Optimal Reconfiguration of Distribution System by PSO and GA using graph theory

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Abstract-- This paper investigates the ability of particle swarm optimization (PSO) in cooperating by graph theory for network reconfiguration to reduce the power loss and voltage profile enhancement of distribution system. The numerical results are presented on a distribution system to illustrate the feasibility of the proposed method by PSO using graph theory. Furthermore, to validate the obtained results by PSO using graph theory, Genetic Algorithm (GA) using graph theory is applied and the results are compared.

Key-Words -- Distribution systems, reconfiguration, particle swarm optimization, Genetic Algorithm, loss reduction, graph theory.

1 Introduction

Network reconfiguration in distribution system is realized by changing the status of sectionalizing switches, and is usually done for loss reduction or for load balancing in the system. Distribution systems are radially structured to simplify overcurrent protection. Each distribution system includes a number of lines, sectionalizing switches installed on this line, and other component such as tie switches connecting other distribution lines. By changing the open and closed status of the feeder switches, load currents can be transferred from feeder to feeder.

The early work on feeder reconfiguration for loss reduction is presented by Civanlar *et al.* [1]. In [2], Baran *et al.* defined the problem for loss reduction and load balancing as an integer programming problem. Nara *et al.* [3] presented an implementation using a genetic algorithm (GA) to look for the minimum loss configuration. In [4]–[10], the authors suggested to employ a power flow method-based heuristic algorithm for determining the minimum loss configuration of radial distribution networks. In [9]–[11], the authors proposed a solution procedure employing simulated annealing to search for the solution. In [12], the authors had considered time-varying load analysis to reduce loss. In [13], fuzzy theory and evolutionary programming were employed to solve feeder reconfiguration systems. A parallel tabu search based method is proposed to look for the minimum loss configuration [14]. The use of differential evolution is reported in [15]. Also Jin *et al.* [16] used Binary PSO for load balancing in a distribution system. The work carried out by the authors in [17] used the PSO to look for the minimum loss configuration for a small distributed network.

In this paper, the ability of PSO using graph theory is investigated to find the optimal configuration for larger network with the objective of minimizing real power losses and improving of voltage profile. To validate the results obtained by PSO using graph theory, GA using graph theory is applied.

2 Overview of Particle Swarm Optimization

The Particle Swarm Optimizer is a population based optimization method that introduced by Kennedy and

Eberhart [18]. In PSO, each particle moves in the search space with a velocity according to its own previous best solution and its group's previous best solution [18]. The dimension of the search space can be any positive integer. Each particle updates its position and velocity with the following two equations:

$$X_i(t+1) = X_i(t) + V_i(t+1) \quad (1)$$

where $X_i(t)$ and $V_i(t)$ are vectors representing the current position and velocity respectively.

$$V_{i,j}(t+1) = wV_{i,j}(t) + c_1 r_{1,j}(pb_{i,j} - X_{i,j}(t)) + c_2 r_{2,j}(gb_j - X_{i,j}(t)) \quad (2)$$

where $j \in 1,2,...,d$ represents particle dimension. $0 \le w < 1$ is an inertia weight determining how much of particle's previous velocity is preserved, c_1 and c_2 are two positive acceleration constants; and $r_{1,j}, r_{2,j}$ are two uniform random sequences sampled from U(0, 1), pb_i is the personal best position found by the i^{th} particle and gb is the best position found by the entire swarm so far.

3 Overview of GENETIC ALGORITHM

Genetic Algorithm (GA) has desirable characteristics as an optimization tool and offer significant advantages over traditional methods. They are inherently robust and have been shown to efficiently search the large solution space containing discrete or discontinuous parameters and non-linear constraints, without being trapped in local minima [19].

GA may be used to solve a combinatorial optimization problem. The GA searches for a solution inside a subspace of the total search space. Thus they are able to give a good solution of a certain problem in a reasonable computation time. The optimal solution is sought from a population of solutions using random process. Applying to the current population the following three operators create a new generation: reproduction, crossover and mutation. The reproduction is a process dependant on an objective function to maximize or minimize, which depends on the problem.

4 Overview of graph theory

In graph theory, a graph is made up of dots connected by lines where two dots can only be connected by one line [20]. In graph theory, a dot is known as vertex and a line known as edge. The degree of a vertex in a graph is the number of edges that touch it and it is defined by the following equation:

$$\deg(V) = \sum_i E_i \quad (3)$$

The size of a graph is the number of vertices that it has. A path is a route that can be traveled along edges and through vertices in a graph. All of the vertices and edges in a path are connected to one another. Therefore, a graph is a pair $G = (V, E)$ of sets where the elements of V are the vertices or nodes or points of the graph G and the elements of E are its edges or lines.

A cycle is a path which begins and ends on the same vertex. A cycle is sometimes called a circuit. The number of edges in a path or a cycle is called the length of the path.

A vertex v is incident with an edge e if $v \in e$, then e is an edge at v. A matrix is defined as incidence matrix with the size of $V \times E$ as follows:

$$m_{ij} = \begin{cases} 1 & e_i \text{ is connected to } v_i \\ 0 & \text{else} \end{cases} \quad (4)$$

A graph that is not containing any cycles is called a tree. In a tree graph with V vertices and E edges, the following equation is satisfied

$$V = E - 1 \quad (5)$$

The number of the cycles in graph tree is given by the following equation:

$$cycle = (E+1) - V \quad (6)$$

5 study system and problem formulation

The study systems is adopted from the literature which is a distribution system consists 28 sectionalizing switches and 5 tie switches as shown in Fig. 1. The system data can be found in [21]-[22].

The objective function of the network reconfiguration is to minimize the total power losses as well as improving voltage profile. The objective function can be expressed as follows:

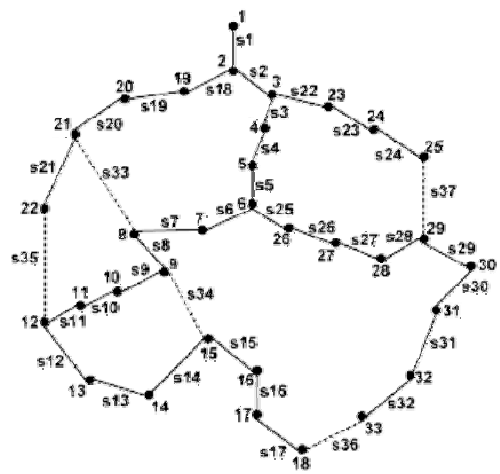

Fig. 1: 33 Bus distribution system

$$\min\ f = \min\left((P_{T,Loss}) + \sum_{i=1}^{N} |V_i - 1| + C \right) \quad (7)$$

where, $P_{T,Loss}$ is the total real power loss of the system, and V_i is the voltage of N buses. After reconfiguration of the network, the radial characteristics of the network should be kept and all loads have to be in service. In view of this, C is defined as the penalty factor for existing mesh or in the case of isolating some loads by following equation

$$C = A \cdot number(mesh) + B \cdot number(Isolated) \quad (8)$$

where A and B are equal to one.

In addition to Equ. (7), other objective function is considered as follows:

$$\min\ f = \min\big((P_{T,Loss}) + C\big) \quad (9)$$

where the system is reconfigured based on the minimizing the reduction of loss.

The voltage magnitude at each bus must maintain within its limits. The current on each branch has to lie within its capacity rating. These constraints are expressed as follows:

$$V_{\min} \le |V_i| \le V_{\max} \quad (10)$$

$$|I_i| \le I_{i,\max} \quad (11)$$

where,

$|V_i|$ ، $V_{\max}$ and $V_{\min}$ are voltage magnitude of the i^{th} bus, minimum and maximum voltage limits respectively.

$|I_i|$ and $I_{i,\max}$ are current magnitude and maximum current limit of i^{th} branch .

For solving the problem, first of all, the power flow must be calculated. Since the distribution systems are radially structured and after reconfiguration the radial characteristics of network is still kept, a simplified power flow equation used in [17] are applied in this paper.

6 PSO & GA using graph theory for feedder reconfigration

PSO using graph theory is applied for network reconfiguration in order to have minimum losses in the network as well as improving voltage profile. To use the graph theory, the buses of the network considered as nodes (V) and the number of switches known as edges (E). Also, the number of meshes in the network is known as the number of cycles in the graph theory. To retain a radial network structure, only one switch is opened in each mesh where the total number of open switches is equal to the total number of meshes so that no feeder section can be left out of service. To have a radial network structure, a tree graph should be reached.

To find the best configuration for the network, the algorithm started by checking the degree of the nodes. Those nodes with one degree will be deleted followed by deleting of the connected edges. Then the algorithm checks whether the network is radial and all loads are in service otherwise the penalty factor is increased in Equ. (7) or (9).

In the PSO algorithm, n particles are generated randomly where n is selected to be 50. In the study system, there exist 5 meshes. Therefore, each particle is a d-dimensional vector in which $d = 5$. The initialization is made on the position randomly for each particle. The number of iteration is considered to be 100, which is the stopping criteria.

The parameter in (2) must be tuned. These parameters control the impact of the previous velocities on the current velocity where, in this paper, $c_1 = c_2 = 1.4$ and w is decreasing linearly from 0.9 to 0.1.

Each particle in the population is evaluated using the objective function defined by Equ. (7) or (9) searching for the particle associated with f_{best}.The best previous position of the i^{th} particle is recorded and represented as: $pb_i = (pb_{i,1}, pb_{i,2}, pb_{i,3}, pb_{i,4}, pb_{i,5})$ and the index of the best particle among all of the particles in the group is for the *gb*. Using the *gb* and *pb*, particle velocity and position is updated according to (1) and (2).

To find the best reconfiguration for the two networks, suitable lines to be opened are selected based on 20 independent runs, under different random seeds. The obtained results are given in Table 1 for two different objective functions (Equ. (7) or (9)).

TABLE 1. THE OBTAINED RESULTS BY PSO FOR THE STUDY NETWORK

Network configuration		Tie switches	Power loss (*KW*)	Min.Voltage magnitude (*Pu*)
Original configuration		33, 34, 35, 36, 37	204.5	0.9129
After reconfiguration	Equ. 9	6, 9, 14, 32, 37	143.7	0.9374
	Equ. 7	7, 9, 14, 27, 32	144.1	0.9399

Table 1, shows that considering the switches 7, 9, 14, 27 and 32 as tie switches, the distribution system reconfigures to a network with a minimum losses and a better bus voltage magnitude profile.

The average best-so-far and the mean cost function of each run are recorded and averaged over 20 independent runs. To have a better clarity, the convergence characteristics in finding the best configuration for the network are given in Figs. 2-3. Also, bus voltage magnitude profile of the original system and reconfigured system based on Equ. (7) are shown in Figs. 4-5.

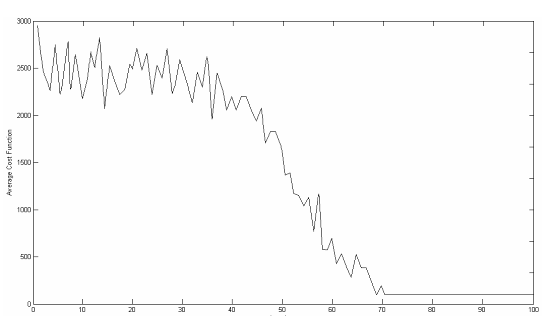

Fig. 2. Convergence characteristics of PSO on the average cost function in finding the solution based on Equ. (7).

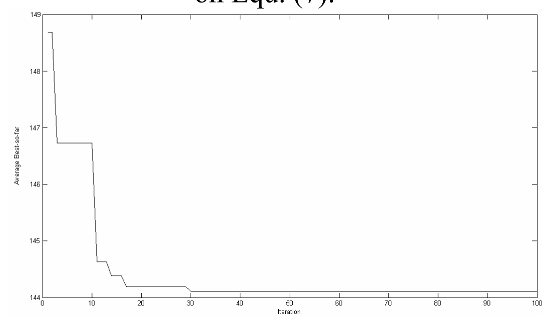

Fig. 3. Convergence characteristics of PSO on the average best-so-far in finding the solution based on Equ. (7).

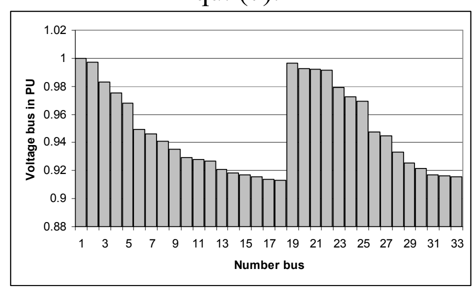

Fig. 4. Bus voltage magnitude profile of the original system.

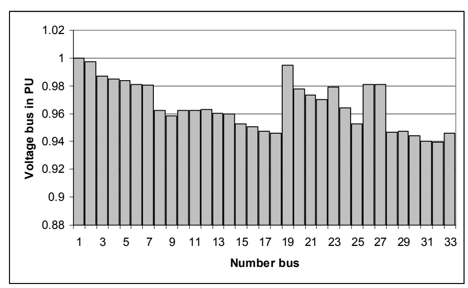

Fig.5 Bus voltage magnitude profile of the system after reconfiguration by PSO based on Equ. (7).

To validate the results obtained, GA is applied to solve the problem. A configuration is considered with five genes. The number of chromosomes for a population is set to be 50. In this paper, one point crossover is applied with the crossover probability $p_c = 0.9$ and the mutation probability is selected to be changed linearly from $p_m = 0.05$ to $p_m = 0.005$. Also, a weighted roulette wheel is used. As in the PSO, the number of iteration is considered to be 100. The obtained results by GA given in Table 2 shows that the switches 7, 9, 14, 28 and 32 should be opened to get the best configuration based on Equ.

(7). Tables 1 and 2 show that the obtained results by PSO and GA have difference in one switch. PSO finds the switch 27 to be opened while GA finds the switch 28 to be opened. Fig. 1 shows that these two switches are next to each other. Comparing the obtained results by PSO and GA show that GA performs better than PSO. The convergence characteristics of GA to find the solution over 20 independent runs are shown in Figs. 6-7, where, these figures show that GA has a better convergence rate.

Table 2. The obtained results by GA for the first study network

Network configuration		Tie switches	Power loss (*KW*)	Min.Voltage magnitude (*Pu*)
Original configuration		33, 34, 35, 36, 37	204.5	0.9129
After reconfiguration	Equ. 9	7, 9, 14, 32, 37	140.4	0.9397
	Equ. 7	7, 9, 14, 28, 32	140.7	0.9412

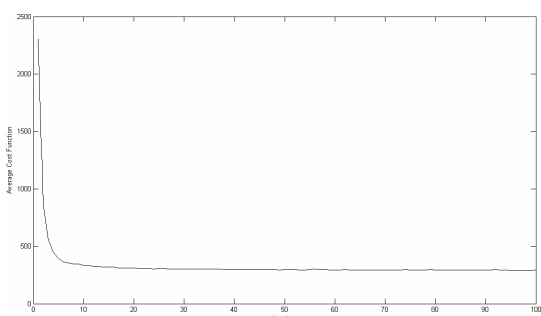

Fig. 6. Convergence characteristics of GA on the average cost function in finding the solution based on Equ. (7).

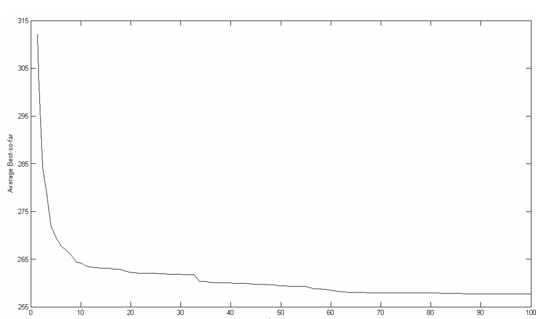

Fig. 7. Convergence characteristics of GA on the average best-so-far in finding the solution based on Equ. (7).

7 Conclusions

In this paper, PSO and GA using graph theory are applied to configure two distribution networks to minimize losses and voltage profile enhancement. Graph theory helps the GA and PSO algorithms to find the radial configuration for distribution network easily. The obtained results by two algorithms are compared. Although the obtained results by PSO in [17] for a small distribution network was promising but the obtained results in this paper show that GA is performing better than PSO. The PSO has been proven to be very effective for static and dynamic optimization problems. But in some cases as shown in this paper when the problem becomes complex, it converges prematurely without finding a local optimum. Thus; it is possible for the standard PSO to converge prematurely without finding even a local extermum. To overcome of the premature converge, other version of PSO known as Guaranteed Convergence Particle Swarm Optimization (GCPSO) should be used where the authors are working on it.

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