Multiple DG Allocation by Crow Search Algorithm for Power Loss Reduction

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Abstract **- This paper proposes a new meta-heuristic method for optimal sizing of distributed generator (DG). The objective of this paper is to reduce power losses and to improve voltage profile of the radial distribution network by placing multiple distributed generators at optimal locations. Analytical expressions are used in solving this paper for setting up of DG. In this study, Crow Search Algorithm (CSA) is used for optimal sizing of distributed generators (DG). CSA is a meta-heuristic algorithm inspired by the intelligent behavior of the crows. Crows stores their excess food in different locations and memorizes those locations to retrieve it when it is needed. They follow each other to do thievery to obtain better food source. This analysis is tested on IEEE 33 bus and IEEE 69 bus under MATLAB environment and the results are compared with the results of Improved analytical (IA) method and identified that percentage loss reduction in crow search algorithm is more than the percentage loss reduction in improved analytical method.**

Keywords— Distributed generation, Optimal location, Optimal DG size, Crow Search Algorithm, IA method

I. INTRODUCTION

Central power plants can generate power in the range of several hundreds of mega watts (MW) to few giga watts (GW) [1]. In many areas these power plants are not economical due to day by day reducing fuel reserves, increasing fuel costs and also due to stricter environmental regulations [2]. But, the renewable energy generation through wind or solar is more feasible in both economical and technical considerations. This has resulted installation of small power plants connected to the distribution side of the network, close to the end users and hence these are said to be as "embedded" or "distributed" generation (DG) [3]. DG is capable in preventing T&D system expansion by providing required power demand and it can also prevent the extension of new transmission lines to energize new substations. It is moderate in its size and behaviour.

DGs benefits are as follows: [4]

1. Transmission and distribution losses reduces
2. With DG placement, Voltage profile improves and hence, power quality of that system will be improved
3. DG is assumed as pollution free as the most of these sources are designed using green energy
4. DG can provide possibility of selling excess power to the grid and to the neighbouring customers.

Distributed generation generally consists of different types of renewable and non renewable energy resources. Wind, ocean, geo thermal, photovoltaic or thermal are the examples for renewable energy technologies. Internal combustion engine, micro turbine, fuel cell etc are examples for non renewable energy technologies. Depending upon the type of power delivered by these resources, they are classified into different types. [5]

The system efficiency mainly depends on line losses and voltage profile when transferring power from one point to another point. If the system efficiency decreases, the end users will face problems like poorer power quality, higher cost and voltage variation [6]. In improving this system efficiency, Distributed generation (DG) is more popular in modern power system technologies. But, placing the DG in optimal location and finding the optimal size is a complex optimization problem. Improper selection of optimal location or the DG size will lead to increase in the power losses compared to the power losses without DG. Hence, in this paper, optimal location is calculated by using Analytical Expressions [7] and optimal sizing of DG sources is done by using Crow Search Algorithm (CSA) [8] for providing reduced power loss and better voltage profile in the radial distribution network.

II. LOSS REDUCTION METHODS

Power loss in the system can be reduced by placing properly selected DG size at optimal locations. Different authors proposed different methods for finding the optimum place and size of DG unit. In this paper, Analytical expressions are used for the calculation of optimal location and size of DG units [9]. The Analytical expressions and their methodology are based on the exact loss formula which has been explained in [7]. DG location can also selected by sensitivity analysis and size by simulated annealing method with an objective to reduce losses has been proposed in [10]. With the use of sensitivity factor, the optimal location and size of DG can be determined without using jacobian matrix for power loss reduction [11]. Genetic algorithm based technique is also used for optimal location and sizing of DG for loss reduction but it will take much time to converge [12]. Ant colony optimization proposed to calculate the location of DG to enhance the system reliability in [13]. Enhancement in voltage profile and power loss reduction can be achieved by using particle swarm optimization (PSO) also [14]. A combined GA and PSO method is presented in [15]. PSO is a

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population based meta-heuristic algorithm and it works in two steps such as calculating particle velocity and updating the position. It works in less computational time and requires very little memory [16] but it easily suffers from partial optimization. A method for DG placement using "2/3 rule" has been proposed in [25]. It is very simple and easy to apply but it is not effective with some loads which are non-uniformly distributed. An analytical approach can be used for placing single DG in radial systems as well as in loop systems, but, in this approach, optimal sizing is not considered. An analytical approach based on the exact loss formula was presented in [7], which was used to find the optimal size and location. In this method, the load flows is required to be done twice i.e., before DG placement and after the DG placement for loss calculation. In this paper, Crow search algorithm is used which was designed by A. Askarzadeh in 2016 [8] and it was designed based on the greedy behaviour of crows. It is very easy to implement. This algorithm has only fewer parameters to adjust and it takes less time to convergence. The above mentioned features are very important in solving optimization problem. Hence, this algorithm is used in this paper for optimal sizing of DG.

III. Problem Formulation

The real power loss in a system can be calculated by equation (1) and it is also called as "Exact loss formula" and it was explained in [7].

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n}\left[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j - P_iQ_j\right)\right] \quad (1)$$

Where

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_j) \quad (2)$$

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin(\delta_i - \delta_j) \quad (3)$$

$r_{ij} + jx_{ij} = z_{ij}$ ij^{th} element if [Z_{BUS}] is an impedance matrix;

N is number of buses

P_i and Q_i are Real and Reactive power injections at node 'i' respectively. P_j and Q_j are Real and Reactive power injections at node 'j' respectively. Real and reactive power injection equations are as below:

$$P_i = (P_{DGi} - P_{Di}) \quad (4)$$

$$Q_i = (Q_{DGi} - Q_{Di}) \quad (5)$$

Where, P_{DGi} and Q_{DGi} are the real power injection and reactive power injection from DG placed at node i respectively. P_{Di} and Q_{Di} are real power demand and reactive power demand at the node i respectively [9].

$$P_{DGi} = \frac{\alpha_{ii}(P_{Di} + aQ_{Di}) - X_i - aY_i}{a^2\alpha_{ii} + \alpha_{ii}} \quad (6)$$

Where

$$a = \pm\tan(\cos^{-1}(PF_{DG})) \quad (7)$$

$$X_i = \sum_{j=1, j\neq i}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) \quad (8)$$

$$Y_i = \sum_{j=1, j\neq i}^{N}(\alpha_{ij}Q_j + \beta_{ij}P_j) \quad (9)$$

'+' sign indicates for injecting Reactive power

'- 'sign indicates for consuming Reactive power

α and β are the loss coefficients. These coefficients depend on magnitude of voltage and voltage angle at each bus [7].

A. Selection of DG size

After finding optimal location of DG, the DG is placed at that location and then its size can be selected by varying the DG in small steps up to the point where real power loss is minimum value. The real power loss is calculated by "back ward - forward sweep" load flow algorithm. [18]

B. Selection of power factor

The optimal power factor of DG units for a radial distribution network can be calculated as below. The power factor of the combined load of the system (PF_D) is given as

$$PF_D = \frac{P_D}{\sqrt{P_D^{\,2} + Q_D^{\,2}}} \quad (10)$$

The total active and reactive power of the load demand is

$$P_D = \sum_{i=1}^{N} P_{Di} \quad (11)$$

$$Q_D = \sum_{i=1}^{N} Q_{Di} \quad (12)$$

The power factor of the single DG injected (PF_{DG}) is given as

$$PF_{DG} = \frac{P_{DG}}{\sqrt{P_{DG}^{\,2} + Q_{DG}^{\,2}}} \quad (13)$$

The possible minimum total power loss can be achieved only if the power factor of DG selected to be equal to that of the combined load [19].

IV. Crow Search Algorithm

Crow Search Algorithm is a meta-heuristic algorithm proposed by A. Askarzadeh in 2016 [8]. It was designed by observing the intelligent behaviour of crows. Crows store their excess food in different locations in the environment which is considered as a search space and they can memorize those storage locations when they want to retrieve it. They are greedy and follow each other and do thievery to get the best food source. When one crow is following the other there are two chances to reach best food source which depends on the awareness of that crow which is being followed by other. If it is aware about the other crow which is trying to do thievery, it protects its caches by diverting that crow to other location.

Based on this intelligent behaviour the principles of CSA can be listed as follows:

1. Crows live in the form of flock.
2. They can memorize the position of their caches.

3. They follow each other to do thievery.
4. By a probability, they protect their hiding places from being pilfered.

Assume that there is a search space with dimensions'd' including a no. of crows. The no. of crows in defines flock size which is equal to N .A vector $x^{i,iter}$ (i= 1,2,…..N; iter = 1,2, ……, $iter^{max}$) specify the position of crow "i" at time (iteration)

$$x^{i,\,iter} = [x_1^{i,iter}, x_2^{i,iter}, \ldots\ldots\ldots x_d^{i,\,iter}] \quad (15)$$

- $iter^{max}$ = maximum no. of iterations.
- $m^{i,\,iter}$ = the position of hiding place of crow 'i' at iteration 'iter'.
- $m^{j,\,iter}$ = crow 'j' wants to visit its hiding place at iteration 'iter'.

At this iteration, crow i wants to follow crow j to find crow j's hiding place to do thievery.
In this case two states may happen:

State1:
Crow 'i' is following crow 'j' but crow 'j' not aware of it.
In this case crow "i" will reach the crow j's hiding place.

$$x^{i,iter+1} = [x^{i,iter} + r_i \times fl^{i,iter} \times (m^{j,iter} - x^{i,iter})] \quad (16)$$

Where, r_i is a random number with a uniform distribution between 0 and 1and $fl^{i,iter}$ is the flight length of crow 'i' at iteration iter.

State2:
Crow j knows that the crow "i" is following it. So, to protect its hiding place from crow "i", crow j will go to another position in the search space other than its hiding place.

State3:
Totally states 1 and 2 can be expressed as follows:

$$x^{i,iter+1} = \begin{cases} [x^{i,iter} + r_i \times fl^{i,iter} \times (m^{j,iter} - x^{i,iter})] & r_i \geq AP^{j,iter} \\ \text{A random position} & \text{otherwise} \end{cases}$$

Where, r_j is a random number with uniform distribution between 0and 1 and $AP^{j,iter}$ denotes the awareness probability of crow 'j' at iteration lies between 0 and 1. Crow "i" memory will update to $x^{i,iter+1}$, if the objective function value $f(x^{i,iter+1})$ is better than the $f(x^{i,iter})$. Otherwise, it will store the previous memory status. The CSA flow chart is as shown in Fig.1.

V. RESULTS AND DISCUSSION

In this paper, the objective function is to reduce the power loss in a radial distribution network. The proposed CSA methodology is tested on two systems with varying sizes. The first system is a 33 bus radial distribution system with a total load of 12.368 MW and 4.186 MVAr. The second system is a 69 bus radial distribution system with a total load of 3.7 MW and 2.3 MVAr. This test is conducted by placing single DG, two DGs and three DGs at optimal locations in two systems and type of DGs used are type 1 DG and type 3 DG. These tests are performed by developing analytical simulation tool in MATLAB environment based on the proposed methodology and results are compared with the Improved Analytical method (IA method) [21]. For performing the calculations, CSA parameters awareness probability (AP) and flight length (fl) are taken as 2.5 and 0.2 respectively which are mentioned in [20]. Flock size is 20 and maximum no. of iterations t_{max} is 50. Results of CSA and IA methods are compared for same number of iterations.

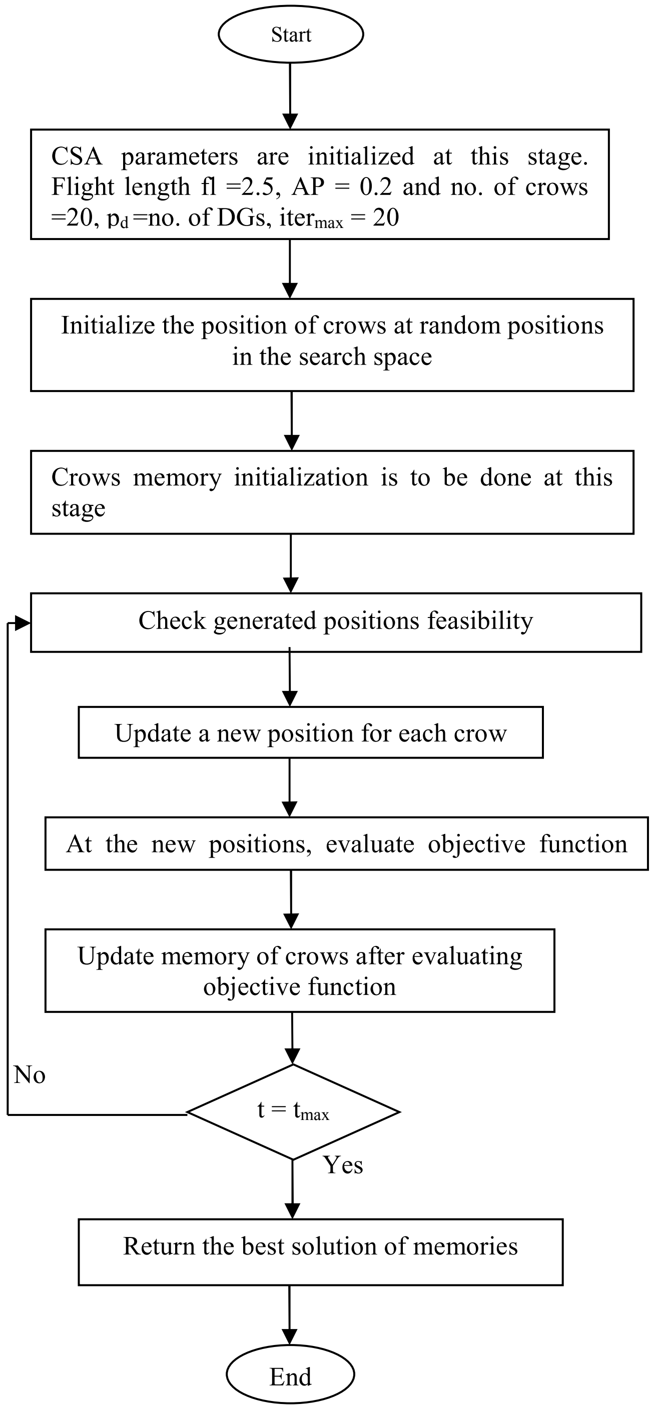

Fig. 1. Flow chart of the proposed CSA [20]

A. Assupmtions:

The assumptions for this paper are as follows:

1. The maximum number of DG units is three, with the size each from 250 kW to the total load plus loss.
2. The maximum voltage at each bus is 1.0 p.u.

B. Type 1 DG placement:

1) 33 Bus system :

Comparison of CSA and IA method results for IEEE 33 bus system with type 1 DG is as shown in Table-I. The real power loss is 211 kW in 33 bus system without DG. After placing single DG at bus 6 in this distribution network, the real power loss is reduced from 211 kW to 113 kW by using IA method. In Crow search algorithm the real power loss is further reduced to 111.01 kW. In IA method the DG size is 3010 kW and in case of Crow search algorithm 2591.76 kW for single DG placement. In case of placing two DGs simultaneously of sizes 2010 kW and 1010 kW at 6 and 15 buses respectively in IA method, the power loss is reduced from 211 kW to 101.06 kW. But, in Crow search algorithm, with the DG sizes 1918.01 kW and 633.51 kW the real power loss is further reduced to 91.55 kW after placing them at buses 6 and 15 respectively. In case of placing three DG's simultaneously of sizes 1010 kW, 1010 kW and 1010 kW at 6, 15 and 33 buses respectively in IA method, the power loss is reduced from 211 kW to 95.07 kW. But, in Crow search algorithm, with the DG sizes 1198.67 kW, 673.5 kW and 616.85 kW the real power loss is further reduced to 79.88 kW.

Table I. COMPARISON OF DIFFERENT METHODS FOR IEEE 33 BUS SYSTEM WITH TYPE 1 DG

Method	**DG schedule**	**Without DG**	**With DG**		
			1DG	***2 DGs***	***3 DGs***
	Optimum bus	--	6	6 15	6 15 33
IA Method [21]	DG size (kW)	--	3010	2010 1010	1010 1010 1010
	Loss (kW)	211	113	101.6	95.07
	Percentage loss reduction (%)	--	46.44	51.84	54.94
	Minimum voltage (p.u)	0.9038	0.9483	0.9607	0.9811
Crow Search Algorithm	DG size (kW)	--	2591.76	1918.01 633.51	1198.6 673.5 616.85
	Loss (kW)	211	111.01	91.55	79.88
	Percentage loss reduction (%)	--	47.38	56.61	62.14
	Minimum voltage (p.u)	0.9038	0.9424	0.9543	0.9703

2) 69 bus system :

Comparison of CSA and IA method results for IEEE 69 bus system with type 1 DG is as shown in Table-II. The real power loss is 224 kW in 69 bus system without DG. After placing single DG at bus 63 in this distribution network, the real power loss is reduced from 224 kW to 88.42 kW by using IA method. In Crow search algorithm the real power loss is further reduced to 86.98 kW. In IA method the DG size is 2010 kW and in case of Crow search algorithm 1807.03 kW for single DG placement. In case of placing two DGs simultaneously of sizes 2010 kW and 10 kW at 63 and 18 buses respectively in IA method, the power loss is reduced from 224 kW to 88.0 kW. But, in Crow search algorithm, with the DG sizes 1727.57 kW and 513 kW the real power loss is further reduced to 75.02 kW after placing them at buses 63 and 18 respectively. In case of placing three DGs simultaneously of sizes 10 kW, 10 kW and 2010 kW at 63, 18 and 61 buses respectively in IA method, the power loss is reduced from 224 kW to 83.54 kW. But, in Crow search algorithm, with the DG sizes 560.76 kW, 553.7 kW and 1311.51 kW at 63, 18 and 61 buses respectively the real power loss is further reduced to 71.97 kW.

Table II. COMPARISON OF DIFFERENT METHODS FOR IEEE 69 BUS SYSTEM WITH TYPE 1 DG

Method	**DG schedule**	**Without DG**	**With DG**		
			1DG	***2 DGs***	***3 DGs***
	Optimum bus	--	63	63 18	63 18 61
IA Method [21]	DG size (kW)	--	2010	2010 10	10 10 2010
	Loss (kW)	224	88.42	88.0	83.54
	Percentage loss reduction (%)	--	60.52	60.71	62.70
	Minimum voltage (p.u)	0.9092	0.9691	0.9695	0.9696
Crow Search Algorithm	DG size (kW)	--	1807.03	1727.51 513	560.76 553.7 1311.51
	Loss (kW)	224	86.98	75.02	71.97
	Percentage loss reduction (%)	--	61.16	66.50	67.87
	Minimum voltage (p.u)	0.9092	0.9679	0.9795	0.9830

C. Type 3 DG placement:

1) 33 bus system:

Comparison of CSA and IA method results for IEEE 33 bus system with type 3 DG is as shown in Table-III. The power factor of DG is taken as combined load power factor in both methods. The combined load power factor is 0.85 lagging. After placing single DG at bus 6 in this distribution network, the real power loss is reduced from 211 kW to 75.63 kW by using IA method. In Crow search algorithm the real power loss is further reduced to 68.30 kW. In IA method the DG size is 2360 kVA and in case of Crow search algorithm

2998.76 kVA for single DG placement. In case of placing two DGs simultaneously of sizes 2360 kVA and 10 kVA at 6 and 15 buses respectively in IA method, the power loss is reduced from 211 kW to 74.55 kW. But, in Crow search algorithm, with the DG sizes 2370.78 kVA and 697.16 kVA the real power loss is further reduced to 46.73 kW after placing them at buses 6 and 15 respectively. In case of placing three DGs simultaneously of sizes 1190 kVA, 10 kVA and 1190 kVA at 6, 15 and 33 buses respectively in IA method, active power loss is reduced from 211 kW to 55.50 kW. But, in Crow search algorithm, with the DG sizes 1571.81kW, 681.27 kW and 768.23 kW at 6, 15 and 33 buses respectively the real power loss is further reduced to 27.59 kW.

Table III. COMPARISON OF DIFFERENT METHODS FOR IEEE 33 BUS SYSTEM WITH TYPE- 3 DG

Method	DG schedule	Without DG	With DG		
			1DG	*2 DGs*	*3 DGs*
	Optimum bus	--	6	6 15	6 15 33
IA Method [21]	DG size (kVA)	--	2360	2360 10	1190 10 1190
	Power factor		0.85 lagging	0.85 lagging	0.85 lagging
	Loss (kW)	211	75.63	74.55	55.50
	Percentage loss reduction (%)	--	64.156	64.466	73.696
	Minimum voltage (p.u)	0.9038	0.9458	0.9466	0.9473
Crow Search Algorithm	DG size (kVA)	--	2998.76	2370.78 697.16	1571.81 681.27 768.23
	Power factor	--	0.85 lagging	0.85 lagging	0.85 lagging
	Loss (kW)	211	68.30	46.73	25.79
	Percentage loss reduction (%)	--	67.63	77.85	87.77
	Minimum voltage (p.u)	0.9038	0.9566	0.9701	0.9827

2) 69 bus system:

Comparison of CSA and IA method results for IEEE 69 bus system with type 3 DG is as shown in Table-IV. The combined load power factor is 0.81 lagging. After placing single DG at bus 63 in this distribution network, the real power loss is reduced from 224 kW to 60.73kW by using IA method. In Crow search algorithm the real power loss is further reduced to 28.10 kW. In IA method the DG size is 1240 kVA and in case of Crow search algorithm 2172.20 kVA for single DG placement. In case of placing two DGs simultaneously of sizes 1240 kVA and 10 kVA at 63 and 18 buses respectively in IA method, the power loss is reduced from 224 kW to 59.0 kW. But, in Crow search algorithm, with the DG sizes 2049.21 kVA and 683.7 kVA the real power loss is further reduced to 11.61 kW after placing them at buses 63 and 18 respectively. In case of placing three DGs simultaneously of sizes 10 kVA, 10 kVA and 1240 kVA at 63, 18 and 61 buses respectively in IA method, active power loss is reduced from 224 kW to 57.90 kW.

Table IV. COMPARISON OF DIFFERENT METHODS FOR IEEE 69 BUS SYSTEM WITH TYPE-3 DG

Method	DG schedule	Without DG	With DG		
			1DG	*2 DGs*	*3 DGs*
	Optimum bus	--	63	63 18	63 18 61
IA Method [21]	DG size (KVA)	--	1240	1240 10	10 10 1240
	Power factor		0.81 lagging	0.81 lagging	0.81 lagging
	Loss (KW)	224	60.73	59.0	57.90
	Percentage loss reduction (%)	--	72.88	73.66	74.15
	Minimum voltage (p.u)	0.9092	0.9618	0.9619	0.9602
Crow Search Algorithm	DG size (kVA)	--	2172.20	2049.21 683.7	504.32 492.95 1784.22
	Power factor	--	0.81 lagging	0.81 lagging	0.81 lagging
	Loss (kW)	224	28.10	11.61	8.38
	Percentage loss reduction (%)	--	87.45	94.816	96.25
	Minimum voltage (p.u)	0.9092	0.9720	0.9943	0.9928

But, in Crow search algorithm, with the DG sizes 504.32 kVA, 492.95 kVA and 1784.22 kVA at 63, 18 and 61 buses respectively the real power loss is further reduced to 8.38 kW. Compression between IA method and CS algorithm are shown in Fig.2.

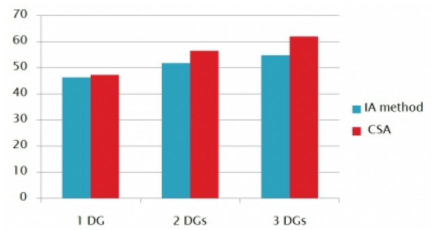

Fig.2(a) 33 bus with type 1 DG placement

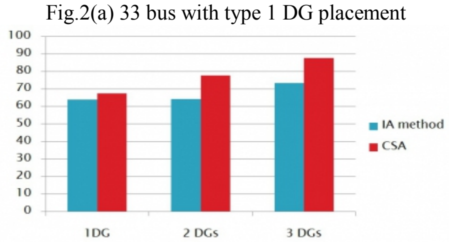

Fig. 2(b) 33 bus with type 3 DG placement

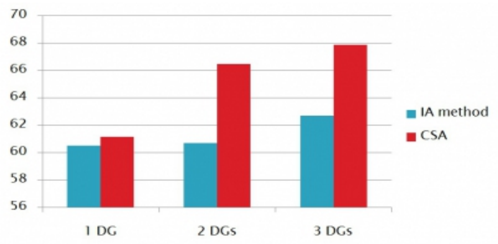

Fig. 2(c) 69 bus type 1 DG placement

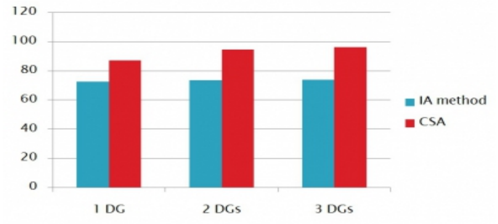

Fig. 2(d) 69 bus type 3 DG placement

Fig.2. Comparing Power loss reduction in IEEE 33 bus and IEEE 69 bus systems with IA method and CSA

CONCLUSIONS

This paper main objective is to reduce power losses and to improve voltage profile of the radial distribution network by placing multiple distributed generators at optimal locations using Crow search algorithm. This analysis was done on IEEE 33 and IEEE 69 buses and the results are compared with IA method which shows that results obtained by CSA method are much better than IA method results. Analytical expressions are used for finding the optimal location of DG. Load flow analysis is done by using backward sweep method and the power factor is selected by using fast approach method.

The DG size and real power loss are reduced in crow search algorithm with type 1 DG placement compared to IA method. In type 3 DG placement, the real power loss is reduced using crow search algorithm compared to IA method. In the two test systems, total 12 cases are considered with different no. of DGs. The percentage loss reduction in two test systems with CSA and IA method are compared in Fig. 2. The percentage loss reduction with CSA 0.94%, 4.8%and 7.2% more with type 1 one DG, type 1 two DGs, type 1 three DGs respectively and 3.47%, 13.384% and 14.074% is more with type 3 one DG, type 3 two DGs, type 3 three DGs respectively in 33 bus system than the percentage loss reduction in IA method. The percentage loss reduction with CSA are 0.64%, 5.79%and 5.17% more with type 1 one DG, type 1 two DGs, type 1 three DGs respectively and 14.57%, 20.526% and 22.1% more with type 3 one DG, type 3 two DGs, type 3 three DGs respectively in 69 bus system than the percentage loss reduction with IA method. In all the above cases, we can clearly observe that the percentage loss reduction is more by using CSA compared to IA method. Hence, we can conclude that the proposed Crow search algorithm is highly suitable in optimal sizing of DG in radial distribution systems compared to IA method.

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