus *i*, Y_{ij} and θ_{ij} are the admittance magnitude (resp. angle) of branch connecting bus *i* and *j*.

2) Inequality Constraints

a) Voltage constraint: The voltage at each bus in the network should be within the acceptable margin. In this study, the voltage variations are set at 0.90 pu and 1.05 pu, respectively.

$$V_{\min} \leq V \leq V_{\max} \tag{5}$$

Where V_{min}, V_{max} are the lower and upper limits of bus voltage, respectively.

b) Active power losses constraint: The losses after installing DG in power grid should be less than or equal losses before installing DG.

$$PL \text{ with } DG \leq PL \text{ without } DG \tag{6}$$

*c) Distributed generation size constraint:*The active and reactive power generated by each DG unit must be less than the total active and reactive loads of the network, respectively. as following:

$$0 \le size\ of\ DG(P_{DG}) \le \sum_{i=1}^{N_{bus}} P_{Di} \quad (7)$$

$$0 \le size\ of\ DG(Q_{DG}) \le \sum_{i=1}^{N_{bus}} Q_{Di} \quad (8)$$

where P_{Di} and Q_{Di} are the active and reactive load demand at the same bus.

III. MULTI OBJECTIVE OPTIMAL PLACEMENT AND SIZING OF DEFFERENT DGS (MO-OPSDGS)

Numerous methods are available to solve multi-objective optimization problems such as weighted sum approach [15], e-constraint method [16], and evolutionary algorithms [17]. In this paper, the proposed multi-objective model of the MO-OPSDGs is solved using the weighted sum method. In this method, several weights are used for the conflicting objective functions to generate different Pareto optimal solutions and then the several weights selects the most satisfactory solution from the optimal Pareto set. Hence, the overall objective function is the weighted sum of individual objective functions as follows:

$$Min(H) = w_1 H_1 + w_2 H_2 \quad (9)$$

Where

$$w_1 + w_2 = 1 \quad (10)$$

Since the both objective functions H_1 and H_2 are not in the same dimension and range, a fuzzy satisfying method is used to calculate the normalized form of the objective functions in (12). The fuzzy membership of every objective function maps it to the interval [0,1]. More generally, the *i-th* objective function of H_i is normalized as follows.

$$H_{m,pu}^{(k)} = \begin{cases} 1 & H_m^{(k)} \le H_m^{\min} \\ \dfrac{H_m^{\max} - H_m^{(k)}}{H_m^{\max} - H_m^{\min}} & H_m^{\min} \le H_m^{(k)} \le H_m^{\max} \\ 0 & H_m^{(k)} \ge H_m^{\max} \end{cases} \quad \begin{matrix} \forall m = 1,2,\ldots,n \\ \forall k = 1,2,\ldots,D \end{matrix} \quad (11)$$

In this paper for objective functions Eqs. (2) and (4), a fuzzy membership function is expressed as follows:

$$P_{loss\,pu} = H_{1.pu} = \frac{P_{loss}^{\max} - P_{loss}}{P_{loss}^{\max} - P_{loss}^{\min}} \quad (13)$$

$$SI_{pu} = H_{2.pu} = \frac{SI^{\max} - SI}{SI^{\max} - SI^{\min}} \quad (14)$$

After running the MO-OPSDGs for different values of weighting factors, to select the best compromising solution, fuzzy satisfying method based on logistic membership function is used. After normalization the objective functions best solution is obtained as follows.

$$BCS = \underset{k}{Max}(\mu^k) = \underset{k}{Max}\left(\frac{P_{loss\,pu}^{(k)} + SI_{pu}^{(k)}}{\sum_{k=1}^{D} P_{loss\,pu}^{(k)} + \sum_{k=1}^{D} SI_{pu}^{(k)}} \right) \quad (15)$$

IV. PROPOSED ALGORITHM

Bat Algorithm is a nature inspired metaheuristic algorithm implemented by Yang, is inspired by echolocation of microbats. Echolocation is typical sonar which bats utilize to search prey and to avoid obstacles. These bats emit very loud sound pulse and listen for the echo that bounces back from the surrounding objects [18]. Thus a bat can compute how far they are from an object. Moreover bats can distinguish dramatically between an obstacle and a prey even in complete darkness [19]. In order to transform these characteristics of bats to algorithm, Yang idealized some rules [20]:

- All bats use echolocation to sense distance, as well as they also recognize the difference between food/prey and background barriers in some magical manner;
- Bats fly randomly with velocity v_i at position x_i with a frequency f_{min}, varying wavelength and loudness A_0 to look for prey. They can routinely tune the wavelength (or frequency) of their emitted pulses and adjust the rate of pulse emission $r \in [0, 1]$, depending on the proximity of their target; and
- Although the loudness can vary in many manners, we assume that the loudness varies from a great (positive) A_0 to a least constant value Amin.

The frequency factor controls step size of a solution in BA. This factor is assigned to random value for every bat (solution) between lower and upper limits [f_{min}, f_{max}]. Velocity of a solution is proportional to frequency and new solution rest on its new velocity.

$$f_i = f_{\min} + (f_{\max} - f_{\min}) \cdot \beta \quad (16)$$

$$v_i^k = v_i^{k-1} + (x_i^k - x^*) \cdot f_i \quad (17)$$

$$x_i^k = x_i^{k-1} + v_i^k \quad (18)$$

Where $\beta \in [0,1]$ indicates randomly generated number, x^* represents current global best solutions.

For local search part of algorithm (exploitation) one solution is selected among the selected best solutions and random walk is applied.

$$x_{new} = x_{old} + \varepsilon A^t \quad (19)$$

Where A^t is average loudness of all bats at this time step ε is a random number in the interval [0, 1].

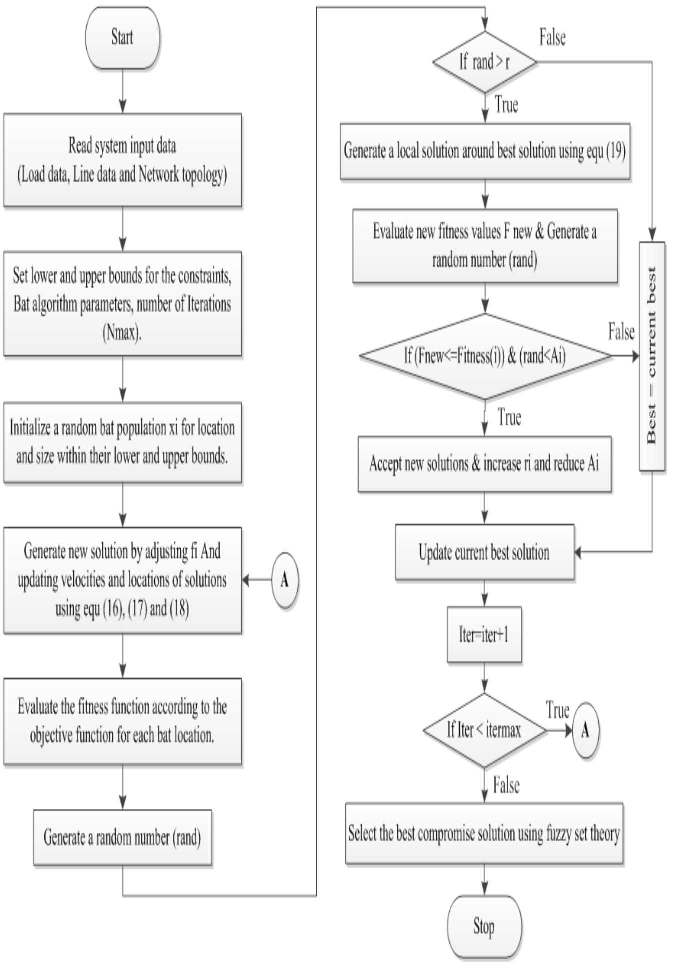

Fig. 2. BA flowchart for DG unit placement and sizing.

V. RESULTS AND DISCUSSION

The proposed algorithm in the present investigation has been tested on two different test feeders. The first feeder used in this paper is a 33-bus radial distribution network with total load of 3.72 MW and 2.3 MVAr [21] and the second one is 69-bus radial distribution network with a total load of 3.80 MW and 2.69 MVAr [22]. The optimization has been carried out in on an Intel Dual-core™ PC with 2.10-GHz speed and 2 GB RAM.

In this study two cases have been analyzed. The first case considers the optimal allocation is based on minimization of the active power losses independently. Table I shows the optimal placements of different DG units' placement by the proposed algorithm for both the test feeders. Furthermore, the results for the PSO method [12] and IA method [10] are also presented for comparison purposes. It is observed from the results, in the first distribution feeder the optimal location is the same in the all approaches but the size are slightly changed. In the second test system, bus 61 is the best location for installation of different types of DG.

In the second case minimization of active power losses and maximization of voltage stability are considered together into the fitness function. The detailed analysis of the results obtained for this case has been presented in the Table II. The results obtained from the proposed algorithm of type-1are also compared with the PSO algorithm [12] and NSGA-II method [17]. For different types DGs location the optimal buses for 33 and 69-bus feeders are found to be 7 and 61 respectively.

It can be observed from Table I and Table II that the TAPL for 33 and 69-bus test feeders have been reduced after installation of the various types DGs in both cases but has been significantly in the first case. Improving up to (type-1: 11.48%, type-2: 8.15% and type-3: 3.65%) and (type-1: 9.41%, type-2: 9.43% and type-3: 12.25%) in each of the 33 and 69-bus networks respectively.

Figs. 3, 5 and 7, 9 show the voltage profile before and after the allocation of different types DGs for 33 and 69-bus distribution feeders for the Case I and Case II, respectively. From these last, it is demonstrated that the voltage profile improvement of the test feeders and the voltage levels at every bus for the networks are improved and placed in an acceptable range.

Figs. 4, 6 and 8, 10 show the voltage stability indices without and with of various types DGs for 33 and 69-bus test feeders for the Case I and Case II, respectively. The graphical representation of VSI results shows the presence of DGs enhances the voltage stability of the test feeders but have to enhance the largest in the second case.

Through the column the last in a Table I and II, the different types DG units location have also increased the loadability of the system. However the improvement is the greatest in the second case. Allowing by adding more loads without experiencing the problem of voltage collapse.

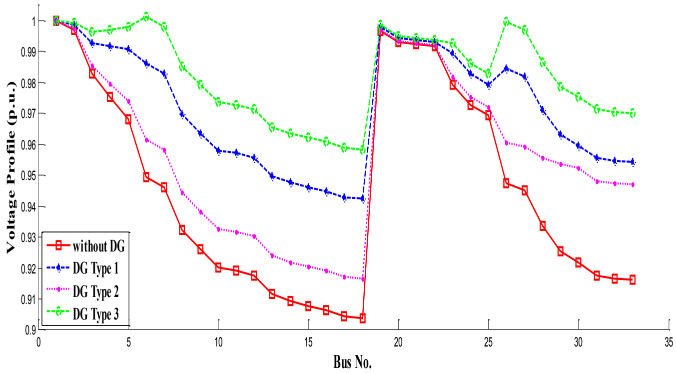

Fig. 3. Voltage profile for 33 bus test system (Case 1)

TABLE I. IMPACT OF DG PLACEMENT ON SYSTEM PERFORMANCE USING PROPOSED ALGORITHM ON THE CASE 1.

Test system	DG type	Approach	Installed DG units		Ploss (kW)	TAPLR (%)	Min(SI)	System loadability
			Bus	*Size*				
33 Bus	**No DG**				**211**		**0.6672**	**3.40**
	Type-1	BA	6	2.5902	111	47.40	0.7886	3.70
		PSO [8]		2.5903	111	47.40	0.7886	
		IA [4]		2.49	111.17	47.31	0.7838	
	Type-2	BA	30	1.2580	151.38	28.25	0.7055	3.58
		PSO [8]		1.2583	151.38	28.25	0.7055	
		IA [4]		1.24	151.39	28.25	0.7050	
	Type-3	BA	6	3.099	67.87	67.83	0.8431	3.84
		PSO [8]		3.099	67.87	67.83	0.8431	
		IA [4]		3.014	67.98	67.78	0.8381	
69 Bus	**No DG**				**225**		**0.6833**	**3.20**
	Type-1	BA	61	1.8827	83.56	63.29	0.8793	3.94
		PSO [8]		1.8827	82.56	63.29	0.8793	3.94
		IA [4]		1.81	83.36	62.86	0.8778	3.92
	Type-2	BA	61	1.3299	152.04	32.43	0.7504	3.48
		PSO [8]		1.3299	152.04	32.43	0.7504	
		IA [4]		1.33	152.04	32.43	0.7504	
	Type-3	BA	61	2.245	23.17	89.70	0.8945	4.22
		PSO [8]		2.279	23.26	89.65	0.8952	4.24
		IA [4]		2.235	23.18	89.69	0.8943	4.22

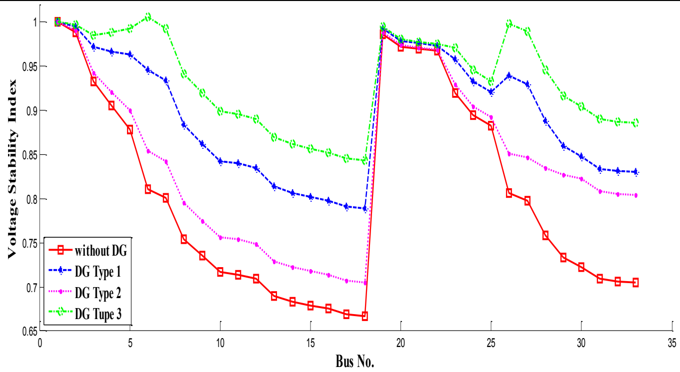

Fig. 4. Voltage stability for 33 bus test system (Case 1)

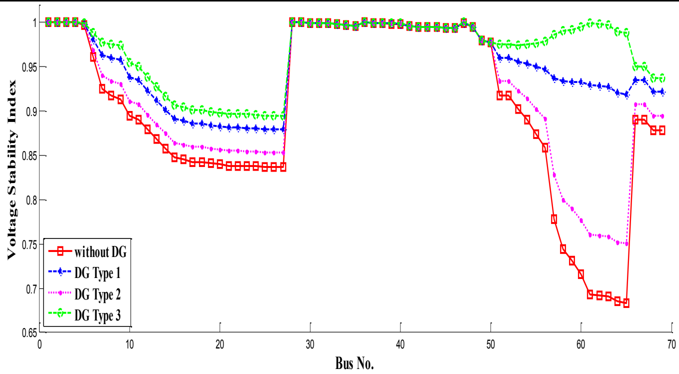

Fig. 6. Voltage stability for 69 bus test system (Case 1)

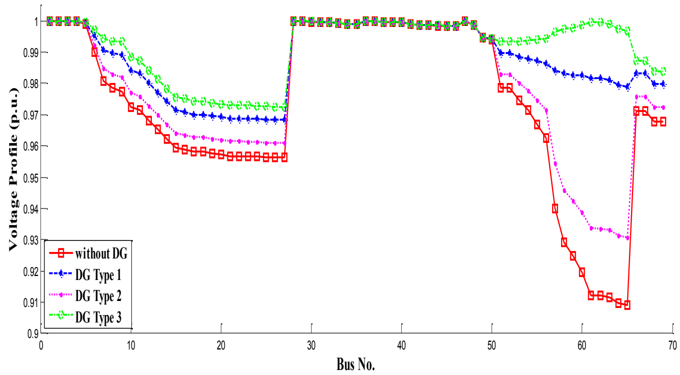

Fig. 5. Voltage profile for 69 bus test system (Case 1)

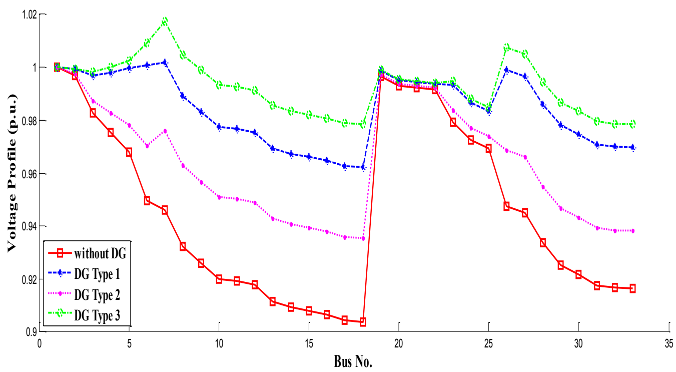

Fig. 7. Voltage profile for 33 bus test system (Case 2)

TABLE II. IMPACT OF DG PLACEMENT ON SYSTEM PERFORMANCE USING PROPOSED ALGORITHM ON THE CASE 2.

Test system	DG type	Approach	Installed DG units		Ploss (kW)	TAPLR (%)	Min(SI)	System loadability
			Bus	*Size (Mega)*				
33 Bus	**No DG**				**211**		**0.6672**	**3.40**
	Type-1	MOBA	7	3.7150	135.20	35.92	0.8573	3.88
		NSGA II [12]		3.7150	135.20	35.92	0.8573	3.88
		PSO [11]		2.8951	114.89	45,55	0.8149	3.78
	Type-2	MOBA	7	2.30	168.59	20.10	0.7653	3.62
	Type-3	MOBA	7	3.6190	75.56	64.18	0.9162	4
69 Bus	**No DG**				**225**		**0.6833**	**3.20**
	Type-1	MOBA	61	2.6598	103.75	53.88	0.8955	4.24
		NSGA II [12]		2.6638	103.96	53.80	0.8956	4.24
		PSO [11]		2.0264	84.04	62,65	0.8824	4.03
	Type-2	MOBA	61	2.0726	173.27	23	0.7849	3.62
	Type-3	MOBA	61	3.1758	50.74	77.45	0.9168	4.66

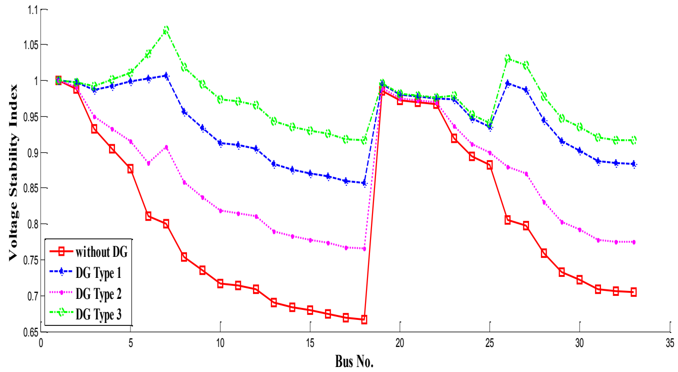

Fig. 8. Voltage stability for 33 bus test system (Case 2)

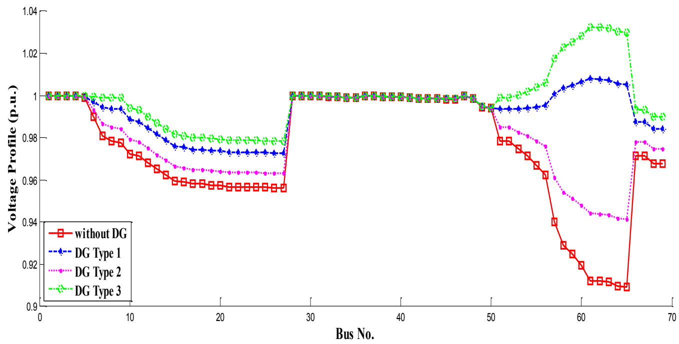

Fig. 9. Voltage profile for 69 bus test system (Case 2)

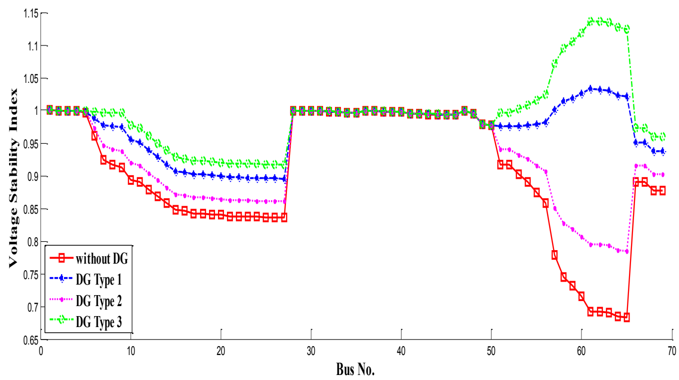

Fig. 10. Voltage stability for 69 bus test system (Case 2)

VI. CONCLUSION

This paper has presented the allocation of diverse types of DGs using BA technique for active and reactive power compensation, considering minimization of power losses and maximization of voltage stability. Bat Algorithm (BA) is utilized to solve the multi-objective function. The proposed algorithm is tested on 33 and 69-bus radial distribution networks. This paper has also compared the proposed approach with other existing algorithms. The proposed technique is found better in performance than other approaches. From results it can be concluded that:

- Power losses system has been decreased significantly;
- System loadability has been increased;
- Voltage profile of systems has been improved;
- Voltage stability index has been enhanced; and
- Bus voltage stability has also been increased.

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