Determination of Optimal Capacity and Location ofDistributed Generations in Radial DistributionSystems using Krill Herd Algorithm

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Abstract

Reliability and active power loss are two fundamental parameters in the design and planning of distribution systems that have always attracted the attention of power distribution systems designers and engineers. The improvement of reliability and the reduction of power loss are investigated as the primary objective functions and voltage profile as the secondary objective function. A method based on Krill Herd algorithm is adopted to optimize a single objective function that consists of a number of distinct objective functions and is made up of different weight coefficients in order to locate distributed generation units. Further, the results obtained from this algorithm will be compared to those of other methods. To evaluate the accuracy and efficiency of the proposed algorithm in finding optimal responses, standard grids including IEEE 33-bus and 69-bus radial distribution systems are employed.

Keywords: Distributed Generations(DG), Krill Herd Algorithm(KH), Radial Distribution Systems, Reliability

1- Introduction

Numerous factors have encouraged power system designers to adopt distributed generations focusing on new energies [1,2,3]. Among the aforesaid factors are the followings: the ever-increasing growth of population and modernization of lifestyles and, as a result, the increased rate of electric power demand as well as limitations in constructing huge and centralized power plants and utilizing power transmission and distribution lines and, on the other hand, the reduced destructive effect of environmental pollutants, etc.

Distributed generation is generally small-scale generation in the vicinity of the location of consumption [4]. Owing to the above-mentioned reasons and also the advancements in power electronics and energy storage devices for support in emergency situations [5], these generations have gained a great deal of attention in the present competitive markets Navigant journal predicted the installed capacity of distributed generations will exceed 165GW with an economic profit of 182 billion dollars in 2023 from 87.3GW with an economic profit of 97 billion dollars in 2014[6].

If distributed generations are installed with a proper size and location in a distribution system, system performance is considerably improved and all or a part of active or reactive

power delivered to the loads can be supplied thus reducing feeder current and loss. However [7,8], if the size and location of DGs are inappropriately determined, a return current from the largerDG will be caused thus increasing power loss. That is why reduced power loss has invariably been a highly important topic in determining the location and optimal capacity of distributed generation units.A great number of optimization techniques have so far been adopted to determine the location and optimal capacity of distributed generation units in a distribution system [9-13].

Krill Herd algorithm is utilized in this paper to determine the optimal location of distributed generation units. The second section presents the formulation of the optimization problem. The third section introduces the proposed algorithm.The fourth section explains the implementation. Finally, the fifth section puts forward the conclusion.

2- Problem Formulation

This paper mainly aims to determine the location and optimal capacity of distributed generation units in order to reduce power loss, improve reliability, and reduce the size of DG.Each of these individual goals has been converted to a distinct objective function using weight coefficients. The objective function is generally as follows:

$$Minimize \quad J = \sum_{m=1}^{3} k_m . J_m$$
$$k_m \in [0,1], \quad \sum_{m=1}^{3} k_m = 1 \tag{1}$$

where J_m are individual objective functions and k_m is the weight coefficient with the

following values in descending order of importance:$k_1=0.4, k_2=0.35, k_3=0.25$.

2.1. Power loss

Addressing power loss is an important goal in the majority of papers. It is also considered to be the most important individual goal in here and it is expressed as follows:

$$P_{Lt} = \sum_{i=1}^{n} I_i^2 R_i$$
$$J_1 = \frac{P_{Loss,i}}{P_{Loss,base}} \tag{2}$$

where I_i is the current of the i-th branch after the implementation of load distribution. R_i is the resistance of the i-th branch, $P_{Loss,i}$ pertains to the i-th particle after DG installation, and $P_{Loss,base}$ is the initial value of P_{Loss}.

2.2. Determination of the capacity of the installed DG

The smaller the size and capacity of the installed DG, the more economically viable it will be and the loss cost will be required to achieve the respective goals. Hence, the following equation will be a part of the individual objective function:

$$J_2 = \frac{\sum_{j=1}^{m} P_{DGi,j}}{\sum_{j=1}^{n} P_{load,j}} \tag{3}$$

where $P_{DGi,j}$ is the power of the installed DG at the j-th location for the i-th particle, $P_{load,j}$ is the active power of the j-th load point, m is the number of recommended DGs, and n is the total number of load points.

2.3. Reability

Undistributed power may be expressed as follows as a reliability criterion for power supplyin distribution system:

$$ENS = \sum_{i=1}^{Np} ENS_i = \sum_{i=1}^{Np} L_i \sum_{j=1}^{Nc} r_{ij} \lambda_{ij}$$

$$J_3 = \frac{ENS_i}{ENS_{base}}$$
(4)

where N_c is the number of components the failure of which leads to a power outage for the subscribers of the i-th load point, N_p is the total number of grid load points, λ_{ij} is the power outage rate of the j-th subscribers as a result of failure in the i-th component, r_{ij} is the average duration of power outage, L_i is the average load of the subscribers of the i-th load points, ENS_i is the unfed power calculated for the i-th particle after the installation of the recommended DGs, ENS_{base} is the unfed power calculated for the initial grid without DG installation.

2.4. Constraints governing the problem

• Power balance constraint

$$P_{Slack} + \sum_{i=1}^{N} P_{DGi} = \sum_{i=1}^{N} P_{Di} + P_L$$
(5)

• Active power constraint

$$P_{DGi}^{min} \leq P_{DGi} \leq P_{DGi}^{max}$$
(6)

• Power loss constraint

$$\sum Loss_k(withDG) \leq \sum Loss_k(withoutDG)$$
(7)

• Unsupplied power constraint

$$\sum EENS_k(withDG) \leq \sum EENS_k(withoutDG)$$
(8)

• Bus voltage constraint

$$|V_i|^{min} \leq |V_i| \leq |V_i|^{max}$$
(9)

• Bus current constraint

$$|I_i| \leq |I_i|^{max}$$
(10)

3- Krill Herd Algorithm

A novel biologically-inspired algorithm, namely krill herd (KH) was proposed forsolving optimization tasks by Amir Hossein Gandomi and Amir Hossein Alavei in 2012. The KH algorithm is based on the simulation of the herding behavior of krill individuals. The minimum distances of each individual krill from food and from highest density of the herd are considered as the objective function for the krill movement [14]. The time-dependent position of the krill individuals is formulated by three main factors: (i) movement induced by the presence of other individuals (ii) foraging activity, and (iii) random diffusion.

3.1. Lagrangian model of the krill herding

the following Lagrangian model is generalized to an n dimensional decision space:

$$\frac{dX_i}{dt} = N_i + F_i + D_i$$
(11)

where N_i is the motion induced by other krill individuals; F_i is the foraging motion, and D_i is the physical diffusion of the ith krill

individuals.

- Motion induced by other krill individuals

The krill individuals try tomaintain a highdensity and move due to their mutual effects[15]. For a krill individual, this movement can be defined as:

$$N_i^{new} = N^{\max} \alpha_i + \omega_n N_i^{old} \qquad (12)$$

Where,

$$\alpha_i = \alpha_i^{local} + \alpha_i^{t\,\arg et} \qquad (13)$$

and $N^{\max}$ is the maximum induced speed, it is as much as 0.01 (ms^{-1}). ω_n is the inertia weight of the motion induced in the range [0, 1], N_i^{old} is the last motion induced, α_i^{local} is the local effect provided by the neighbors and $\alpha_i^{t\,\arg et}$ is the target direction effect provided by the best krill individual.

- Foraging motion

The foraging motion is formulated in terms of two main effective parameters. The first one is the food location and thesecond one is the previous experience about the food location. This motion can be expressed for the ith krill individual asfollows:

$$F_i = V_f \beta_i + \omega_f F_i^{old} \qquad (14)$$

$$\beta_i = \beta_i^{food} + \beta_i^{best} \qquad (15)$$

and V_f is the foraging speed,it is as much as 0.02(ms^{-1}). ω_f is the inertia weight of the foraging motion in the range [0, 1], is the last foraging motion, β_i^{food} is the food attractive and β_i^{best} is the effect of the best fitness of the ith krill so far.

- Physical diffusion

The physical diffusion of the krill individuals is considered to be a random process. This motion can be express in terms ofa maximum diffusion speed and a random directional vector.It can be formulated as follows:

$$D_i = D^{\max} \delta \qquad (16)$$

where $D^{\max}$ is the maximum diffusion speed, and δ is the random directional vector and its arrays are random values between -1 and 1 [16]. $D^{\max} \in [0.002, 0.010](ms^{-1})$and a random number in this range is also used in this study. The better the position of the krillis, the less random the motion is.

3.2. Motion process of the KH algorithm

In general, the defined motions frequently change the position of a krill individual toward the best fitness. The foragingmotion and the motion induced by other krill individuals contain two global and two local strategies. These are working in parallel which make KH a powerful algorithm.

Using different effective parameters of the motion during the time, the position vector of a krill individual during the interval t to $t + \Delta t$ is given by the following equation:

$$X_i(t + \Delta t) = X_i(t) + \Delta t \frac{dX_i}{dt} \qquad (17)$$

It should be noted that Δt is one of the most important constants and should be carefully set according to the optimization problem. This is because this parameter works as a scale factor of the speed vector. Δt completely depends on the search space and it seems it can be simply obtained from the following formula:

$$\Delta t = C_t \sum_{j=1}^{NV} (UB_j - LB_j) \qquad (18)$$

where NV is the total number of variables, and LB_j and UB_j are lower and upper bounds of the jth variabl (j =1,2,..., NV),respectively. Therefore, the absolute of their subtraction shows the search space. It is empirically found that C_t is a constant number between [0, 2]. It is also obvious that low values of C_t let the krill individuals to search the space carefully.

3.3. Genetic operators

To improve the performance of the algorithm, genetic reproduction mechanisms are incorporated into the algorithm. The introduced adaptive genetic reproduction mechanisms are crossover and mutation which are inspired from the classical DE algorithm. A basic representation of the KH algorithm is presented in Fig. 1.

4- Simulation Results

To demonstrate the capability of the proposed algorithm, simulations were implemented on to standard grids, namely IEEE 33-bus and 69-bus grids, and the results were compared to those of other methods. Four DG types were considered for the existing circumstances with 500, 750, 1000, and 1500 kilowatts of capacity. To study reliability, repair time and maneuver time were considered to be 5 hours and 1 hour, respectively.

4.1. Standard IEEE 33-bus grid

Simulation was conducted on a standard IEEE 33-bus grid, which is generallyadopted to investigate power loss and voltage profile [17]. The following results were attained.

Table. 1 shows the results of applying the proposed technique as well as those of other techniques. Figure. 2 is the single-line diagram of the IEEE 33-bus grid.

The results of Table. 1 indicate that KH algorithm managed to reduce power loss up to 62.53% outperforming all other algorithms in doing so. To provide a more tangible expression and compare the results

obtained from KH algorithm and other techniques, Figure. 3, 4, and 5 respectively exhibit undistributed power, power outage duration, and voltage profile of the 33-bus grid under experiment.
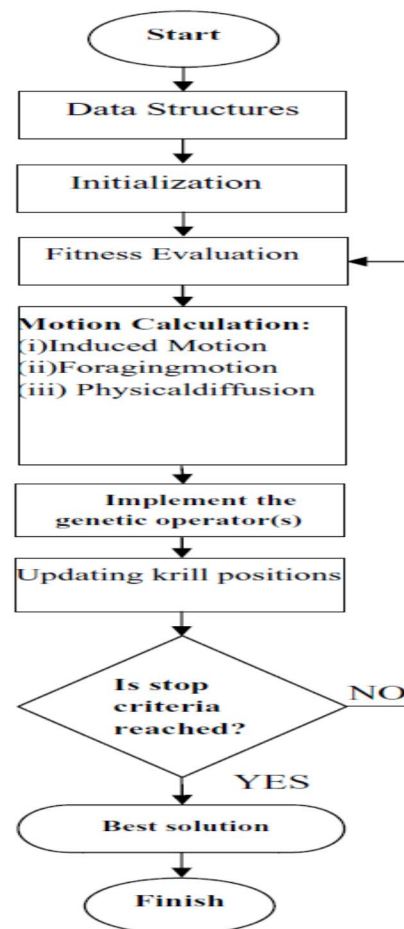

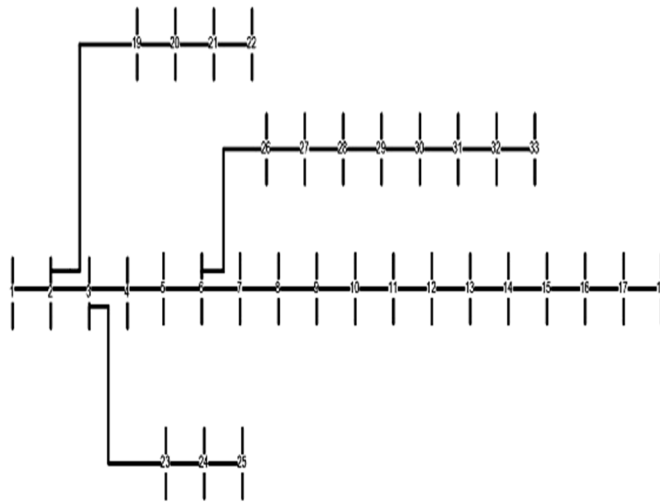**Fig. 1.** Simplified flowchart of the krill herd algorithm.

Fig. 2. The single-line diagram of the IEEE33-bus grid

Table. 1. Results of determining the location and optimal capacity of DGs on IEEE 33-bus grid

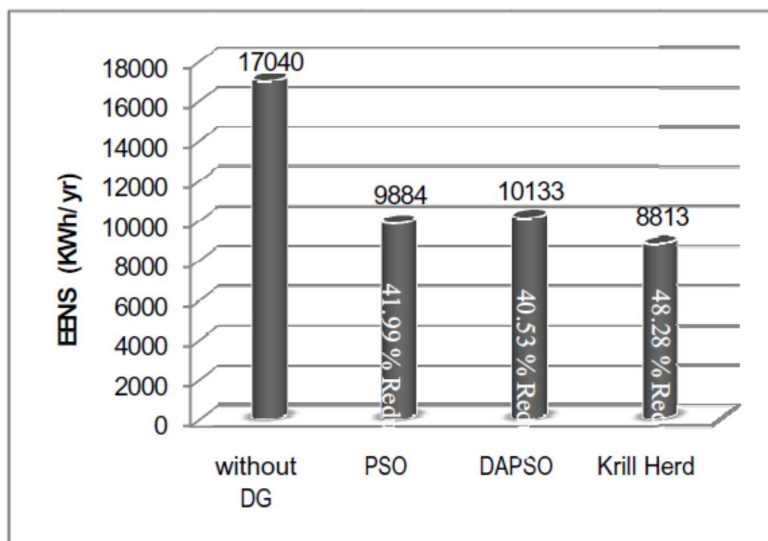| Technique	Location (Bus)	Installed DGs (MW)	Power loss (KW)	Bus voltage(p.u.)		EENS (KWh/yr)	SAIDI (hr/yr.cust)
				Least	Average		
Without DG	-	-	210.99	0.9038	0.9453	17040	4.5867
ABC	6,15	2.5	89.96	0.9510	0.9696	-	-
IA	6,12,31	2.52	81.05	-	-	-	-
LSF	15,18,32	2.43	85.05	-	-	-	-
PSO	7,12,17,32	2.25	81.48	0.9707	0.9828	9884	2.6607
DAPSO	15,26,32	2.25	81.41	0.9705	0.9811	10133	2.7277
KH	8,16,26,32	2.25	79.05	0.9702	0.9805	8813	2.3724

Fig. 3. Expected energy not supplied in different methods for the 33-bus grid under experiment
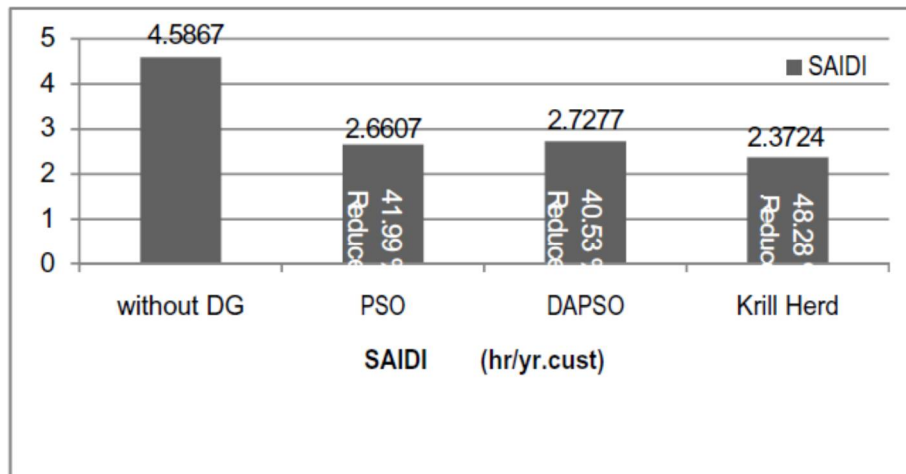
Fig. 4. The system average interruption duration index of the consumers of the 33-bus grid under experiment
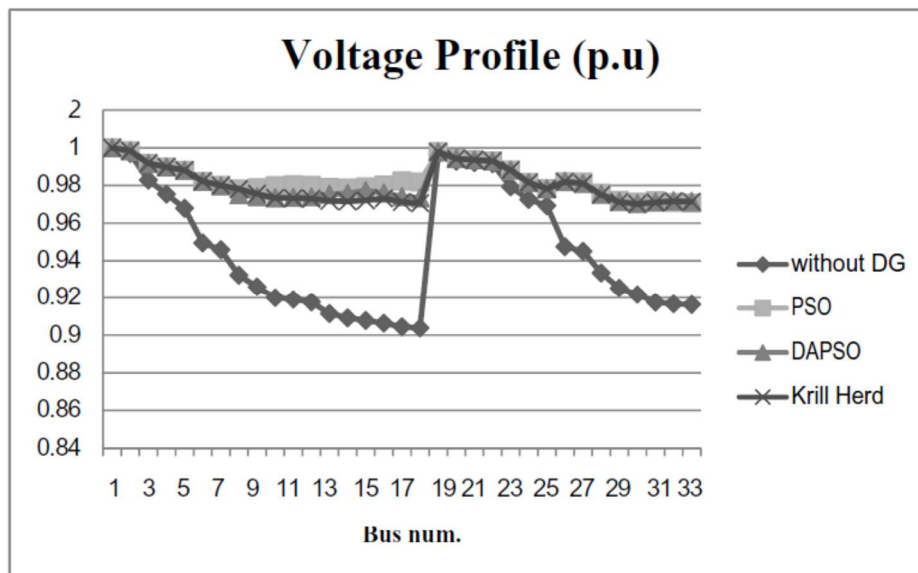

Fig. 5. Voltage profile the 33-bus grid under experiment

It may be deduced by observing Figure. 5 that the greatest values of voltage deviation occur around buses 7-18 and 27-33. All techniques mentioned here try to improve weak buses. A review of Table. 1 reveals that all algorithms selected a suitable location for the injection of DG in order to improve the distribution grid and the aforesaid parts. Figure. 5 clearly shows the success of the algorithms run to improve voltage deviation.

The results of Table. 1 clearly show that KH algorithm outperforms artificial bee colony (ABC) algorithm [18] and even other methods.

4.2. Standard IEEE 69-bus grid

Simulation was carried out again on a standard IEEE 69-bus grid, which is a large grid. The results were obtained as follows.

Table.2demonstrates the results of applying the proposed technique as well as other techniques. The single-line diagram of the standard IEEE 69-bus grid is in Figure.6.
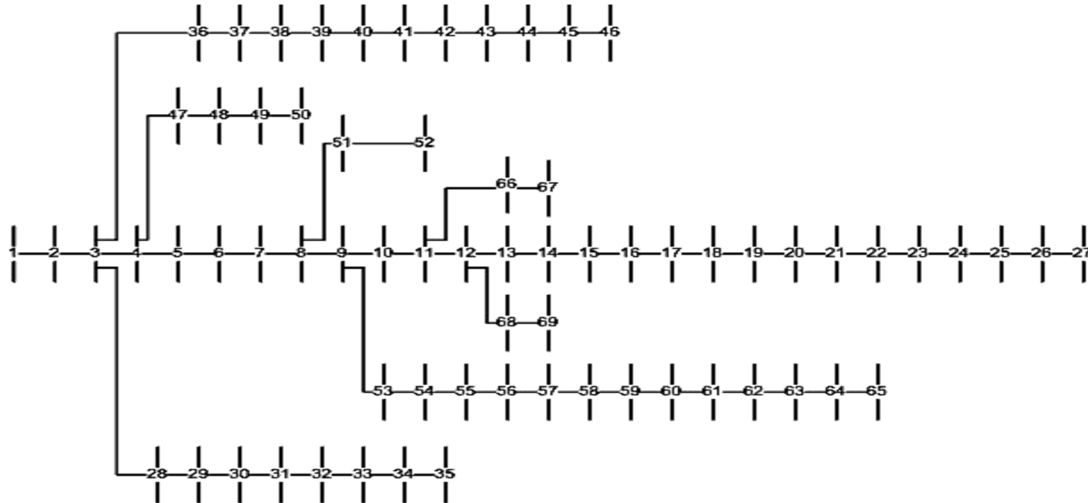

Fig. 6. The single-linediagram of the IEEE69-bus grid

Table.2. Results of determining the location and optimal capacity of DGs on IEEE 69-bus grid

Technique	Location (Bus)	Installed DGs (MW)	Power loss (KW)	Bus voltage(p.u.)		EENS (KWh/yr)	SAIDI (hr/yr.cust)
				Least	Average		
Without DG	-	-	224.89	0.9092	0.9734	286040	75.2589
PSO	27,31,37,44,60	2	156.66	0.9261	0.9820	254670	67.0095
DAPSO	3,19,31,52,58	2	152.28	0.9264	0.9824	259440	68.2631
KH	14,22,46,60	1.6	147.39	0.9286	0.9854	217910	57.3245

The results of Table. 2 show that PSO and DAPSO both demand higher power in kilowatts and, consequently, higher cost in comparison with Krill Herd technique. Krill Herd algorithm outperformed its competitors reducing grid loss up to 34.46%. This algorithm also yielded more favorable results in terms of reliability indices.

5- Conclusion

The determination of the location and optimal capacity of distributed generation units was investigated in terms of power loss and reliability indices in distribution grids. The effect of the above-mentioned factors was studied numerically. The results attained suggest that the proposed technique is efficient.

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