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Application of Bird Swarm Algorithm for Optimal Allocation of Renewable Energy Driven Distributed Generation

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***Abstract:** With the rapid increase in electrical energy demand and consumption of fossil fuels, electric utilities are looking towards the new green power technologies which utilize non-conventional energy sources like solar, wind and biomass for power generation. Distributed generation (DG) is the most popular and efficient technology that utilizes non-conventional sources. In this article, renewable energy driven DG technologies are proposed to meet the increased load demand and diminish the power loss in the distribution network. Identification of appropriate buses to place DGs in distribution system plays a crucial role in improving the technical and economic benefits of a DG. A new sensitivity technique, index vector (IV) method is used to locate the most appropriate node to connect DG. A new meta-heuristic optimization technique, bird swarm algorithm (BSA) is used to determine the optimal size of DG. Two most popular test systems, IEEE 33 & 69 systems are considered to test and validate the proposed method.*

***Keywords:** Bird swarm algorithm, distribution system, distributed generation, index vector method, power loss minimization*

I. INTRODUCTION

Now a day's demand for electrical energy is expeditiously increasing which forces electrical distribution companies to expand their traditional distribution station which is not economical at present deregulated environment. Introduction of distributed generation (DG) which can efficiently utilize renewable energy sources for the production of clean and green electric power to meet the load growth is attracting distribution companies' attention. DG is defined [1] as the production of small-scale power from few kilowatts to few megawatts fed at the distribution level. DG is also termed as "decentralized generation", "local generation", "embedded generation" or "dispersed generation". DGs depending on the type of fuel used for their operation are categorized [2] as renewable energy (solar, biomass, wind) driven DGs and non-renewable energy or fossil fuel driven DGs. DG can provide numerous technical, economic as well as environmental benefits [3]. Traditional distribution networks are designed as passive networks to transport electrical energy from the centralized power plant to consumers. Introduction of high level of DG into the distribution network may cause increased power loss and decreased reliability of power supply [4]. Hence size and location of DG plays vital role in distribution network design.

Previously, several analytical approaches have been suggested by scientists and researchers to extract the most appropriate location for incorporation of DG. A 2/3 rule was proposed by [5] for placement of DG in distribution system consists of uniformly distributed loads. An analytical method was proposed by authors in [6] for optimal placement and sizing of time varying DGs in radial as well as networked distribution systems with time varying loads. An analytical method for minimization of power loss in distribution network by optimal placement and sizing using power stability index was proposed by authors in [7]. Simultaneous placement and sizing of DG and capacitor was proposed [8]. In [8] Sensitivity analysis is used for optimal placement and analytical method is used for sizing. Particle swarm optimization technique [9], artificial bee colony optimization [10], krill herd algorithm [11] are used for optimal allocation of different kinds of DGs in distribution network. From the above literature study, it is noted that the proposed BSA method has not been applied for a particular DG allocation problem.

The next sections of this paper are arranged as follows. Section 2 explores different types of DGs and their mathematical modelling, section 3 covers formulation of objective function, section 4 reveals index vector method, section 5 gives a brief explanation about proposed BSA, section 6 includes test cases and result and section 7 presents final conclusion of the work.

II. DG TYPES AND MATHEMATICAL MODELLING

Based on real and reactive power injection or absorption, DGs are mainly arranged in to four kinds [12].

Type-1 DG: only active power generator. Solar Photo Voltaic cells (SPV) are best example.

Type-2 DG: both active & reactive power generator. Gas turbines (GT) are example.

Type-3DG: active power generator & reactive power consumer. Wind turbines (WT) comes under this category.

Type-4 DG: only reactive power generator. Synchronous condensers come under this category.

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The mathematical representation of DG power generation is depicted in below table.

TABLE1. Types of DGs and power equations

DG Type	Active power	Reactive power	DG power factor
1	P_{DGi}	0	1
2	$P_{DGi}=S_{DGi}*Cos\Phi$	$Q_{DGi}=S_{DGi}*Sin\Phi$	Equals to load power factor
3	P_{DGi}	$Q_{DGi}=-(0.5+0.04(P_{DGi})^2)$	$\frac{P_{DGi}}{\sqrt{P_{DGi}^2+Q_{DGi}^2}}$
4	0	Q_{DGi}	0

III. OBJECTIVE FUNCTION AND CONSTRAINTS

The main motive of this problem is to diminish the power loss due to active componet of current in the distribution network.

$$\text{Min f=min(total power loss)} \tag{1}$$

The constraints are

- Power balance constraints

$$P_{Loss}+P_d=P+\sum P_{DG} \tag{2}$$

- Voltage constraints

$$0.95\leq V_i\leq 1.05 \tag{3}$$

IV. INDEX VECTOR METHOD

Most appropriate bus of distribution system to incorporate DG is located using index vector (IV) method [13] and is explained as follows. Index vector for 'n' bus system is given below

$$\text{IV}[n]=\frac{1}{V_n^2}+\frac{I_{q,k}}{I_{p,k}}+\frac{Q_{eff,n}}{Q_{total}} \tag{4}$$

Where,

V_n = voltage magnitude of bus n

$Q_{eff,n}$=effective reactive load at bus n

Q_{total}=total reactive load

$I_{q,k}$=reactive component of current in branch k

$I_{p,k}$=real component of current in branch k

V. BIRD SWARM ALGORITHM

Bird swarm algorithm (BSA) [14] is a very recently (2015) developed, bio-inspired optimization technique. BSA is developed based on the intelligence observed in communication and social behaviour of bird swarms. Basically most of the birds exhibit three types of behaviours such as foraging, vigilance and flight behaviour.

A. Foraging behaviour

All birds in the swarm searches for food based on its previous experience and swarms experience. This behaviour can be mathematically expressed as below

$$X_{m,n}^{t+1}=X_{m,n}^{t}+(P_{m,n}-x_{m,n}^{t})\times C\times \text{rand}(0,1)+..... \\ (g_n-X_{m,n}^{t})\times S\times rand(0,1) \tag{5}$$

In the above expression (5) rand(0,1) represents a uniformly distributed random number between (0,1) and $n\in[1,2,....,D]$. S and C are respectively named as social accelerated and cognitive accelerated coefficients and both are positive numbers. $P_{m,n}$ is the previous best position of m[th] bird and g_n is the previous best position of swarm.

B. Vigilance behaviour

Each and every bird in the swarm competes with rest of the swarm to get a position in the middle of the swarm to protect themselves from the predators. Hence, each bird in the swarm would not move continuously towards the centre. Mathematically these motions can be written as follows:

$$X_{m,n}^{t+1}=X_{m,n}^{t}+A1(mean_n-X_{m,n}^{t})\times rand(0,1)+.... \\ A2(P_{q,n}-X_{m,n}^{t})\times rand(-1,1) \tag{6}$$

$$A1=a1\times\exp\left(-\frac{PFit_m}{sumFit+\varepsilon}\times \text{N}\right) \tag{7}$$

$$A2=a2\times\exp\left(\left(\frac{PFit_m-PFit_q}{|PFit_q-PFit_m|+\varepsilon}\right)\frac{N\times PFit_q}{sumFit+\varepsilon}\right) \tag{8}$$

Where,

q ($q\neq m$) is a randomly selected positive numbers between 1 and N.

a1 and a2 are positive numbers in [0 2].

$PFit_m$ represents the m[th] bird's best fitness value

sumFit denotes sum of the best fitness of all the birds in the swarm

ε is a small number which is used to eliminate zero-division error

$mean_n$ represents average position of the n[th] bird in the swarm

C. Flight behaviour

While searching food the birds may travel from one location to other location due to predation threat or any other reason and once again at arrived site they would forage for food. Some birds of the swarm called producers would search for food patches while the rest of the swarm called scroungers try to feed from the food patches identified by the producers. The mathematical representation of producer and scrounger behaviour may be as follows

$$X_{m,n}^{t+1}=X_{m,n}^{t}+randn(0,1)\times X_{m,n}^{t} \tag{9}$$

$$X_{m,n}^{t+1}=X_{m,n}^{t}+(X_{q,n}^{t}-X_{m,n}^{t})\times FL\times rand(0,1) \tag{10}$$

Here randn(0,1) represents Gaussian distributed random value with 0 and 1 respectively as mean and standard deviation. $q\in[1,2,.....N]$, $q\neq m$ and $FL\in[0\,2]$. FL is a following factor which means scrounger can follow producer while searching food

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VI. RESULTS & DISCUSSIOSN

Two test systems shown in figure 1 and figure 4 are considered to explore the effectiveness of proposed method.

A. IEEE 33-bus RDS

The required data about the first test system depicted in figure 1 has been extracted from [15] and recorded in table 2. As bus 15 is being on top priority from IV method, it has been chosen as candidate bus to incorporate DG. Simulation is carried out after incorporation of DG and the results are tabulated in table 3.

TABLE 2. First test system specifications

Base MVA	Base KV	Active load (KW)	Reactive load (KVAr)	Active Power loss (KW)	Reactive power loss (KVAr)
100	12.66	3715.00	2300.00	210.99	143.03

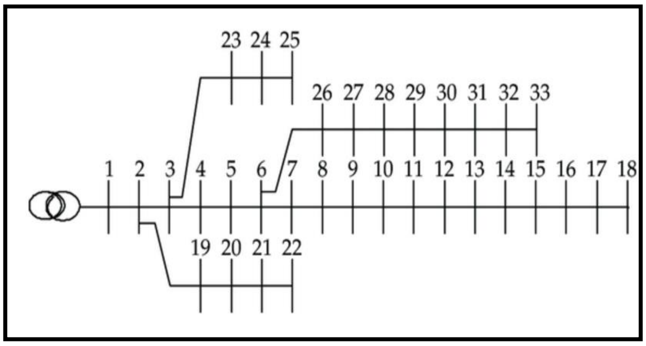


Fig. 1. Schematic diagram of 33 bus system

TABLE 3. Results of 33-bus system

Type of DG	DG place	DG size (KVA)	Active loss(KW)	Reactive loss(KVAr)	Minimum voltage
Without DG	----	----	210.99	143.03	0.9038
Type-1	15	1060.99	133.503	90.737	0.9327
Type-2	15	1263.05	107.774	74.529	0.9392
Type-3	15	1117.04	200.669	139.223	0.9252
Type-4	15	612.04	183.932	125.615	0.9224

In this section the effect of different DG technologies on real and reactive power losses are analyzed. As depicted in table 3 the values revealed that after incorporation of type-1 DG at bus 15, the real losses are reduced from 210.99 kW to 133.50 which results in reduction of real power loss by 36.72%. where as the reactive losses are reduced from 143.03KVAr to 90.73KVAr which results in minimization of reactive loss by 36.56%. Similarly with type-2 DG operating at optimal power factor, real and reactive losses are reduced by 48.92% and 47.89%, respectively. With type-3 real and reactive losses are reduced by 4.89% and 2.66%, repectively. After type-4 DG sitting at bus 15, the real and reactive losses are reduced by 12.82% and 12.17%, respectively. The above values revealed that type-2 DG is more efficient in minimizing both real and reactive losses. The required DG size is more incase of type-2 DG as copmpared to other three types of DGs.

Prior to the incorporation of different types of DGs, bus 18 is at lowest voltage level with a value 0.9038p.u. As depicted in figure 2, with the connection of type-1,2,3 and 4, the minimum voltage level is improved to 0.9327p.u,0.9392p.u,0.9252p.u and 0.9224 p.u, respetively.From these values it is clear that type-2 DG has more positive effect on voltage.

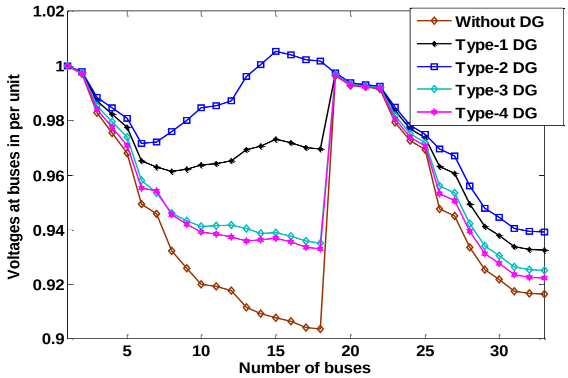


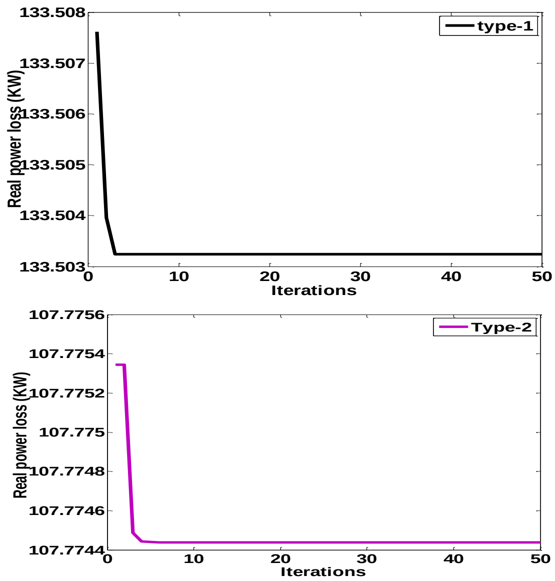
Fig. 2 Voltage profile of 33-bus system

Comparative assessment of DG technologies has been made in this section and the results are reported in table 4. Comparison is made with respect to power loss, minimum voltage and required DG size. The results clearly shows that the proposed method is efficient than the previous method [13] in the literature.

TABLE 4. Comparison of 33-bus results

Method	DG location	DG size (KW)	Real loss	Reactive loss	Minimum voltage
VSI [13]	16	1000	136.75	92.659	0.9318
Proposed	15	1060.99	133.50	90.73	0.9327

Convergence curves of a proposed BSA applied on 33-bus system are depicted in figure 3. It shows that's the BSA converged quickly.



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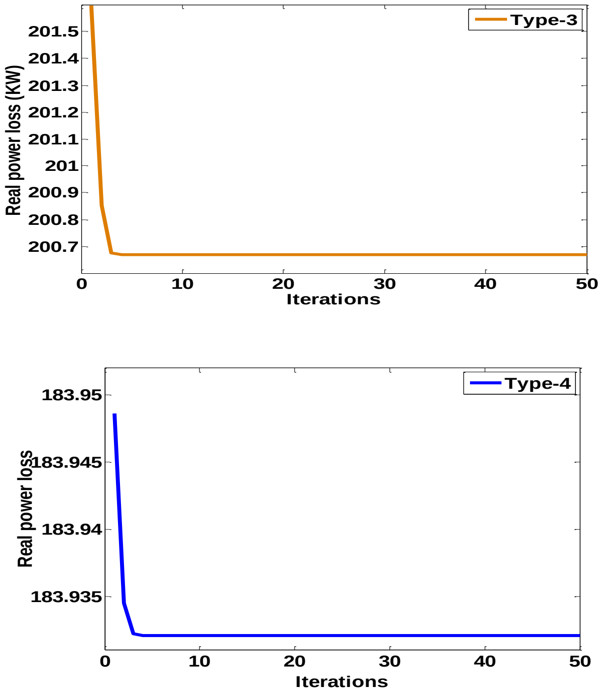

Fig. 3. Convergence characteristics of proposed BSA algorithm foe 33-bus system

A. *IEEE 69-bus system*

The required data about the second test system depicted in figure 4 has been extracted from [15] and recorded in table 5. As bus 61 is being on top priority from IV method, it has been chosen as candidate bus to incorporate DG. Simulation is carried out after incorporation of DG and the results are tabulated in table 6. From the results it can be inferred that minimum power loss is obtained with type-2 DG. The minimum voltage level is also better improved with type-2 DG.

TABLE 5. Specifications of 69-bus system

Base MVA	Base KV	Total connected load		Power loss	
		Active (KW)	Reactive (KVAr)	Active (KW)	Reactive (KVAr)
100	12.66	3802.19	2694.60	225.00	102.17

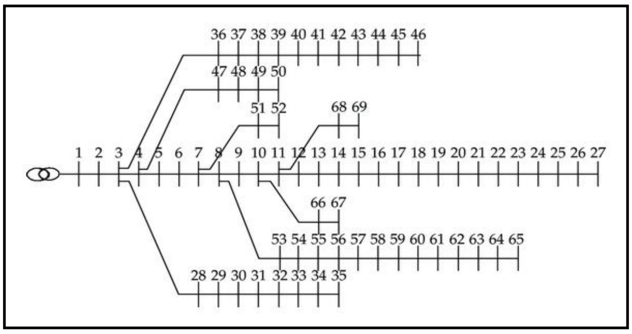

Fig 4. Schematic diagram of 69-bus system

TABLE 6. Results of 69-bus system

Type of DG	DG location	DG size (KVA)	Active loss (KW)	Reactive loss (KVAr)	Minimum voltage(p,u)
Without DG	----	-----	225	102.17	0.9092
Type-1	61	1872.703	83.221	40.529	0.9682
Type-2	61	2243.865	23.1684	14.371	0.9724
Type-3	61	1780.864	158.004	72.457	0.9596
Type-4	61	1329.992	152.040	70.496	0.9303

In this section the effect of differen DG types on real and reactive power losses are analyzed. As depicted in table 6 after incorporation type-1 DG at bus 61, the real and reactive losses are reduced by 63.01% and 60.33%, respectively. With type-2 DG running at optimal power factor, real and reactive losses are reduced by 89.70% and 85.93%, respectively. With type-3 real and reactive losses are reduced by 29.77% and 29.08%, repectively. After type-4 DG sitting at bus 15, the real and reactive losses are reduced by 32.44% and 31.00%, respectively. With the above values it is clear that type-2 DG is more efficient in minimizing both real and reactive losses.However, required DG size is more incase of type-2 DG.

Prior to the incorporation of different types of DGs, bus 65 is at lowest voltage level with a value 0.9092p.u. As depicted in figure 5, with the connection of type-1,2,3 and 4, the minimum voltage level is improved to 0.9682 p.u, 0.9724p.u, 0.9596p.u and 0.9303p.u, respetively. From these values it is clear that type-2 DG has more positive effect on voltage.

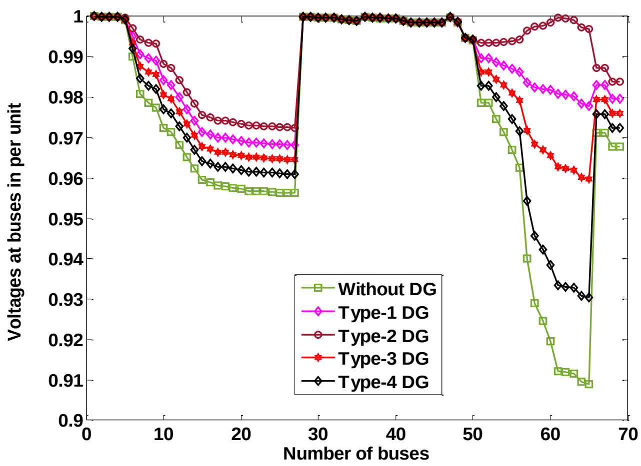

Fig 5. Voltage profile of 69-bus system

Comparative assessment of DG technologies has been made in this section and the results are reported in table 7. Comparison is made with respect to power loss, minimum voltage and required DG size. The results clearly show that the proposed method is efficient than the previous method [13] in the literature.

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Table1. Comparison of 69-bus system results

Method	DG location	DG size (KW)	Real loss (KW)	Reactive loss (KW)	Minimum voltage (p.u)
VSI [13]	65	1450	112	55.10	0.9660
Proposed	61	1872.70	83.22	40.52	0.9682

Convergence curves of a proposed BSA applied on 69-bus system are depicted in figure 6. It shows that's the BSA converged quickly.

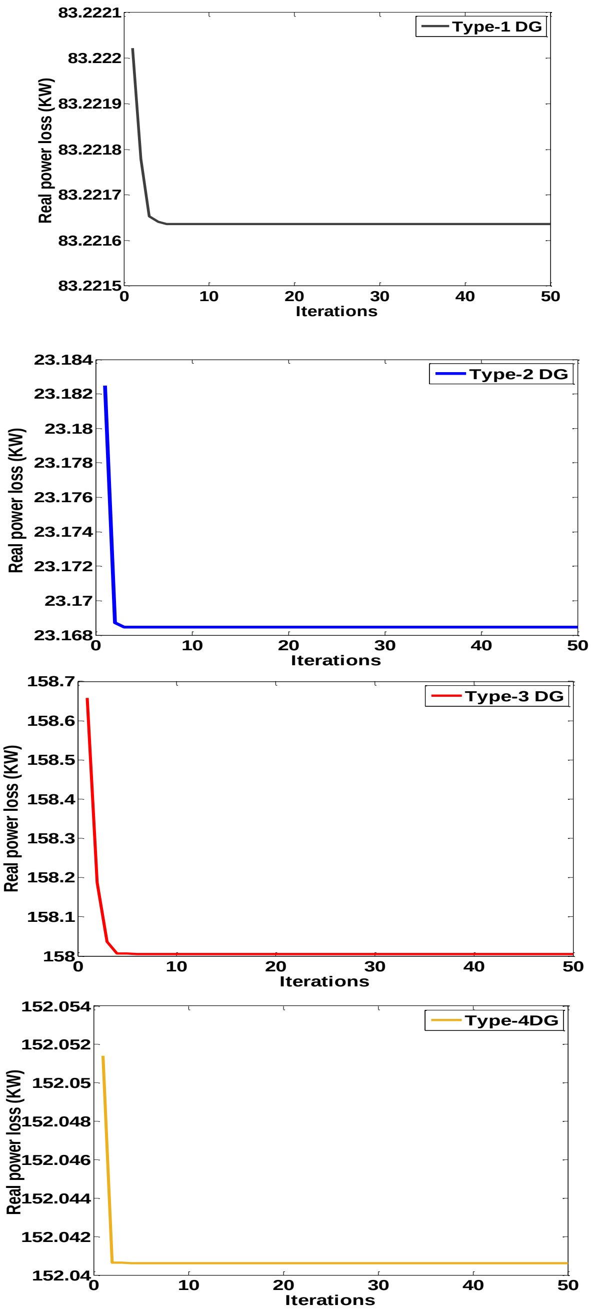

Fig 6. Convergence characteristics of proposed BSA algorithm for 69-bus system

VII. CONCLUSION

In this work, a very recently developed, BSA is implemented for optimal allocation of renewable energy driven DG units for power loss reduction. Four types of DG units and two popular test systems, 33 and 69 bus systems are used for effectiveness evaluation of proposed method. A new method, index vector method is used to locate optimal DG location. From the results, it is observed that highest power loss reduction is obtained with type-2 DG unit operating at load power factor. The overall voltage profile enhancement is also better with type-2 DG unit.

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