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DGs Placement in the Radial Distribution System for Loss Reduction

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Abstract: *This paper presents a new algorithm for optimal placement and sizing of DGs on distribution systems with an aim of reducing the power losses and improving voltage stability. The proposed approach determines the control variable settings such as placement and size of DG for minimization of real power loss with impact of voltage stability in the distribution system. Further, the impacts of DG on the distribution system are studied with an importance on power losses and capacity savings. The proposed approach is examined and tested on actual power network of Jiroft Province, Iran and the simulation results are presented and discussed.*
Key words: *Harmony Search Algorithm, voltage profile, loss Minimization, DGs*

INTRODUCTION

The function of a distribution system is to deliver electrical power from the transmission network to end users. The distributed generation (DG) is a power source that can be playing an important role in the distribution system in case of power demand. The distribution systems are usually unbalanced and have a high R/X ratio compared to transmission systems, which results with the effect of high voltage drops and power losses in the distribution feeders. The vital tasks in the distribution system are reduction of power losses and improvement of the system voltage profile. Many research works have been carried out in this direction since the supporting of analytical and software approach. Power loss reduction and voltage profile improvement are goals for electricity utilities. Distribution system reconfiguration and optimal capacitor placement are two of the low Cost available tools for Power loss reduction and voltage profile improvement. Reconfiguring the network means altering its topology by changing the status of normally opened and normally closed switches. This paper propose the optimal place and capacity of DGs to reduce losses, improve voltage profile to actual power distribution network. Distribution system is the final link between high voltage transmission systems and consumers which transport the electric energy from bulk substation to many services or loads, thus causes more power and energy losses. Hence there is a need to reduce the system losses. By minimizing the power losses, the system may acquire longer life span and has greater reliability. Feeder reconfiguration is a very important tool to operate the distribution system at minimum cost and improve the system reliability and security. The reconfiguration of a distribution system is a process, which alters the feeder topological structure by changing the open/close status of the switches in the distribution system. Two types of switches, normally closed switches (sectionalizing switches) and normally open switches (tie switches), are used in primary distribution systems for protection and configuration management. Distribution network reconfiguration for loss reduction is a complicated combinatorial, non-differentiable, constrained optimization problem since the reconfiguration involves many candidate switching combinations. Several papers have considered the problem of optimal network reconfiguration using different optimization techniques.

Merlin and Back [1] introduced the concept of changing the topology of distribution systems for loss minimization. They proposed a branch and bound method. Searching for a minimum loss operating spanning tree configuration for urban power distribution System, is presented in [2]. Branch exchange method and derived a simple formulate to estimate the loss reduction is presented in [3]. The heuristic algorithms that are based on optimum power flow are reported in [4] and developed in [5]. The power loss reduction and load balancing reconfiguration problem is formulated as an integer programming method presented in [6]. In [7], an algorithm has been proposed to obtain switch pattern as a function of time. Determine a configuration with minimal power losses using a genetic algorithm (GA) has been proposed in [8]. An improved genetic algorithm based on fuzzy multi-objective approach has been suggested in [9] to solve the problem. A method based on binary particle swarm optimization (BPSO) algorithm is presented in [11]. An algorithm based on the heuristic rules and fuzzy multi objective approach for optimizing network configuration is presented in [11]. Ant colony search algorithm (ACSA) to solve the reconfiguration problem presented in [12]. The network reconfiguration problem has been solved by a harmony search algorithm (HSA) presented in [13]. Multi-objective quantum-inspired artificial immune system approach for optimal network reconfiguration in distribution system is presented in [14] and distribution systems reconfiguration using ant colony optimization and harmony search algorithms presented in [15]. In this paper to solve the reconfiguration problem in distribution systems the plant grows simulation algorithm (PGSA), is used

The capacitor placement problem is the determination of the location, number and sizes of capacitors to be placed on a radial distribution system in an optimal manner. Several papers have considered the problem of optimal capacitor placement using different optimization techniques. Grainger and Lee [16–18] formulated the problem using a non-linear programming model and solved it by simple iterative procedures based on gradient search. Dynamic programming was also used to solve the capacitor placement problem in [19]. The optimal placement of fixed and switchable capacitors in radial distribution networks considering time varying load and load uncertainty based on a proposed genetic algorithm (GA) method is presented in [21]. Optimal capacitor placement using modified differential evolution (DE) algorithm is presented in [21]. Attia et al. proposed an approach based on artificial bee colony algorithm to allocate static capacitors along radial distribution networks [22]. Teaching Learning Based Optimization (TLBO) approach to minimize power loss and energy cost by optimal placement of capacitors in radial distribution systems is presented in [23].

II. Power Loss Reduction

Typically, power losses in distribution system highly regarded for power utility companies because, the losses, reducing the efficiency of energy transfer to the consumers and the economic losses caused by the power losses, imposed on electricity companies. Various solutions have been proposed to reduce the losses in the distribution system. Optimal network reconfiguration is well suited solution to loss reduction [1]. An other practical ways to loss reduction is optimal capacitor installation in the distribution systems [25].

III. Voltage Profile Improvement

Due to the loads variable in the distribution systems and changing time to time, and also due to the radial structure of power distribution system, most consumers in the end of radial systems, has not desired voltage level. One of the main purposes of the distribution system operators is providing desirable voltage level for consumers. DG and capacitor installation in the distribution system can help to improve the voltage profile. Voltage variations in the distribution system must be control in specified range (+7% _ 13%) [26].

IV. Formulation

In this paper, the objective is to minimize the system power loss under a certain load pattern through network optimization while electrical and operational constraints are met, that is the process of altering the topological structures of distribution network by changing the open/closed status of switches so as to minimize total system real power loss. The objective function of the problem is,

Minimiz $P_{loss} = \sum_{i=1}^{nl} R_j \frac{P_j^2 + Q_j^2}{V_j^2}$ (1)

The branch's capacity and voltage magnitude at each branch and each bus must be maintained within limits. These constraints are expressed as follows:

For any branch

$$s_j \leq s_{j,max}$$

For any bus : $|V_{i,min}| \leq |V_i| \leq |V_{i,max}|$

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

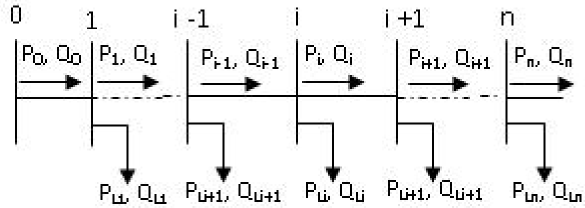

Figure 1: Single line diagram of main feeder

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

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

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

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 losses of all line sections of the feeder, which is given as

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

Considering the practical capacitors, there exists a finite number of standard sizes which are integer multiples of the smallest size Q0 c. Besides, the cost per Kvar varies from one size to another. In general, capacitors of larger size have lower unit prices. The available capacitor size is usually limited to

$$Q_c^{max} = LQ_c$$

Therefore, for each installation location, there are L capacitor sizes {$1Q_C$, $2Q_c$, $3Q_c$, … ,LQc} available. Given the annual installation cost for each compensated bus, the total cost due to capacitor placement and power loss change is written as

$$COST = K_p \times P_T^{LOSS} + \sum_i^c (K_{cf} + K_i^c Q_i^c)$$

Where n is number of candidate locations for capacitor placement, Kp is the equivalent annual cost per unit of power loss in \$/(kW-year); K_{cf} is the fixed cost for the capacitor placement. Constant K_i^c is the annual capacitor installation cost, and, i = 1, 2, ... , n are the indices of the buses selected for compensation. The bus reactive compensation power is limited to

$$Q_i^c \leq \sum_{i=1}^n Q_{Li}$$

Where $1Q_c$ and LQ_c are the reactive power compensated at bus i and the reactive load power at bus i, respectively. THD index presents the impact of the harmonics on network and is considered in the objective function according to the following equation

V. Power Flow

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 [12]. Single line diagram of main feeder depicted in Fig 2.

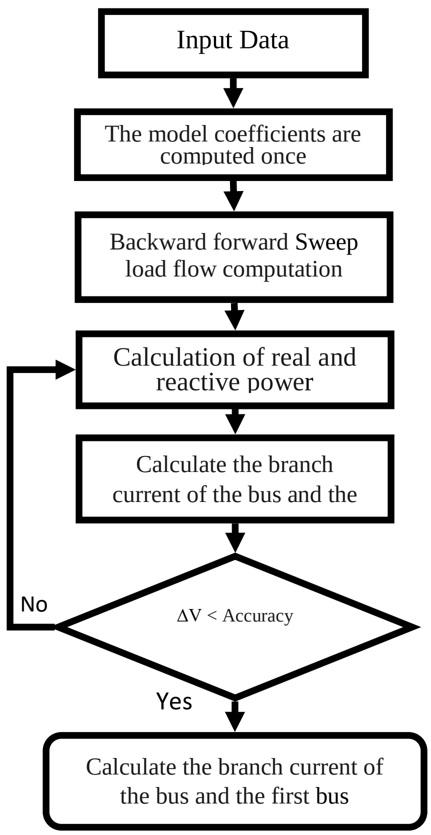

Fig 2. Single line diagram of main feeder

VI. Test Results

To study the proposed method, actual power network of Jiroft Province, Iran is simulated. Figure 4 illustrates the single-line diagram of this network.

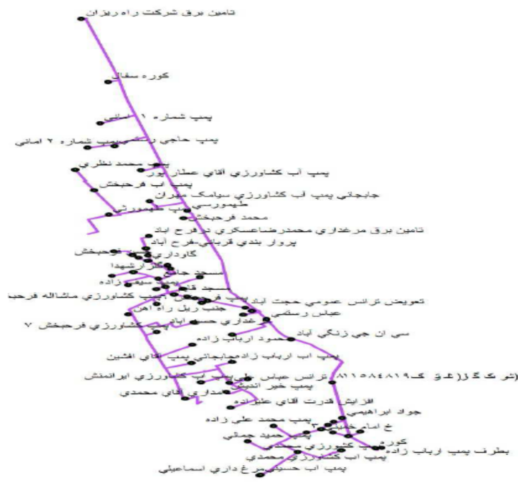

Fig 4. Single-line diagram of actual power network of jiroft Province

Initially, a load flow was run for the case study in both fundamental frequency and harmonics frequencies without installation of capacitor. The base values of the system are taken as 20kV and 45MVA. Table 2 depicts the locations and capacity of DGs. 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. In addition, capacity produced of all the units are less than the reactive load of the network. The following figure depicts the voltage of distribution buses, before and after installing five DG resources and clarifies the impact of these resources on voltage profile.

Table 1: Results of power flow and harmonic power flow before installation of capacitor

Bus Number	V (pu)
1	1.0
2	0.9999
3	0.9998
4	0.9988
5	0.9988
6	0.9987
7	0.9985
8	0.9889
9	0.9879
10	0.9849
11	0.97
12	0.93
13	0.89
14	0.9849

15	0.9849
16	0.91
17	0.92
18	0.95
19	0.94
20	0.89

Table 2: Optimal place and capacity of DGs

Location [#bus]	Capacity [MVA]
5	3.5
8	9
10	3.45
15	8
19	11.35

In addition the total network loss, which was 10.05MW before installing capacitor, has diminished to the 4.55MW which shows 45.81% decrease. Table 3 shows the impact of installing capacitor on THD of buses.

Table 3: Results of power flow and harmonic power flow after installation of capacitor banks

Bus Number	V (pu)
1	1.0
2	0.9999
3	0.9999
4	0.9999
5	0.9999
6	0.9988
7	0.9988
8	0.9888
9	0.9881
10	0.9885
11	0.99
12	0.97

13	0.91
14	0.988
15	0.988
16	0.95
17	0.96
18	0.98
19	0.95
20	0.93

The detailed pu voltages profile and THD bar of all the nodes of the system before and after capacitor placement are shown in the Figure 4.

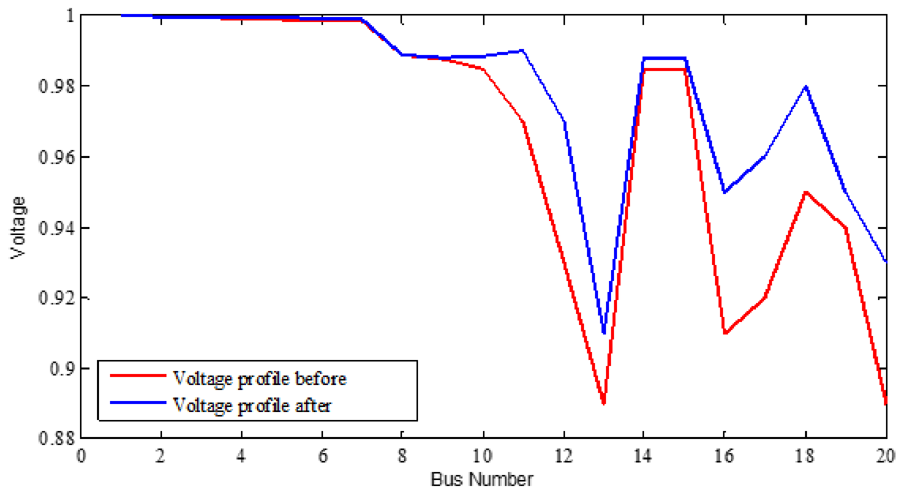

Fig 5: Voltage profile of 20 bus system before and after capacitor placement

VII. Conclusion

In the present paper, a new algorithm (HSA) for optimal placement and sizing of DGs on distribution systems with an aim of reducing the power losses and improving voltage stability. Simulations are carried on actual power network of Kerman Province, Iran. The results obtained by the proposed method outperform the other methods in terms of quality of the solution and computation efficiency. The main advantage of harmony search algorithm (HSA) is that it does not require external parameters such as cross over rate and mutation rate etc, as in case of genetic algorithms, differential evolution and other evolutionary algorithms and these are hard to determine in prior. The other advantage is that the global search ability in the algorithm is implemented by introducing neighborhood source production mechanism which is a similar to mutation process.

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