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Research Article

OPTIMAL LOCATION AND SIZING OF DGS FOR IMPROVING DISTRIBUTION SYSTEM PERFORMANCE USING EVOLUTIONARY OPTIMIZATION TECHNIQUE

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A B S T R A C T

In this paper, a comprehensive planning methodology is proposed that can minimize the line loss, maximize the stability and improve the voltage profile and load balancing in a radial distribution network, by using distributed generation units (DGs). The injection of the distributed generation (DGs) sizes at different buses are optimally controlled. The objective function includes: power losses reduction, maximization of voltage stability, voltage profile improvement and load balancing in a radial distribution network, while minimizing the cost and the number of DGs. Linearized Biogeography Optimization Technique (LBBO) is used to solve the previously stated problem. The proposed method is applied on IEEE-33 bus radial distribution system. Both technical advantages and economic savings of adding DG units to the system are discussed. Test results show that the proposed method is effective and has a high capability in finding optimum solutions along with the enhancement of system performance and significant economic savings.

INTRODUCTION

Distribution system causes about 13% of the losses of the power system according to the previous literature. Also the voltage drop in the system causes significant losses. The expansion of the distribution system due to the increase of demand can cause further voltage drop in addition to the increase of power losses and load imbalance, that can cause reduction of voltage stability. To solve this problem, the use of Distributed Generation (DGs) sources is increased. DGs are used to reduce losses, improving the voltage profile, increasing the efficiency of energy, higher power quality and system reliability improvement. DGs can be categorized as renewable and non-renewable sources. DGs has also several economic advantages such as decrease of operational costs, optimized production, decreasing the cost due to energy savings and increase in protection of critical loads.

A hybrid Genetic Algorithm/Particle Swarm Optimization technique was used to solve the optimal location and sizing of DGs on distribution system problem. The main objective of the paper is to minimize the power loss and maximize voltage regulation maintaining the operational and security constraints (Mouradi & Abedinie, 2010).

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An artificial Bee Colony was presented by Abu-Mouti & El-Hawary, (2011) to obtain the optimal DGs size, power factor and location to minimize the total system real power loss. An improved analytical (IA) was proposed by Hung & Mithulananthan, (2013) , where generation placement in large scale primary distribution networks was discussed. The IA method calculates the size and location of four different DG types. An optimal location and sizing of renewable DGs was obtained using evolutionary programming by Khatod *et al.*, (2013). A Conversion Voltage Reduction (CVR) and Distributed Generation integration strategy was proposed to minimize the load consumption in distribution networks, while maintaining the lowest voltage level within a specified range (Wang *et al.*, 2013). A multiple replication procedure was implemented to test the solution stability. A multi-objective function is introduced to obtain the optimal DG location, where the objective function was developed from several performance factors such as power losses indices and voltage deviation and reliability indices (Bohre *et al.*, 2016).

Problem Formulation

The optimal location and sizing problem of DGs is categorized as an optimization problem that have a non-linear objective function with equality and inequality constraints. This objective function comprises: reducing power losses, DGs installation costs, improving voltage profile and stability of the system and help in balancing the current of the system in any radial distribution network (Mouradi *et al*., 2014).

This objective function is illustrated as follows:

$$Min(F_T=f_1+k_1f_2+k_2f_3+k_3f_4) \quad (1)$$

Where, k_1, k_2 and k_3 are penalty coefficients for objective functions of f_2, f_3 and f_4, respectively. These coefficients are adjusted according to importance degree of objective functions. $k_1 = 0.6$,

$k_2 = 0.35$ and $k_3 = 0.05$ are considered in this paper.

Power Losses (f_1)

DGs are used to reduce the active losses of the whole system. To calculate the network active power losses:

$$f_1= P_{RPL}= \sum_{i=2}^{n_n} (P_{gni} - Pd_{ni} - V_{mi}V_{ni}Y_{ni}\cos(\delta_{mi} - \delta_{ni} - \theta_{ni})) \quad (2)$$

Improving voltage profile (f_2)

The objective function for improving the voltage profile is:

$$f_2=\sum_{n_i=1}^{n_n} (V_{ni} - Vr_{ated})^2 \quad (3)$$

Voltage stability Index (f_3)

Consider a branch of a radial system as shown in figure (1), the voltage stability index of the system changed as a result of connecting DGs.

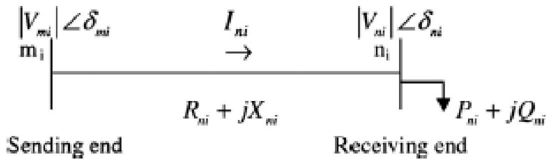

Fig 1 A branch of a radial distribution system

The equation used to calculate this index is presented to solve the load flow for radial system (Vovos & Bialek, 2005). The voltage stability index of the system is calculated as follows:

$$SI(n_i)= |V_{mi}|^4 -4[P_{ni}(n_i)R_{ni} + Q_{ni}(n_i) X_{ni}] |V_{mi}|^2 - 4[P_{ni}(n_i)R_{ni}+Q_{ni}(n_i)X_{ni}]^2 \quad (4)$$

$$f_3= \frac{1}{SI(ni)} \qquad n_i =2; 3; \ldots ; n_n \quad (5)$$

For a stable operation of the distribution system SI(ni) must be greater than zero and the maximum value of SI(ni) for n_i=2, 3, 4,....,n_n, which causes minimum value of f_3, that is considered as a feasible solution. Buses with minimum voltage stability index may be unstable. To improve the voltage stability SI(n_i) must be minimized (Charkavorty & Das, 2001) as a result the objective function must be minimized.

Load Balancing (f_4)

This part of the objective function represents the load balancing of the line. The following equation represents it (Prasad *et al*., 2008)

$$f_4=1/n_n \sum_{i=1}^{n_n} (S_{ni}/S_{i\,max}) \quad (6)$$

Constraints

Load balancing constraint

$$P_{gni}-P_{dn}i-V_{ni} \sum_{j=1}^{N} V_{nj}\, Y_{nj} \cos(\delta_{mi} - \delta_{ni} - \theta_{ni}) =0 \quad (7)$$

$$V_{ni+1}{}^2= V_{ni}{}^2-(r_{rni+1} P_{ni}+ x_{ni-1} Q_{ni}) + (r_{ni+1}{}^2+x_{ni+1}{}^2(P_{ni}{}^2+Q_{ni}{}^2)/V_{ni}{}^2) \quad (8)$$

Voltage constraint

The voltage range as follows

$$V_{min}\le V_{ni}\le V_{max} \quad (9)$$

System load balancing

$$LB_i=\sum_{i=1}^{n_n} (S_{ni}/S_{i\,max}) \quad (10)$$

DG constraints

The DG source must have an allowable rating and power factor as follows

$$S_{DGmin}\le S_{DGni}\le S_{DGmax} \quad (11)$$

$$pf_{DGmin}\le pf_{DGn}i\le pf_{DGmax} \quad (12)$$

Thermal limit

Final thermal limitation of distribution lines of the network must not exceed the following range

$$lS_{ni}l \le lS_{nimax}l \quad ni = 1.....N \quad (13)$$

Also, active power and power factor of DGs must be between the maximum and minimum levels

$$P_{DG} = [0, P_{DGmax}] \quad (14)$$

Economic evaluation of applying DGs simultaneously

DGs installation cost

$$C_{IDG} = \sum_{i=1}^{n_{DG}} C_{DGni} \,.\, K_{IDG} \quad (15)$$

Operation and maintenance cost of DGs

$$C_{o\&mDG} = \sum_{y=1}^{nyr} \sum_{i=1}^{N_{DG}} PW_y.\, P_{gni}.\, K_{EDG}.\, T \quad (16)$$

where, the presenting worth factor PW is formulated as follows:

$$PW= (1+InfR)/(1+IntR) \quad (17)$$

Economic saving

Purchased power's cost from substation which includes losses for a passive RDS is equal to:

$$C_{ssbef.plac}=\sum_{y=1}^{nyr} PW_y.K_{ss}.(Real(V_{ss}.I_{inj}{}^*)^{bef}.T \quad (18)$$

By installing DGs, the distribution companies can provide their portion of power demands from these resources and also compensating losses by DGs. In this case, after installing DGs, the cost of purchased power from substation for an active RDS is reduced to:

$$(C_{ssbef.plac}-C_{ssaft.plac})=\sum_{y=1}^{nyr}PWy.K_{ss}.(Real(V_{ss}.I_{inj}^{*})^{bef.}-Real(V_{ss}.I_{inj}^{*}))^{aft.}).T \qquad (19)$$

In fact an economical saving or benefit is yielded. The benefit which includes total costs of the DGs in period their life time can be formulated as follow:

$$\text{Final benefit} = (C_{ssbef.\ plac} - C_{ssaft.\ plac}) - (C_{IDG} + C_{o\&mDG} + C_{cap}) \qquad (20)$$

The flow chart of the proposed procedure is illustrated in figure (2) as follows:

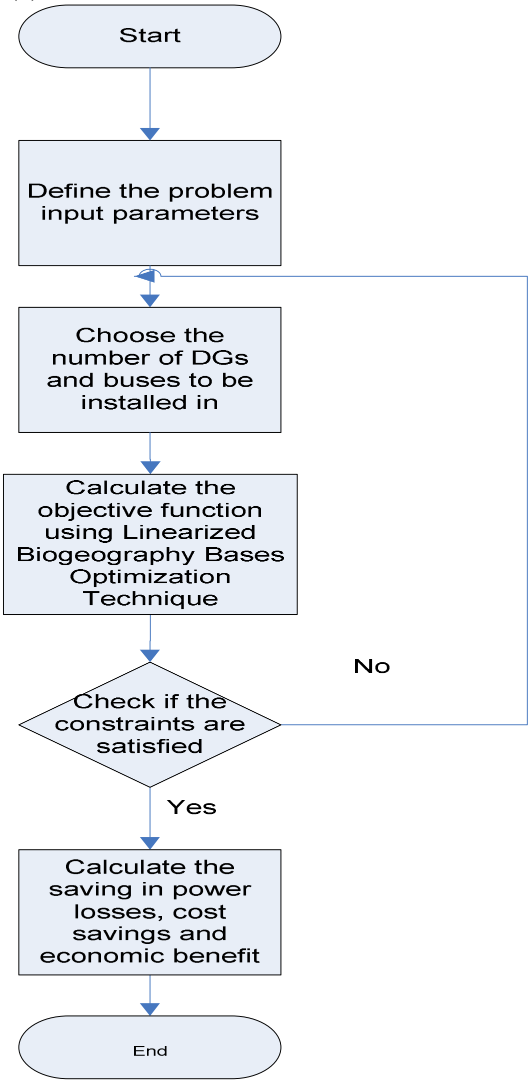

Fig 2 Flow Chart of the proposed procedure

Linearized Biogeography Optimization Technique

Linearized Biogeography-Based Optimization (LBBO) technique was developed in 2014 from the Biogeography-Based Optimization (BBO) technique, which was proposed in 2008 by Dan Simon. Biogeography is the environmental science that deals with the geographical distribution of species and ecosystem in geographic space. BBO is inspired from the island biogeography. The study of species composition and richness on the islands is called biography, which the island biogeography is the study which explains the factors affecting the diversity of the species on a specific community. Several factors affect the species distribution such as food, temperature, area of the land and topographic factors, etc. As a result, some improvement occurs due to the exchange of features due to the species movement between areas. BBO algorithm operates on a population of individuals called a habitat. A habitat is a geographically isolated island. The fitness of any habitat is indicated by a habitat suitability index (HSI). The variables that characterize habitability are called suitability index variables (SIVs). One of the important factors that affects the species distribution on the islands is the Migration. Migration is represented by two processes, the emigration and the immigration between islands. In biogeography, the emigration is that the species leave the island but don't become extinct. Similarly in BBO, Emigration is the sharing of any solution features from one individual to another so that the solution features remains unchanged in the emigrating individual. While the immigration is the process in which the solution features of an individual is replaced by a new solution feature from another individual. Figure (3), shows the relationship between the immigration rate λ and the emigration rate μ and the species count (Simon, 2008).

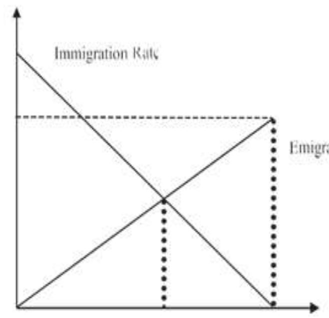

Fig 3 Immigration rate, emigration rate vs species count curve.

When there is no species in the habitat, the maximum immigration rate is I, in which it is achieved and the emigration is equal to zero. S_{max} is the maximum number of species in the habitat. When S_{max} is achieved the immigration rate is equal to zero and the emigration rate is at its maximum (E). Mutation is another factor affecting the species richness of an island. The mutation operator is used to retain the diversity of individuals and break away local optimums, similar to the Genetic Algorithm. For each candidate solution S, there is a mutation probability associated:

$$M(S)=\frac{M_{max}(1\ \ Ps)}{P_{max}} \qquad (21)$$

Where, M_{max} is a user defined parameter, Ps is the species count of habitat and P_{max} is the maximum species count.

Mutation is achieved based on the mutation probability of a habitat by replacing a certain SIV with a random generated one. The BBO algorithm is illustrated as follows:

1. Select the BBO parameters, that includes the maximum migration rates E, I, S_{max} the maximum mutation rate m_{max}, the minimal emigration rate θ
2. Select a random set of habitats
3. For each habitat, select the immigration rate λ and the emigration rate μ
4. By using the migration rates, compute the habitats fitness
5. Update the species count for each habitat, then re-compute the new fitness
6. From step (3), to perform the next iteration until the predefined number of generations is reached or an acceptable solution is found

BBO treats each solution feature independently. It is not rotationally invariant (Simon *et al*., 2014). As a result BBO performs poorly when it is applied on non-separable functions. Another weakness is its local search ability. To overcome the BBO drawbacks, LBBO was developed as follows:

a. Linearization of BBO migration: To make the migration more rotationally invariant
b. By applying the gradient descent to BBO: To overcome the weakness of the local search ability
c. A global grid search strategy: To cover the search space
d. Constraints
e. Latin hypercube strategy: To cover the whole search space nearby the current best individual
f. Initialization and restart

Simulation Results

Test system

To solve the previous problem using the LBBO technique, it was applied on an IEEE 33- bus radial distribution system is used as illustrated in figure (4) to validate the proposed method.

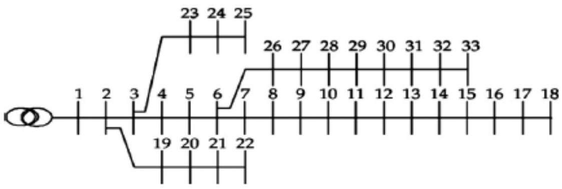

Fig 4 Single line diagram of IEEE 33- bus system

Pre installing the DGs, the real power losses of the 33-bus RDS is 130 KW. The objective function is obtained as follows:

Table 1 Objective Function without using DGs

Case	F1	F2	F3	F4
No DGs	20.20	0.0494	0.8599	0.3386

To observe the effect of adding the DGs to the RDS, three cases are studied (using 2, 3 and 4 DG sources). The proposed method is implemented using Matlab and applied on the test system.

To Solve this problem, some assumptions and constraints are used:

a. Maximum power of DGs is assumed to be 1.2 MW
b. The Power Factor of the DGs used is 1

The results are divided into two parts

Results relating to network performance and technical advantages

As per illustrated Table 2, shows the real power losses and savings in real power losses in KW for the three cases. Table 3 shows the objective function values for the three cases.

Table 2 Real Power Losses after using DGs

Case	No. of DGs	n_{DG}	DG Capacity (MW)	Total MW of DGs	Real Power losses in kW	Savings in kW
1	2	6, 15	1.05, 1.06	2.11	103	27
2	3	6, 15, 25	1.06, 1.05, 1.09	3.2	78	52
3	4	6, 15, 25, 32	1, 0.7, 1, 1.02	3.72	51	79

Table 3 Objective function values

Case	F1	F2	F3	F4
1	8.532	0.048	1.0677	0.23
2	8.5	0.0023	1.0594	0.1938
3	0.0095	0.0062	0.854	0.19

As shown in the results above, by employing DGs, the savings in power losses (KW) increases which increases the efficiency of the system. The losses decreases using the proposed method from 20-60% by increasing the number of DGs.

Also, the performance of the system is enhanced as the objective function values are minimized. By comparing the results shown in tables (2) and (3), the values of the voltage profile, voltage stability index and load balancing are improved.

Results relating to economic savings

In this subsection, the economical saving is discussed. The cost of purchased power dispatched from substation including losses and the cost energy saving is discussed for all case studies.

Table 4 Cost of Purchased Power dispatched from substation including Losses

Case	Without DGs	1	2	3
Cost of Purchased Power dispatched from substation including Losses (M$)	7.67721	3.9101	3.9162	3.9209

Table 5 Economic results

Case	Saving in M$	Final Benefit in M$
1	3.767	2.4236
2	3.761	1.9635
3	3.756	1.6559

As illustrated in table 4, by using the proposed method in addition to the technical advantages, the cost of purchased power from substation including losses post installation of DGs is decreased by 51%.

Also, the economic saving and final benefit obtained after 5 years is illustrated in table 5. It is shown that, by employing DG sources the savings in cost increases.

CONCLUSION

In this paper the Linearized Biogeography Based Optimization (LBBO) technique is proposed to solve the problem of optimal placement and sizing of DGs in a radial distribution system. This method is applied on an IEEE 33-bus distribution system. Both technical performance and economic issues are studied in this paper. The results yielded to the minimization of losses, voltage stability, improvement of voltage regulation index and the load balancing with reduction of the purchased energy from the substation, which proves the effectiveness of the LBBO.

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Annex I Nomenclature

RDS	Radial Distribution system	$\lvert S_{ni}^{max} \rvert$	Maximum apparent power at bus n_i
n_n	Total number of buses in the RDS	Y_{ni}	Admittance between bus n_i and m_i
n_i	Receiving bus number (2,3,..n)	θ_{ni}	Phase angle of Yi=Yni ∟θ_{ni}
m_i	Sending bus number	δ_{ni}	Phase angle of voltage at bus $_{ni}$
I	Branch number that feed bus n_i	δ_{mi}	Phase angle of voltage at bus $_{mi}$
N	Total number of branches (n_n-1)	I_{ni}	Current of branch i
N_{DG}	Total number of DGs	R_{ni}	Resistance of branch i
C_{DG}	Capacity of the DG	X_{ni}	Reactance of branch i
n_{DG}	Bus number of DG installation	SI(n_i)	Voltage stability index of node n_i
P_{gni}	Active power output of the DG at bus n_i (pu or MW)	LBi	Load Balancing Index of bus i
Q_{gni}	reactive power output of the DG at bus n_i (pu or Mvar)	pf^{DG}	Power factor of DG_i at bus n_i
P_{dni}	Active power demand at bus n_i (pu or MW)	S^{DG}	Apparent power of DG_i at bus n_i
Q_{dni}	Reactive power demand at bus n_i (pu or Mvar)	K_1, K_2, K_3	Penalty coefficient (0.6, 0.35, 0.06 respectively)
$P_{ni}(n_i)$	Total real power demand at bus n_i	F_1	Term representing the network's real power losses
$Q_{ni}(n_i)$	Total reactive power demand at bus n_i	F_2	Term representing the network's voltage profile
P_{gni}^{min}	Minimum active power output of the DG at bus n_i	F_3	Term representing the network's voltage stability
P_{gni}^{max}	Maximum active power output of the DG at bus n_i	F_4	Term representing the load balancing
P_{RPL}	Real power losses of n_n-bus distribution system	K_{IDG}	DG installation cost ($/MW)=500,000
Q_D	Total reactive power demand	n_{yr}	Planning period (year)=5
V_{ni}	Voltage at bus n_i	T	1 year Period=8760 hrs
V_{mi}	Voltage at bus m_i	IntR	Interest rate=9%
V_{ni}^{min}	Minimum voltage at bus n_i	InfR	Inflation rate=12.5%
V_{ni}^{max}	Maximum voltage at bus n_i	K_{EDG}	Operation and maintenance cost of DG sources ($/MWh)= 36
V_{ss}	Nominal Voltage of substation (1pu or 12.66 KV)	$I_{inj.}$	Injected current from substation to RDS
K_{ss}	Energy market price ($/MWh)=49		

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