OPTIMUM DISTRIBUTED GENERATION PLACEMENT

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Abstract: This paper presents a formulation for the optimum Distributed Generator (DG) placement which considers minimization of the line loss, a technical factor, and minimization of installation and maintenance cost, an economical factor. The problem is configured as a constrained optimization problem, where the optimal number of DGs, along with their sizes and bus locations, are simultaneously obtained. This problem has been solved using Genetic Algorithm(GA), a traditionally popular stochastic optimization algorithm. A 33-bus radial distribution system is considered as the case study where the effectiveness of the proposed algorithm is demonstrated.

Keywords – Distributed Generator, Genetic Algorithm

1. Introduction

The global concerns about the environment, combined with the progress of technologies to connect renewable energy sources to the grid and deregulation of electric power market have diverted the attention of distribution planners towards grid-connected distributed generation (DG) systems. Most of the DG energy sources are designed using green energy which is assumed pollution free [1]. The technical benefits include improvement of voltage, loss reduction, relieved transmission and distribution congestion, improved utility system reliability and power quality. All these benefits are achieved by installing DG at proper location with proper size. In [2] a distribution network planning method considering distributed generation (DG) for peak cutting is proposed. The method combines the solution techniques with genetic algorithm with the heuristic approach (GA). The aim of DG implementation is to minimize the sum of feeder investments, DG investments, energy loss cost and the additional cost of DG for peak cutting. In some research, the optimum location and size of a single DG unit is determined [3–4], while in others the optimum locations and sizes of multiple DG units are determined [5–7].

The present work presents a formulation of the optimization objective for designing an optimal DG placement problem. The algorithm attempts to simultaneously determine the suitable number of DGs, their sizes and bus locations for a given distribution network, when a certain objective function is minimized. This objective function considers both the technical objectives and the economical objectives. The technical objectives include minimization of the line loss, and minimization of node voltage deviation in the distribution network. The economical objectives include minimization of the actual costs involved in DG placements i.e. essentially installation and maintenance costs. This formulation also considers several operational constraints, like maintaining the apparent power flow in each branch within limits and maintaining each bus voltage within limit. This paper presents a method for solving this problem using genetic algorithm for radial distribution systems. For each potential solution created by the genetic algorithm in each generation, the entire power flow calculations are carried out. Based on these analyses, the fitness value of each solution is evaluated. The utility of the proposed scheme is quantified in terms of maximization of a performance measure, defined as the equivalent cost savings (i.e. momentary benefits) evaluated for the solution determined, from the condition when the system did not employ any DG. The results demonstrate the usefulness of the scheme proposed.

2.The problem formulation

2.1. Objective functions

The optimal DG placement problem has been formulated in this paper with the objective of simultaneous minimization of technical hazards and economic costs incurred. In this sense, Minimization of active power losses, an essential requirement in a distribution system, for efficient power system operation, is to achieve reduction in the real power loss, as far as possible. The real power and reactive power losses are dependent on the system operating condition and are given by equations 1 and 2.

Objective I: Minimization of power losses

Real power loss = P_L

$$= ((V_i - V_j) / R_{ij})^2 * R_{ij} \quad (1)$$

Reactive power loss =Q_L

$$= ((V_i - V_j) / R_{ij})^2 * X_{ij} \quad (2)$$

where R_{ij} is the line resistance between bus i and bus j, The objective of the placement technique will be to minimize the total real power loss. Mathematically, the objective function for this case can be formulated as:

Minimize PL = k=1Nsc Loss k. (3)

Where Loss $_k$ is the real power loss corresponding to the section k and N_{SC} is the total number of sections.

Objective II: Minimization of the total cost of DGs

This objective is purely formulated from the economic point of view that the cost increases as a function of both the number of DGs and the size of each individual DG installed. Hence this objective can be mathematically formulated as:

Minimize C DG = KC ∑i=1NDG P DG I (4)

Where C_{DG} is the total cost associated with the DG units,$P_{DG\,i}$ is the size of the i^{th} DG, N_{DG} is the total number of DG connected and Kc is the cost of DG per KW.

2.2 Operational constraints

The optimal placement problem must not only comprise several objectives but also must satisfy certain operational constraints. This is required from the consideration that the design must be a realistic one and the process of achieving certain objectives should not jeopardise or produce negative impact on some other system aspects. These operational constraints can be categorized as:

2.2.1 Constraint I: Power flow limits

For safe operation of the entire system, the apparent power that is transmitted through each branch l (S_l) must not exceed the thermal limit ($S_{l\ max}$) of the line or transformer in steady state operation:

$$Sl \leq Sl\ max \quad (5)$$

2.2.2 Constraint II: Bus voltages

From the point of view of system stability, power quality, etc., each bus voltage (V_i) must be maintained around its nominal value ($V_{i\ nom}$) within a permissible voltage band, specified as [$V_{i\ min}$, $V_{i\ max}$], Where $V_{i\ min}$ is the minimum permissible value of voltage at bus i and $V_{i\ max}$ is the maximum permissible voltage at bus i. This can be mathematically described as:

$$Vi\ min \leq Vi \leq Vi\ max \quad (6)$$

2.2.3. Constraint III: The DG capacities

The capacity of each DG ($P_{DG\ i}$) should also be varied around its nominal value. Hence each $P_{DG\ i}$ must also be maintained within a permissible band, specified as [$P_{DG\ min}$,$P_{DG\ max}$], where $P_{DG\ min}$ is the minimum permissible value of each DG capacity and $P_{DG\ max}$ is the maximum permissible value of each DG capacity. This should than the specified minimum value, then the type and cost of the corresponding DG should also be varied. Mathematically speaking:

$$PDGmin \leq PDG \leq PDG\ max \quad (7)$$

3.Cost calculation

The aim of this work is to find out the location and sizes of the DG so as to maximize the net saving by minimizing the energy loss cost for a given period of time with single DG, double DGs, and 3 DGs and by considering cost of the Distributed generators. Therefore, the objective function consists of two main terms: energy loss cost and distributed generation cost.

3.1. Energy loss Cost (ELC)

$$ELC=(EL*GE) \quad (8)$$

Where,

EL = [PL i]*t (9)
t = annual time
PL = power loss in KW
GE= energy loss rate in $/KWhr

3.2. DG Cost (DGC)

It consists of,
1. Installation cost
2. Variable cost

DG C =i=1NDGGI c+i=1NDGPDG i *DG R (10)
Where,
PDG = Power generation from DG in KW
DG R = Rate of DG/KW
GI c = DG installation cost

3.3.Total cost

Total cost = ELC+ DG C (11)

Percentage of Net saving = (Energy loss without DG – (Energy loss cost with DG + DGC))/ (energy loss cost with DG)

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4.Problem solution employing methods

4.1. Load Flow Analysis

Load flow analysis is a steady state analysis of power system, which provides information about the current state of the system for a given generation and load conditions. The R/X ratios of branches in a distribution system are relatively high compared to a transmission system and makes the distribution system ill conditioned. Backward and forward sweep algorithm exploit the radial nature of the distribution system and it is computationally more efficient. Another advantage of this method is that all the necessary data can be stored in vector form, thus saving a lot of computer memory. Convergence is always guaranteed for any type of practical radial distribution network with realistic R/X ratios while using the sweep technique.

This method is the simple and efficient method. Since the node voltages and branch currents are evaluated directly from KVL and KCL respectively. The method converges fast and the results are highly accurate. Backward sweep calculates the branch currents. As an initial step flat voltage profile has been assumed. At the end of each backward sweep updated list of branch currents are saved. The forward sweep calculates the node voltages. Backward and forward sweeps are repeatedly done with the updated values as initial values till the convergence limit reached.

4.2. Solution with Genetic Algorithm

Genetic algorithm (GA) was one of the earliest proposed stochastic search techniques, from the field of evolutionary computation that has been and is still extensively used for multidimensional, nonlinear, physical, gradient free optimization problems [8]. For a practical problem under consideration, this environment corresponds to the problem to be solved and each such agent presents a potential solution for that problem.. For minimization problems, a better agent is determined by its corresponding lower objective function value, which indicates its higher fitness. With time, binary-GA based algorithms have been very often replaced by real-coded GA algorithms, which may employ fixed-length coding or variable-length coding [8]. Essentially speaking, each GA scheme starts with a random creation of initial population and then performs a two-phase based iterative search where, in each generation, they evaluate a fitness function (phase 1) and then create a new population of agents utilizing different selection, crossover, and mutation schemes (phase 2).

Each individual solution in a GA scheme is called a chromosome. The iterative process continues until the objective function is minimized to a desired degree of satisfaction or the maximum number of generations specified has elapsed. In the end, the chromosome that produced the best objective function performance is considered as the fittest individual and this evolves as the solution for the problem in hand. For the present proposed scheme. Where the number of DGs, along with their individual positions and individual sizes are coded.

Each DG can be potentially placed in any bus other than the slack bus. By convention, bus-1 is connected with the substation and is considered as the slack bus. Hence each DG may be connected in any location except bus-1. Also, the design should be so carried out that any two DGs must not be placed at the same location. The iterative GA based solution attempts to obtain that best-fit chromosome for which is minimum. The corresponding chromosome determines the optimum number of DGs, and their suitable placements with corresponding sizes.

As mentioned earlier, each GA scheme utilizes three main mechanisms to evolve a new population of agents for the next generation, namely, selection, crossover, and mutation. For each such mechanism different techniques or algorithms can be implemented. The selection methods specify how the genetic algorithm chooses parents for the next generation. In this work, Roulette Wheel selection, which chooses parents by simulating a roulette wheel with different sized slots, each proportional to the fitness of each individual, is chosen. For the crossover operation, the one point and scattered crossover mechanisms were tested in this study. The one point crossover mechanism exchanges the genetic information, based on a single position, determined at random, in the two selected parents. The mutation mechanism used in this study implied generating a random gene number and flipping the bit found at that position.

5. Results and Discussion

A radial distribution network consists of 33 bus locations, connected by 32 lines is shown in fig(1). The transmission lines are at same voltage levels. All data calculations were performed in per unit basis where the base values were chosen as 100 MVA and 11 kV. The algorithm has been developed and the solution obtained in MATLAB 7.0 environment.

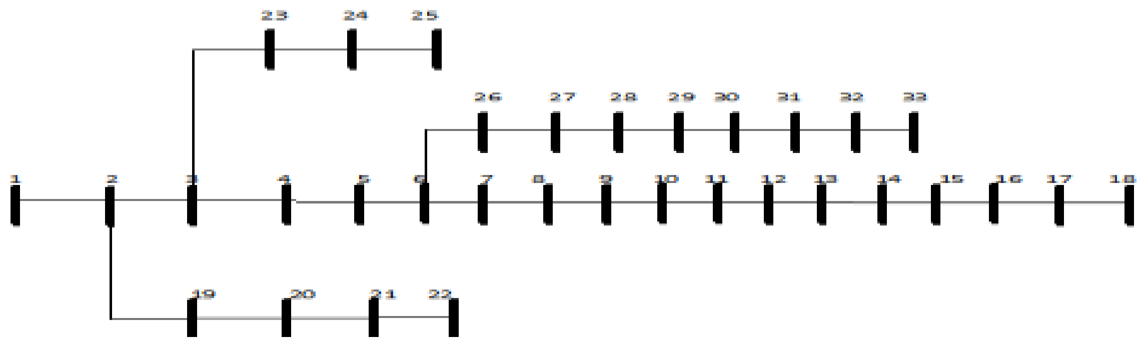

Fig.1.Single line diagram of the 33-bus radial distribution system

Prior to DG placement, the load flow program based on backward and forward sweep power flow method is performed. Based on power flow results, Losses and normalized voltage values are obtained. Bus location selection is based on the occurrences of minimum losses. These values are used to find the candidate buses i.e., DG are placed at suitable bus positions. In this work, the optimal location and size of the DG are obtained for 33-bus radial distribution system. The results are obtained by considering placement of single DG, Two number of DGs and Three number of DGs.The optimal locations for three number of DGs are 30,14,and 32 buses & the corresponding size of the DG are 700 kw,750 KW and 650 KW. And for two number of DGs optimal locations are 14 and 31 buses and the DG ratings are 850 KW and 1100 KW. And for single DG the optimal location is 31 bus and the DG rating is 1100 KW, respectively. The optimal location of buses and size of the DG are obtained by using Genetic algorithm.From the results it is observed that the voltage ratings of the system is increases while increasing the number of DGs in the distribution system. The voltage limit is 0.94 P.U to 1.03 P.U. The size of DG limitation is fixed as 50 KW to 1100 KW.

Table.1. Energy loss and Net saving with and without placement of DG

SL NO.	DG UNITS	LOSS IN KW	Location	SIZE OF DG IN KW	TOTAL ENERGY LOSS COST IN $	%NET SAVING
1	WITHOUT DG	181.97	-	-	159404	-
2	1 DG	89.96	31	1100	111302	30.18
3	2 DG	41.58	14,31	850, 1100	95179	40.29
4	3 DG	35.3663	30,14,32	700, 750,650	98481	38.22

Table.1. shows the results (best location, DG sizes, loss, DG cost and net profit). And also shows that the Power Loss of the system without DG and with DG (single DG, Two DGs, and Three DGs)

6. Conclusion

The DG placement has been studied for 33-bus radial distribution system. Load flow is carried for the radial distribution system using forward and backward load flow method with and without DG. The voltage profile throughout the system is increased, the total power loss and the energy cost of the system has been reduced after the placement of DG at different load profiles in the radial distribution systems. The cost of the system with DG is very less when compared with without DG because the losses are high. Due to that the energy cost is also high. But when we install DG at the distribution system the losses are reduced. By reducing energy losses we can reduce the energy cost. The net savings when we install DG are 30%, 40.2%, 38.22% for the system with single DG,2 DGs, 3 DGs respectively. Finally the voltage profile throughout the system is increased and total power loss in the system has been reduced after the placement of DG at different of load profiles in the radial distribution systems using Genetic Algorithm.

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