Optimal Network Reconfiguration of Large-Scale Distribution System Using Harmony Search Algorithm

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***Abstract*—Electrical distribution network reconfiguration is a complex combinatorial optimization process aimed at finding a radial operating structure that minimizes the system power loss while satisfying operating constraints. In this paper, a harmony search algorithm (HSA) is proposed to solve the network reconfiguration problem to get optimal switching combination in the network which results in minimum loss. The HSA is a recently developed algorithm which is conceptualized using the musical process of searching for a perfect state of harmony. It uses a stochastic random search instead of a gradient search which eliminates the need for derivative information. Simulations are carried out on 33- and 119-bus systems in order to validate the proposed algorithm. The results are compared with other approaches available in the literature. It is observed that the proposed method performed well compared to the other methods in terms of the quality of solution.**

***Index Terms*—Distribution system, harmony search algorithm, loss reduction, network reconfiguration.**

I. Introduction

FEEDER reconfiguration entails altering the topological structure of distribution feeders by changing the open/close status of the switches under both normal and abnormal operating conditions. Since many candidate-switching combinations are possible in a distribution system, finding the operating network reconfiguration becomes a complicated combinatorial, nondifferentiable constrained optimization problem. Distribution system reconfiguration for loss reduction was first proposed by Merlin and Back [1]. They employed a blend of optimization and heuristics to determine the minimal-loss operating configuration for the distribution system represented by a spanning tree structure at a specific load condition. The strength of the algorithm is that an optimal solution can be obtained which is independent of the initial switch status. But the shortcomings in the paper are: 1) contribution of only real component of current was considered while calculating power loss and assumed that the voltage angles are negligible; 2) the losses associated with line equipment are not considered; and 3) the solution proved to be very time consuming as the possible system configurations are 2^n, where n is line sections equipped with switches.

A branch and bound type heuristic algorithm was suggested by Civanlar *et al.* [2], where a simple formula was developed for determination of change in power loss due to a branch exchange. The advantages of this algorithm are rapid determination of a switching configuration which reduce losses and reduced number of switching combinations due to heuristic rules. The disadvantages are: 1) only one pair of switching operations is considered at a time and 2) the reconfiguration of network depends on the initial switch status.

Power flow method-based heuristic algorithm (PFBHA) is suggested by some authors [3]–[5] to determine the minimum loss configuration of radial distribution networks. Shirmohammadi and Hong [3] modeled the weakly meshed networks accurately by using a compensation-based power flow technique. The shortcomings of [3] are the inefficient search strategy which is time consuming and unbalanced multiphase distribution systems are not efficiently modeled. Wagner *et al.* [4] presented the reconfiguration problem as linear transportation problem and approximated the quadratic feeder line section losses as piecewise linear function. This method converges well and is efficient for small distribution systems. However, the analysis of larger networks (those in excess of 1000 buses) would result in an excessive computational burden for real-time implementation. Goswami and Basu [5] proposed a method, in which any switch closure is complemented by the opening of another switch to ensure a radial network. Although the method is suitable for smaller systems, it becomes prohibitive for larger networks as the solution involves a huge number of computations.

Simulated annealing (SA) method was proposed as a solution procedure by some authors [6]–[8] to search an acceptable non-inferior solution. Although mathematically rigorous, the algorithm is very time consuming for any practical problem. Nara *et al.* [9] presented a solution using a genetic algorithm (GA) to look for the minimum loss configuration. They formed strings, which represented switch status, a fitness function consisting of total system losses, and penalty values of voltage drop limit and current capacity limit. Sample results demonstrate that, although the minimal loss solutions were obtained, solution time was prohibitive for even the 97-bus sample system (in excess of

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15 min). Das [10] presents an algorithm based on the heuristic rules and fuzzy multi-objective approach for optimizing network configuration. The four objectives—load balancing among the feeders, real power loss, deviation of nodes voltage, and branch current constraint violation—are modeled and results obtained are encouraging, but criteria for selecting a membership function for each objective are not provided.

Although the methods mentioned above do not have good convergence property, most of them are used due to less computation time requirement for smaller systems. For larger systems, the computation time is prohibitively high and may not be suitable for real-time operation.

In this paper, harmony search algorithm (HSA) is proposed for the minimization of power loss in the distribution system. The proposed method is tested on 33- and 119-bus systems and results obtained are very encouraging. Further, the results converge to optimal solution very fast even for a large system.

The rest of this paper is organized as follows: Section II gives the problem formulation. Section III provides an overview of HSA and describes how this can be applied for the network reconfiguration problem. Section IV presents results of 33- and 119-bus systems and Section V outlines conclusions.

II. Problem Formulation

The network reconfiguration problem in a distribution system is to find a best configuration of radial network that gives minimum power loss while the imposed operating constraints are satisfied, which are voltage profile of the system, current capacity of the feeder, and radial structure of the distribution system. The objective function for the minimization of power loss is described as

$$Minimize\ f = min.(P_{T,Loss}) \tag{1}$$

$$\left.\begin{array}{r} Subjected\ to \quad V_{\min} \le |V_i| \le V_{\max} \\ \text{and} \quad |I_j| \le |I_{j,\max}| \end{array}\right\} \tag{2}$$

$$\left.\begin{array}{r} det(A) = 1\ or\ -1\ (radial\ system) \\ det(A) = 0\ (not\ radial) \end{array}\right\} \tag{3}$$

where

$P_{T,Loss}$	total real power loss of the system;
$\lvert V_i \rvert$	voltage magnitude of bus i;
$V_{\min},\ V_{\max}$	bus minimum and maximum voltage limits, respectively; ($V_{\min} = 0.9$ p.u. and $V_{\max} = 1.0$ p.u.);
$I_j,\ I_{j,\max}$	current magnitude and maximum current limit of branch j, respectively;
A	bus incidence matrix;

The power flows are computed by the following set of simplified recursive equations [11] derived from the single-line diagram shown in Fig. 1:

$$\begin{aligned} P_{k+1} &= P_k - P_{Loss,k} - P_{Lk+1} \\ &= P_k - \frac{r_k}{|V_k|^2}\left\{P_k^2 + (Q_k + Y_k|V_k|^2)^2\right\} \\ &\quad - P_{Lk+1} \end{aligned} \tag{4}$$

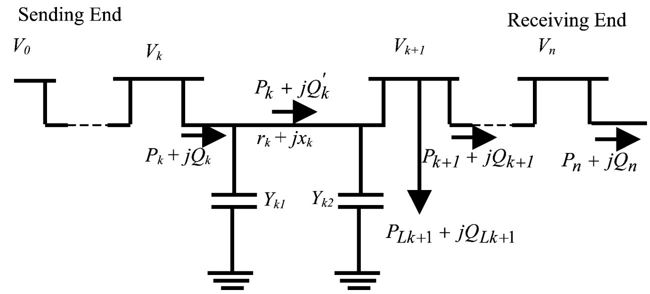

Fig. 1. Single-line diagram of a main feeder.

$$\begin{aligned} vQ_{k+1} &= Q_k - Q_{Loss,k} - Q_{Lk+1} \\ &= Q_k - \frac{x_k}{|V_k|^2}\left\{P_k^2 + (Q_k + Y_{k1}|V_k|^2)^2\right\} \\ &\quad - Y_{k1}|V_k|^2 - Y_{k2}|V_{k+1}|^2 - Q_{Lk+1} \end{aligned} \tag{5}$$

$$\begin{aligned} |V_{k+1}|^2 &= |V_k|^2 + \frac{r_k^2 + x_k^2}{|V_k|^2}\left(\mathrm{P}_k^2 + Q_k'^2\right) \\ &\quad - 2\left(r_k P_k + x_k Q_k'\right) \\ &= |V_k|^2 + \frac{r_k^2 + x_k^2}{|V_k|^2} \\ &\quad \times \left(\mathrm{P}_k^2 + (Q_k + Y_k|V_k|^2)^2\right) \\ &\quad - 2\left(r_k P_k + x_k(Q_k + Y_k|V_k|^2)\right) \end{aligned} \tag{6}$$

where P_k and Q_k are the real and reactive powers flowing out of bus k, and P_{Lk+1} and Q_{Lk+1} are the real and reactive load powers at bus $k+1$. The shunt admittance is denoted by Y_{kl} at any bus k to ground. The resistance and reactance of the line section between buses k and $k+1$ are denoted by r_k and x_k, respectively.

The power loss of the line section connecting buses k and $k+1$ can be computed as

$$P_{Loss}(k, k+1) = r_k.\frac{(P_k^2 + Q_k'^2)}{|V_k|^2}. \tag{7}$$

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

$$P_{T,Loss} = \sum_{k=1}^{n} P_{Loss}(k, k+1) \tag{8}$$

where n is the total number of lines sections in the system.

III. Overview of Harmony Search Algorithm

The HSA is a new metaheuristic population search algorithm proposed by Geem *et al.* [12]. HSA was derived from the natural phenomena of musicians' behavior when they collectively play their musical instruments (population members) to come up with a pleasing harmony (global optimal solution). This state is determined by an aesthetic standard (fitness function). The HSA is simple in concept, less in parameters, and easy in implementation. It has been successfully applied to various