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ORIGINAL ARTICLE

Reliability Enhancement Using Optimal Placement of Distribution Generation in Radial Distribution System

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ABSTRACT
Increasing application of DG on distribution networks is the direct impact of development of technology and the energy disasters that the world is encountering. To obtain these goals the resources capacity and the installation place are of a crucial importance. Line loss reduction is one of the major benefits of DG, amongst many others, when incorporated in the power distribution system. The quantum of the line loss reduction should be exactly known to assess the effectiveness of the distributed generation. In this paper, a new method is proposed to find the optimal and simultaneous place and capacity of these DG units to reduce losses, improve voltage profile too the total loss of a practical distribution system is calculated with and without DG placement and an index, quantifying the total line loss reduction is proposed. To demonstrate the validity of the proposed algorithm, computer simulations are carried out on actual power network of Kerman Province, Iran and the simulation results are presented and discussed.
Keywords Distribution systems, Loss reduction index, DG placement, Imperialist Competitive Algorithm

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INTRODUCTION

The loss minimization in distribution systems has assumed greater significance recently since the trend towards distribution automation will require the most efficient operating scenario for economic viability variations. The power losses in distribution systems correspond to about 70% of total losses in electric power systems [4, 16].To reduce these losses, shunt DG is installed on distribution primary feeders. The advantages with the addition of shunt DGs are to improve the power factor, feeder voltage profile, Power loss reduction and increases available capacity of feeders. Therefore it is important to find optimal location and sizes of DGs in the system to achieve the above mentioned objectives. Distributed Generation (DG) may play an increasingly important role in the electric power system organization and market. Unlike traditional generation, the aim of distributed generation is to generate part of required electrical energy on small scale closer to the places of consumption and interchanges the electrical power with the network. The sitting of distributed generator in distribution feeders is vulnerable to have an impact on the operations and control of power system, a system designed to operate with large, central generating facilities. Distributed Generation can be defined as an electrical power source linked directly to the distribution network or on the consumer side of the meter. Analytical approaches for optimal placement of DG with unity power factor is to minimize the power loss of the system. The planning of the electric system at the presence of DG requires defining of several factors including the best technology to be used, the number and the capacity of the units, the best location, the type of network connection, etc. The effect of DG on operating characteristics of the system such as electric losses, voltage profile, stability, and reliability needs to be appropriately assessed. The problem of DG allocation and sizing is importance crucial task. Installing DG units at no optimal places may result in an increase in system losses, costs, and therefore, having an undesired effect on the system. There may be many locations that do not have overload or voltage problems, where the DG can be located and provide the necessary control [5]. As a result, using an optimization method capable of indicating the best solution for a given distribution network can be very useful for system planning engineers. Selecting the best places for installing DG units and their preferable sizes in large distribution systems is an elaborate optimization problem.

This paper presents analysis of Imperialist Competitive Algorithm (ICA) based system power loss minimization approach and system energy loss minimization approach also the total loss of a practical distribution system is calculated with and without DG placement and an index, quantifying the total line loss reduction for optimal sizing and placement of DG in electrical power systems. The methods are presented to find optimal size and bus location for placing DG using power loss and energy loss minimization in a networked system based on bus admittance, generation information and load distribution of the system. The proposed methods are tested by simulations actual power network of Kerman Province, Iran of 3-DG, 5-DG and 8-DG.

Objective Function

The objective of DG placement in the distribution system is to minimize the annual cost of the system, subjected to certain operating constraints and load pattern. For simplicity, theoperation and maintenance cost of the DG placed in the distribution system is not taken into consideration. The three-phase system is considered as balanced and loads are assumed as time invariant. Mathematically, the objective function of the problem is described as:

$$Min\ f = W_1 \times f_{loss}(r) + W_2 \times f_{ENS}(r)$$

The voltage magnitude at each bus must be maintained within its limits and is expressed as:

$$V_{min} \le \|V_i\| \le V_{max}$$

Where │Vi│ is the voltage magnitude of bus i, V_{min} and V_{max} are bus minimum and maximum voltage limits, respectively.

Formulation

The power flows are computed by the following set of simplified recursive equations derived from the single-line diagram depicted in Figure. 1.

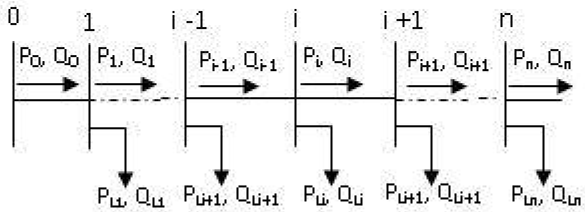

Figure 1: Single line diagram of main feeder

$$P_{i+1} = P_i - P_{Li+1} - R_{ij+1}\frac{P_i^2+Q_i^2}{|V_i|^2}$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{ij+1}\frac{P_i^2+Q_i^2}{|V_i|^2}$$

$$|V_i|^2 = |V_i|^2 - 2\left(R_{ij+1}P_i + X_{ij+}Q_i\right) + \left(R_{ij+1}^2 + X_{ij+1}^2\right) \times \frac{P_i^2+Q_i^2}{|V_i|^2}$$

Where Pi and Qi are the real and reactive powers flowing out of bus i, and P_{Li} and Q_{Li} are the real and reactive load powers at bus i. The resistance and reactance of the line section between buses i and i+1 are denoted by $R_{i,i+1}$ and $X_{i,i+1}$respectively.The power loss of the line section connecting buses i and i+1 may be computed as

$$P_{Loss}(i, i+1) = R_{i,i+1}\frac{P_i^2+Q_i^2}{|V_i|^2}$$

The total power loss of the feeder,P_T^{LOSS} may then be determined by summing up the lossesof all line sections of the feeder, which is given as

$$P_T^{LOSS} = \sum_{i=0}^{n-1} P_{LOSS}(i, i+1)$$

Evolutionary algorithms are usually designed to maximize or minimize the objective function, which is a measure of the quality of each candidate solution [11]. After control variables are coded, the objective function will be evaluated. These values are the measures of quality, which is used to compare different solutions. The better solution joins the new population and the worse one is neglected. Here Total Power Loss in the Distributed Generation is used in formulation of the objective function. Tray said objective function takes the following from:

$Min\ f = W_1 \times f_{loss}(r) + W_2 \times f_{ENS}(r)$

Where $f_{loss}(r)$ loss power for load is level r and $f_{ENS}(r)$ is energy not supplied for load is level r and W_1 is the weighting factor and can be written as following equations

$f_{loss}(k) = C_N(r) \times E_{loss}(r)$

Where $C_N(r)$ is the saving per MW reduction in the peak power loss and E_{loss}(r) is loss power for load level r and is defind as equation

$$E_{loss}(r) = h_r \times \sum_{i=1}^{n} \sum_{j=1}^{n} R_{ij} \left| I_{ij}(r) \right|^2$$

Where R_{ij} and I_{ij} are resistor impedance between buses I and j , respectively A_r is the duration of time.

$$f_{ENS}(r) = \sum U_i \times (\min\{PL_i(r), P_{DGi}^{max}\}) \times c_{shed\,i(r)}$$

Where U_i an average of outage is, $c_{shed\,i(r)}$ is the cost of power outage, $PL_i(r)$ is load it node and P_{DGi}^{max} is the maximum electric power by DG. Average time to confirm any of the loads of the network is obtained from the following equation

$$U_i = \sum_j \lambda_{ij} \times r_j$$

Where λ_{ij} is number of failures per year for equipment failures that result in lost time, is the j and r_j is average time required to fix your equipment after each fault j (hour). The inequality constraint on P_{DGi} of each DG is given by:

$P_{DGi}min \le P_{DGi} \le P_{DGi}max$

Power Flow Analysis Method

The methods proposed for solving distribution power flow analysis can be classified into three categories: Direct methods, Backward-Forward sweep methods and Newton-Raphson (NR) methods. The Backward-Forward Sweep method is an iterative means to solving the load flow equations of radial distribution systems which has two steps. The Backward sweep, which updates currents using Kirchoff's Current Law (KCL), and the Forward sweep, which updates voltage using voltage drop calculations [6].

The Backward Sweep calculates the current injected into each branch as a function of the end node voltages. It performs a current summation while updating voltages. Bus voltages at the end nodes are initialized for the first iteration. Starting at the end buses, each branch is traversed toward the source bus updating the voltage and calculating the current injected into each bus. These calculated currents are stored and used in the subsequent Forward Sweep calculations. The calculated source voltage is used for mismatch calculation as the termination criteria by comparing it to the specified source voltage. The Forward Sweep calculates node voltages as a function of the currents injected into each bus. The Forward Sweep is a voltage drop calculation with the constraint that the source voltage used is the specified nominal voltage at the beginning of each forward sweep. The voltage is calculated at each bus, beginning at the source bus and traversing out to the end buses using the currents calculated in previous the Backward Sweep [6].

Imperialist Competitive Algorithm (ICA)

ICA mimics the social–political process of imperialism and imperialistic competition. ICA starts with an initial population of individuals, each called a country. Some of the best countries are selected as imperialists and the rest form colonies which are then divided among imperialists based on imperialists' power. After forming the initial empires, competition begins and colonies move towards the irrelevant imperialists. During competition, weak empires collapse and powerful ones take possession of more colonies. At the end, there exists only one empire while the position of imperialist and its colonies are the same [4, 12].

1. Produce an initial population P and create the empty external non-dominated set Q.
2. Paste non-dominated members of P into Q.
3. Remove all the solutions within Q, which are covered by any other members of Q. If the number of externally stored non-dominated solutions exceeds a given maximum N', prune Q by means of clustering.
4. Calculate the fitness of all individuals in P and Q.
5. Use binary tournament selection with replacement and select the individuals from P and Q until the mating pool is filled.
6. Apply crossover and mutation operators as usual.
7. If the maximum number of generations is reached, then stop, else go to step 2.

Loss Reduction Analysis

The total loss of the distribution system without DG is given by

$$Loss_{without\,DG} = \sum_{i=1}^{N-1} I_i^2 \times r \times L_i + \sum_{i=1}^{N-1} (P_{ci} + P_{Lv_i})$$

Where I_i is the current flowing through ith section, r is the resistance of line in ohms per unit length, L_i is the length of ith section, P_{ci} is the core loss of ith transformer, P_{Lv_i} is the Losses on the low voltage side of the ith transformer and N is the number of busses in the system [17.23].In order to determine the losses of the system, the core loss of each transformer and the LV side losses on each transformer must be known. It is evident from the above equation that the total losses can be reduced only by reducing the first term which represents the feeder line losses, since the other term representing the core loss and the LV side loss of each transformer remain same independent of the presence of DG.If a DG is inserted at K^{th} bus, the feeder segments up to bus K will carry the difference of the initial current and the injected current by the DG [20].Where I_{Cap} is the current injected by the DG and I_i remains the same at earlier value. The total loss of the distribution system with DG is now

$$Loss_{with\,DG} = \sum_{i=1}^{K-1} (I_i - I_{DG})^2 rL_i + \sum_{i=k}^{N-1} I_i^2 rL_i + \sum_{i=1}^{N-1} (P_{ci} + P_{Lv_i})$$

A factor, loss reduction index (LRI), which quantifies the loss reduction with the insertion of DG, is defined as

$$LRI = \frac{Loss\ in\ the\ system\ with\ DG}{Loss\ in\ the\ system\ without\ DG}$$

The LRI is now obtained as

$$LRI = \frac{Loss_{System\,without\,DG} + K_{Loss} I_{DG}}{Loss_{System\,without\,DG}}$$

Where K_{Loss} is the loss factor given by

$$K_{loss} = \sum_{i=1}^{K-1} (I_{DG} - 2I_i) \times r \times L_i$$

Test Results

To study the proposed method, sample power network is simulated in MATLAB. Figure2 illustrates the single-line diagram of this network. The base values of the system are taken as 20kV and 20MVA. The system consists of 20 distribution transformers with various ratings. The details of the distribution transformers are given in table 1. The details of the distribution conductors are given in Table 2. The total connected load on the system is 2550 KVA and the peak demand for the year is 2120 KVA at a PF of 0.8 lag.

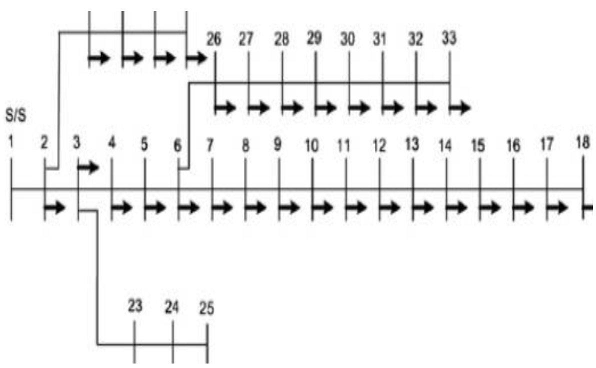

Figure 2: Single-line diagram of actual power network

Table 1: Details of transformers in the system

Rating [KVA]	50	100	250
Number	5	9	6
No load losses [watts]	150	250	480
Impedance [%]	4.5	4.5	4.5

Table 2: Details of conductors in the system

Type	R [Ω/km]	X [Ω/km]	Cmax [A]	A [mm2]
Hyena	0.1576	0.2277	550	126
Dog	0.2712	0.2464	440	120
Mink	0.4545	0.2664	315	70

Initially, a load flow was run for the case study without installation of DG. Table 3 depicts the results of power flow for determination voltage before installation of DG. Table 4 depicts the locations and capacity of DG using Imperialist Competitive Algorithm. As it is clear, all the obtained values confines with all the considered constraints. The obtained penetration lever is 0.27, which is less than the assumed allowable value.

Table 3: Results of power flow before installation of DG

Bus Number	V (pu)
1	1
2	0.9999
3	0.9998
4	0.9997
5	0.9996
6	0.9995
7	0.9994
8	0.9994
9	0.9993
10	0.9993
11	0.9992
12	0.9992
13	0.9991
14	0.9991
15	0.999
16	0.999
17	0.999
18	0.999
19	0.999
20	0.999

Table 4: Optimal place and capacity of DG

Location [#bus]	Capacity of DGs [Mw ; Mvar]
2	0.56 ; 0.35
4	0.68 ; 0.28
6	0.04 ; 0.3
14	0.25 ; 0.11
16	0.65 ; 0.38

In addition the total network loss, which was 10.05MW before installing DG, has diminished to the 4.55MW which shows 45.81% decrease. Table 5 shows the impact of installing DGon THD of buses.

Table 5: Results of power flow after installation of DG

Bus Number	V (pu)
1	1
2	0.999996976
3	0.999975735
4	0.999959762
5	0.999949055
6	0.999943869
7	0.999943698
8	0.999948794
9	0.999941575
10	0.999939624
11	0.999942939
12	0.999951523
13	0.99995177
14	0.999957284
15	0.999968066

16	0.999957654
17	0.999936584
18	0.999920781
19	0.999910246
20	0.999904978

The detailed pu voltages profile and Percentage of lossof allthe nodes of the system before and after DG placement with 5 DG units are shown in the Figure3 and Figure 4.

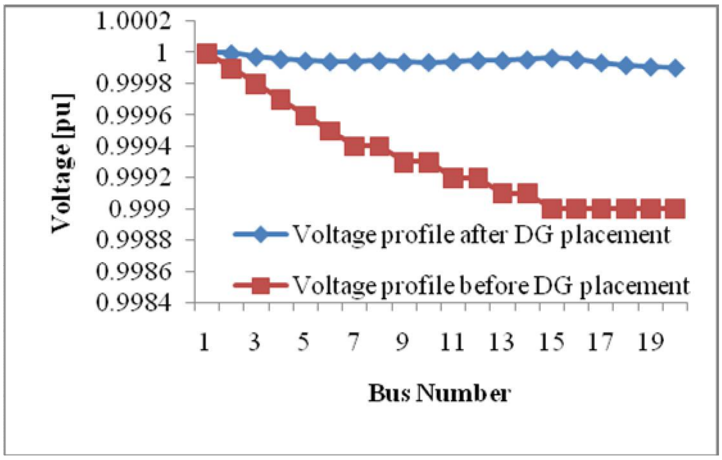

Figure3: Voltage profile of 20 bus system before and after DG placement

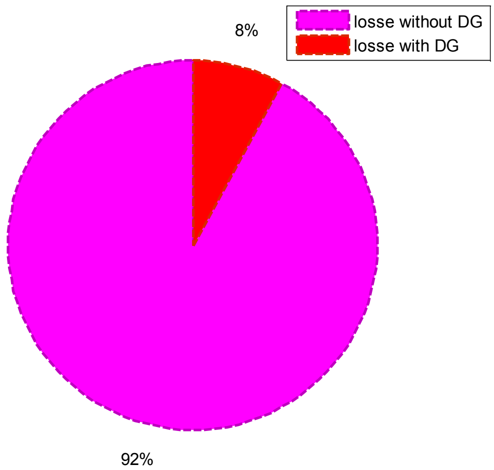

Figure 4: Percentage of loss before and after DG placement

The simulation results are given in Table 6. These results reveal that the inclusions of DG reduce the line losses as expected. It can be shown from the graphs that, LRI decreases marginally, since the core losses of the transformers and the LV side losses remain constant being independent of the presence of DG. It can also be seen that with the increase in the active power capacity of DG, LRI, decrease also with the increase in the number of DG, LRI, due to increasing of active power, decrease.

Table 6: Variation of LRI

Number of DG	place	Picked P, Q [Mw;Mvar]	LRI [%]
3	9,14,18	1.4297 ; 9.0745	0.0814
5	3,10,13,15,18	1.8696 ; 1.0473	0.0445
8	2,3,5,8,10,13,14,19	1.9477 ; 1.4219	0.0245

CONCLUSION
In the present paper, a new population based Imperialist Competitive Algorithm (ICA) has been proposed to solve DG placement problem and quantifying the total line loss reduction in distribution system. Simulations are carried on actual power network of Kerman Province, Iran.The simulation results show that the inclusion of DG, marginally reduce the losses in a distribution system. This is because; the line losses form only a minor part of the distribution system losses and the DG can reduce only the line losses. The other losses viz. the transformer losses and the LV side distribution losses remain unaltered. Hence this fact should be considered before installing a DG into a system.The results obtained by the proposed method outperform the other methods in terms of quality of the solution and computation efficiency.

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