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Elephant Herding Optimization for Optimum Allocation of Electrical Distributed Generation on Distributed Power Networks

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***Abstract* - This paper deals with optimum allocation of distributed generation in the electrical distribution system. Due to rapidly increasing energy demand on the distribution network, the system is experiencing disturbances like equipment overloading, voltage sags and swell. In this paper the thermal and power loss constraints are considered for optimal operation. The optimal placement and sizing of distributed generation on electric distribution network by Elephant herding Optimization (EHO) technique. The conventional optimization technique fails due to its complexity while solving the nonlinear problems. The EHO technique is tested on 5 bus radial distribution system. The intelligent and precise allocation of distributed generation in electric distribution network by using EHO reduces the overloading of the equipment, voltage swell & sag, active power, reactive power and production cost of electricity. Furthermore, the suggested optimization technique is expanded to 24 bus radial distribution and practical Indian system.**

***Keywords:* Distributed Generation, Optimal Allocation, Renewable Energy Sources, Market Liberalization and Elephant Herding Optimization**

I. INTRODUCTION

Recently the initiatives on smart grid and sustainable energy Distributed Generations (DG) are playing an important role in electric power systems. In order to overcome energy demand the advantages of DG [1] are used to their potential. The future active network will effectively and efficiently link small and medium scale electric power sources with customer demands. Due to rapidly increasing energy demand on the distribution network, the system is experiencing disturbances like overloading the equipment's voltage sags & swell, thermal constraints and power loss. The current development in small-sized and modulated power generation technologies have led to large-scale deployment of distributed generation in electrical distribution network [2]. The optimal allocation of distributed generation may provide enormous techno economic and social benefits such as minimized power/energy loss. The optimal location of distributed generation [3] in the electric distribution network is a nonlinear optimization problem, generally comprised of number, location and sizes.

The optimal placement, size and location in the distributed generation have been developed and effectively employed using conventional methods [4,5]. These methods are experienced slow convergence rate in concerned search space. Both real as well as reactive power loss minimization are the objectives for DG placement [6] by using analytical methods. The analytical techniques [7] might not be suitable for complex problems, meta-heuristic and heuristic approaches offer a more feasible and simplified solution. A boundary based algorithm [8] is to obtain distributed generation determines the individual best values by ignoring the effect of other objectives. The allocation of distributed generation in electrical distributed network problem becomes a multi objective optimization [9] problem in which two or more objectives are optimized. The objective IS inconsistent, so multiple objectives are converted into a single-objective problem by assigning weights.

The Heuristic optimization algorithm is introduced to solve the optimal allocation of electrical distributed generation on distributed networks. They are Genetic algorithm [10] is used to place generation, such that loss costs and network disruption are minimized and the rating of the generator gets maximized. The various optimization techniques such as Tabu Search (TS) [11], Particle swarm Optimization (PSO) [12], Artificial Bee Colony (ABC) [13], Bat Motivated Optimization (BMO) [14], Ant Colony Optimization (ACO) [15], Bacterial Swarm Optimization (BSO) [16,17], Enriched Biogeography Based Optimization (EBBO) Algorithm [18] are introduced to solve the optimal allocation in distribution network successfully. The hybrid optimization algorithm include Improved Multi-Objective Harmony Search (IMOHS) [19] is applied to evaluate the impact of DG placement for an optimal planning of a distribution system.

The above mentioned heuristic approach is used to determine the optimal EG size and site from an investment point of view. In these literatures, the Short Circuit Level (SCL) constraints are not considered and the focus of the objective function is on optimal investment rather than maximizing renewable energy. In this paper this SCL and capital investment in new renewable distributed generation units are considered for optimal operation.

In this paper, a new simple nature inspired optimization technique called the Elephant Herding Optimization (EHO) [20] Algorithm inspired by the elephant herding behavior is used. The EHO method is inspired by the herding behavior of male and female elephant. The food and shelter searching technique is the main inspirations in this algorithm. This

EHO method is applied to solve the aforementioned optimal placement of distributed generation on electrical distributed network. In this paper, 5 bus radial distribution networks is considered and solved for optimal location in the distribution network. The fragmentations of this paper are divided into five sections Section 2 explains about the optimal placement of distributed generation problem formulation. Section 3 presents the overview of the proposed EHO algorithm. Section 4 discusses the application of EHO for optimal placement of distributed generation. Section 5 deals with detailed results and discussion followed by conclusion at Section 6.

II. PROBLEM FORMULATION

Embedded Generation is defined as the small capacity generation which is not connected to the transmission system. Now a day more amount of generation is being connected at distribution level, which led to change the characteristics of the power system network. To increase the amount of power generation there must be a change in the planning and design of the electrical distribution network. The majority of embedded generation is from renewable energy sources optimal use of the existing network helps to meet these targets in a cost effective manner. Generation capacity should be allocated across the buses such that none of the technical constraints is cracked and the capacity maximized [3]. Therefore the proposed objective function is

$$J = \sum_{i=1}^{N} P_{EGi} \tag{1}$$

Where P_{EGI} is the EG capacity at the i^{th} bus and without loss it is assumed that there is one generator connected at each bus. The objective function J (MW) is maximized subject to the constraints.

A. Thermal Constraint

The rated current of the lines must not be exceeded

$$I_i < I_i^{rated},\ i\forall N \tag{2}$$

Where I is the current flowing from the generator to bus and is the maximum rated current for the line between each generator.

B. Equipment Ratings

The following ratings considered here are Transformer Capacity, Short Circuit Limit, Short Circuit Ratio and Voltage Rise Effect, the detailed explanations are as follows

C. Transformer Capacity

The amount of power generation connected minus varying peak summer load didn't exceed the higher voltage rating of the transformer.

$$P_{Tx} \le P_{TrCap} \tag{3}$$

Where P_{Tx} refers to power flow through the transmission substation transformer and P_{TrCap} refers to the rating of that transformer.

D. Short Circuit Limit

A maximum short circuit rating for all equipment is laid down in the distribution code. A short circuit calculation is carried out to ensure that this constraint has not exceeded the installed capacity. The constraint is given by

$$SCL_{TX} < SCL_{Rated} \tag{4}$$

SCL is the highest current that breaks the switchgear safely under fault conditions. The contribution of increasing levels of generation at each bus to SCL is determined by short circuit analysis. The SCL contributions of generation at each bus are combined and formalized into an algebraic equation shown as follows

$$\sum_{j=1}^{N} \delta_{jTx} P_{EGj} + \alpha T_x \le SCL_{rated} \tag{5}$$

Where δ_{jTx} is the dependency of the SCL at the transmission station to power injections at bus j and αT_x is the initial SCL at the transmission bus o no generation present.

E. Short Circuit Ratio

The Short Circuit Ratio is the ratio of power generated MW at each bus to the Short Circuit Level at each bus. It indicates the voltage dip near the generator due to outage of feeder. When induction motors are placed in the circuit it leads to voltage instability.

$$\frac{P_{EGi}}{SCL_i.\cos(\varphi)} \times 100 \le 10\%, \forall N \tag{6}$$

Where SCL refers to the SCL at the i^{th} bus and $\cos(\phi)$ is the power factor at the generator. A base value for the SCL at the i^{th} bus is calculated with no generation present on the network. The short circuit characteristic of each bus is formulated into an algebraic equation. The SCL at the i^{th} bus is given by

$$SCL_i = \alpha_i + \sum_{j=1}^{n} \delta_{ji},\ i \ne j,\ i\forall N \tag{7}$$

$$P_{EGi} - 0.1\cos(\varphi)\sum_{j=1}^{N} \delta_{ji} P_{EGj} \le 0.1\cos(\varphi) * \alpha_i \tag{8}$$

F. Voltage Rise Effect

The voltage at the generator is given as

$$V_G = V_L + \frac{RP_L + XQ_L}{V_L} + j\frac{XP_L - RQ_l}{V_L} \tag{9}$$

P_L and Q_L are active and reactive power at the bus V_G and V_L are the voltages at the generator and bus respectively. Thus it is comprehended that the generator voltage will be the load/bus voltage and value related to the impedance of line and the power flows along that line.

The active power flow on the distribution network has a large impact on the voltage because the distributed network is high resistance compared to other lines. This leads to an X/R ratio of approximately rather than a more typical value of on transmission networks. The voltage must be kept within standard limits at each bus

$$V_{\min i} < V_i < V_{\max i} \quad (10)$$

Where $V_{\min}$ and $V_{\max}$ refer to the minimum and maximum voltage limits at the i_{th} bus. The relationship between voltage and power injections at each bus is determined.

As MWs are added at each bus the voltage rises Increasing levels of generation are added incrementally at each bus in turn and load flow analysis is carried out to determine a voltage versus active power characteristic for each bus. By combination of these characteristics the voltage constraint may be formalized into algebraic equations for each bus as shown in the following

$$\mu_i P_{EGi} + \beta_i + \sum_{j=1}^{N} \mu_{ji} P_{EGi} \le V_{\max i},\ i \forall N \quad (11)$$

Where μ_i is the dependency of the voltage level at bus i on power injections at bus i. i.e., the slope of the voltage versus power injection characteristic of the i_{th} bus. β_i refers to the initial voltage level at the i_{th} bus with no generation and μ_{ij} refers to the dependency of the voltage level at bus on power injections at bus.

This analysis is carried out under minimum load conditions as this is the worst-case scenario for voltage rise. Both the standby and normal forward-feed conditions are considered. There is usually more than one possible standby feeding arrangement, but the most severe feeding condition is usually readily identifiable.

III. ELEPHANT HERDING OPTIMIZATION

The EHO [21] search method is based on the herding behavior of elephant groups. In living world the elephants belonging to different clans live together under the directorship of a matriarch (female elephant) and when the male elephants are grown up they leave their family groups.

The elephant behavior in search of food and shelter is modeled in two ways. These include clan updating operator and separating operator. The current position of each clan is updated by the matriarch this process is known as clan updating operator. It is followed by the implementation of the separating operator which enhances the population diversity at the later search phase. Elephant herding optimization is implemented by the following procedure

1. The elephant population is composed of some clans and each clan has fixed number of elephants.
2. The male elephants will leave their family group and live alone far away from the main elephant group at each generation.
3. The elephants in each clan live together under the leadership of a matriarch.

A. Clan Updating Operator

As earlier said all elephants live together under the directorship of a matriarch in each clan. Therefore for each elephant in clan ci, its next position is influenced by matriarch ci. For the elephant *j* in clan C_i , it is updated as

$$X_{new,ci,j} = X_{ci,j} + \alpha \times (X_{best,ci} - X_{ci,j}) \times r \quad (12)$$

Where $\mathrm{X}_{\mathrm{new,ci,j}}$ and $\mathrm{X}_{\mathrm{ci,j}}$ are newly updated and old position for elephant *j* in clan C_i respectively. $\alpha \in [0,1]$ is a scale factor that determines the influence of matriarch C_i on $\mathrm{X}_{\mathrm{ci,j}}$. $X_{best,ci}$ represent matriarch C_i which is the fittest elephant individual in clan C_i, $r \in [0,1]$ Here uniform distribution is used. The fittest elephant in each clan cannot be updated by eqn.(12), i.e., $X_{ci,j} = X_{best,ci}$

For the fittest one, it is updated as

$$X_{new,ci,j} = \beta \times X_{center,ci} \quad (13)$$

Where β is a factor that determines the influence of the $X_{center,ci}$ on $X_{center,ci,j}$. The new individual $X_{new,ci,j}$ in eqn.(13) is generated by the information obtained by all the elephants in clan C_i . $X_{center,ci}$ is the Centre of clan C_i and for the d^{th} dimension it is calculated by

$$X_{center,ci,d} = \frac{1}{n} \times \sum_{j=1}^{nci} X_{ci,j,d} \quad (14)$$

Where $1 \le d \le D$ indicates the d^{th} dimension and *D* is its total dimension. n_{ci} is the number of elephants in clan C_i. $X_{ci,j,d}$ is the d^{th} of the elephant individual $X_{ci,j}$ The Centre of clan C_i, $X_{center,ci}$ is calculated through *D* calculations by eqn.(14).

B. Separating Operator

In elephant's group male elephants leave their family group and live alone. This process is modeled as clan separating & updating operator, which is used for solving optimization problems. In order to further improve the search ability of EHO method. Let us assume that the elephant individuals with the worst fitness will implement the separating operator at each generation as shown in eqn. (15).

$$X_{worst,ci} = X_{\min} + (X_{\max} - X_{\min} + 1) \times r \quad (15)$$

Where $X_{\max}$ and $X_{\min}$ are respectively upper bound and lower bound of individual elephant position. $X_{worst,ci}$ is the worst elephant individual in the clan C_i. $r \in [0,1]$ is a kind of stochastic distribution and uniform distribution in the range [0,1] is used in this paper.

C. Pseudo Code of Clan Updating Operator

For
{
C_i *= 1 to* n_{clan} *(all clans in elephant population) do*
For
{
j = 1 to n_{ci} *(for all elephants in clan* C_i*) do*
Update $X_{ci,j}$ *and generate* $X_{new,ci,j}$ *by eqn. (12)*
If
{
$X_{ci} = X_{best,ci}$ *then*
Update $X_{ci,j}$ *and generate* $X_{new,ci,j}$ *by eqn.(13)*
}
End if
}
End for j
}
End for C_i

D. Pseudo Code of Separating Operator

For
{
C_i *= 1 to* n_{clan} *(all clans in elephant population) do*
Replace the worst elephant in clan C_i *by eqn.(15)*
End for C_i
}

E. Pseudo Code of EHO Algorithm

Initialization: Set generation counter $t = 1$; *Initialize the population; the maximum generation Max Gen*
While
{
t, Max Gen do
Sort all the elephants according to their fitness.
Implement clan updating operator
Implement separating operator as shown
Evaluate population by the newly updated positions
$T = t + 1$
}
End while

IV. IMPLEMENTATION OF EHO FOR OPTIMAL ALLOCATION OF DISTRIBUTED GENERATION ON DISTRIBUTION NETWORK

Usually the elephants form some groups and move in search for food and shelter. In this context, the elephant moment from one location to another location is considered as power flow from one bus to another bus. They update their position and location status. Similarly in the optimal allocation problem; it's related to the bus location and bus data. Elephants communicate with each other by low frequency vibrations. When they find the worst case of disturbances in the search space in a particular place, it communicates with each other clan (groups). Meanwhile, low voltage and high voltage fluctuations are the main cause of disturbance and losses in the distribution network. In a distribution network due to sudden change in load, the bus voltage starts fluctuating. Depends on the voltage fluctuations, the weaker buses are identified. The best position find by the elephant is the best bus (voltage profile) location. The position of the elephant location with more disturbances is the best position for placement of distributed generation.

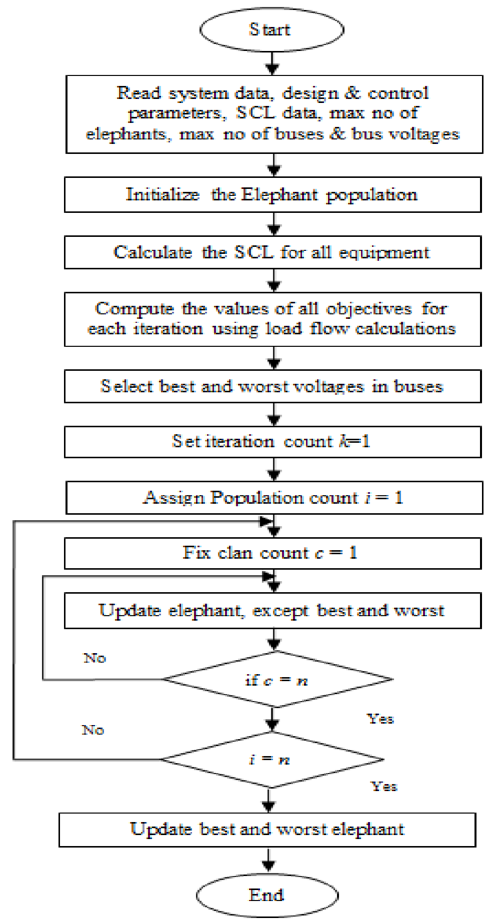

Fig. 1 Flowchart of implementing EHO to optimal placement of distributed generation

The following steps explain the implementation of EHO for optimal DG allocation in distributed networks
Step 1: Initialize max number of elephants, no of elephants, no of buses, bus data node voltages, Short Circuit Level, α and β.
Step 2: Update the best and worst position of the elephant, i.e., best and worst bus voltage.
Step 3: Update the worst position of elephant i.e., worst bus voltage.
Step 4: Elephants will communicate with others to update the current worst position (Local Solution) among the iteration.
Step 5: Now the elephants will keep on herding to find the global best position (worst Location). By finding the worst

location, the voltage profile is improved by placing DG's in the identified bus.

V. RESULTS AND DISCUSSION

The elephant herding optimization technique is tested on 5 bus radial distribution systems [3]. The tail fed 38/110 kV station with 5 buses is shown in Fig. 2. The EHO is verified to test on practical larger networks. This section is chosen to illustrate the results as it demonstrates the potential for network sterilization very well.

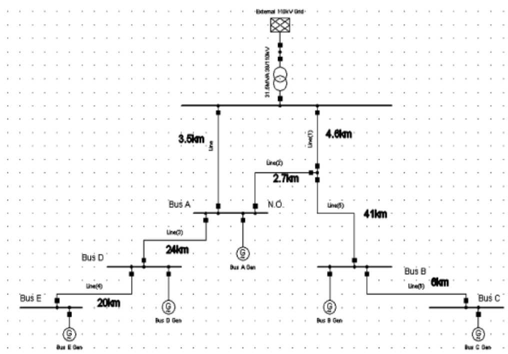

Fig. 2 33 KV 5 bus Radial distribution network diagram

By injecting power at various buses the solitary voltage sensitive attributes are formed and presented in Fig. 3.

By using the solitary voltage sensitive attributes, it is found that bus A is least sensitive to power injections at different buses. The bus A is least sensitive due to bus A is located very near to 38/110 station. The bus B and bus C have similar characteristics because they are connected separately from the network.

The values of $\mu_i(kV/MW)$ are determined from Fig.3. Where μ_i is the dependency of voltage level at the bus *i* on the power injection at bus *i*. The slope of the voltage versus power injection characteristics of i^{th} bus, the values of μ_i are presented diagonally in Table I.

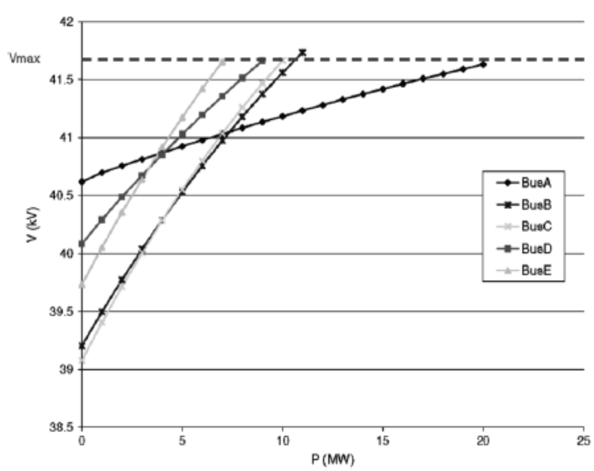

Fig. 3 Individual bus voltage sensitivities to power injections at buses

The values of μ_{ij} are presented in Table I as off diagonal elements. Where μ_{ij} is the dependency of voltage level at bus i on the power injection at bus *j*.

TABLE I VOLTAGE INTERDEPENDENCIES OF 5 BUS SYSTEM

μ (kV/MW)	Bus A	Bus B	Bus C	Bus D	Bus E
Bus A	0.053	0.008	0.007	0.021	0.016
Bus B	0.012	0.218	0.18	0.009	0.007
Bus C	0.012	0.191	0.238	0.009	0.007
Bus D	0.026	0.008	0.007	0.162	0.11
Bus E	0.026	0.008	0.007	0.135	0.234

The individual sensitivity of SCL at 38/110kV station to power injection at individual bus is calculated and presented in Fig.4

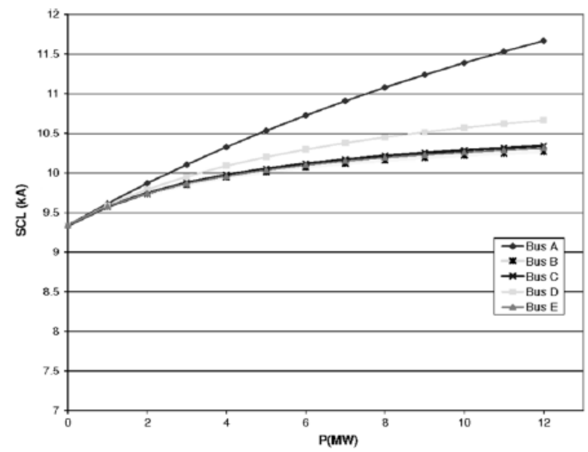

Fig. 4 SCL at 33/11 KV Station vs Power Injections at Individual Buses

The effect of bus on the SCL at 38/110kV station is dependent on the distance from the station. The impact of SCL is very high to bus A as the location of bus A is near to 110kV station. The values of $\delta_{iTX}(kA/MW)$ are shown in Table II. Where δ_{iTX} is the dependency of the SCL at the transmission station to power injection at bus *j*. the slope of the SCL versus power injection characteristics of the j^{th} bus is shown in Fig.4.

TABLE II SCL_{Tx} DEPENDENCIES OF 5 BUS SYSTEMS

Dependency Factor/ Bus	Bus A	Bus B	Bus C	Bus D	Bus E
δ_{Tx} (kA/MW)	0.18	0.11	0.10	0.14	0.11

Case 1: Customer Generation at Bus E

In this case 7 MW of customer generation is allocated to bus E. By EHO algorithm, sensitivity values of the maximum allocation is determined, after 20 iterations the power generation tends to 10.60MW is shown in Table III.

Case 2: Without Preallocated Generation

In this section no generation is prior allocated. The EHO is applied and the total allocation after 20 iterations is determined as 20.65MW. The EHO technique works on all sections of the radially operated distribution system. The severity of system sterilization varies with the level of interdependence between the buses. The distributed system modeled in the paper has a high level of interdependence. Under standby feeding conditions all five buses are connected to the transmission bus by a single bus line. In larger systems there are a number of lines connecting the buses to the transmission bus with normally open points separating sections. This reduces the overall interdependence of the voltage levels, but not of the SCL. Thus the potential for system sterilization is reduced.

TABLE III OPTIMAL ALLOCATION OF DG IN DIFFERENT CASES CONSIDERED

Bus No	Linear Programming Algorithm [3]		EHO (Proposed)	
	Case 1	Case 2	Case 1	Case 2
	Actual Power in bus (MW)	Power Injected (MW)	Power Injected (MW)	Power Injected (MW)
Bus A	0	4.06	0	3.95
Bus B	0	4.30	0	3.82
Bus C	3.60	5.95	3.60	5.27
Bus D	0	5.31	0	4.86
Bus E*	7.60	3.12	7.00	2.85
Total Power Injected	11.20	22.74	10.60	20.65

*7.6 & 7.00 MW are the power injected by customer at Bus E

From the Table III, it is clear that the proposed EHO technique outperforms the Linear Programming Algorithm by the means of the power injection considered in scenario 2. By using the EHO technique the power injected in the bus E and with respect to all other buses is also decreased comparatively, which shows the superiority of the proposed optimization technique. By using this EHO technique 9.19% power injected is reduced, which is clear from the Table III. Meanwhile, the cost incurred in the particular DG will be saved.

The EHO determines the optimal allocation from the capital investment and helps the distribution companies to identify the possibility of faults. The projected technique also reduces the dependency of the individual bus. Moreover the DG allocation at the particular bus is optimized, which improves the stability of the system.

VI. CONCLUSION

This paper proposes the elephant herding optimization technique for optimal allocation and sizing of distributed generation on electrical distribution networks. DG is the perfect solution of today's and future's power generation and distribution system. This could meet the demanding needs of the consumers economically and environmentally by minimizing the cost, complexity associated with on-site power generation, transmission and distribution. The proposed technique is applied on 5 bus radial distribution system and the results are presented. The result clearly indicates that the proposed EHO algorithm gives the optimal results. The proposed EHO technique is capable of producing higher quality results in terms of optimal allocation and sizing of distributed generation. The proposed EHO technique outperforms the conventional technique and the power injected by the DG in the weaker bus is also reduced considerably. The proper allocation and sizing of DG reduces the fuel cost to the distribution companies. Furthermore, this considered optimization technique may apply to the future operation of the Indian power distribution network for the proper constituting electric system.

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