POWER LOSS MINIMIZATION IN DISTRIBUTION SYSTEM USING NETWORK RECONFIGURATION WITH PARTICLE SWARM OPTIMIZATION

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Abstract

Reconfiguration of radial distribution system is significant way of altering the power flow through lines. This paper presents a new method to solve the network reconfiguration problem with an objective of minimizing real power loss and improving voltage profile in radial distribution system(RDS). A Meta-heuristic Particle Swarm Optimization (PSO) is used to reconfigure and identify the optimal tie switches for minimization of real power loss in a distribution network. Different scenarios of reconfiguration of distributed network are considered to study the performance of the proposed method. The constraints of voltage and branch current carrying capacity are included in the evaluation of the fitness or objective function. The method has been tested on 33-bus at four different load levels to demonstrate the performance and effectiveness of the proposed method. The results obtained, shows that improvement in voltages and reduced losses.

Index Terms: Radial distribution system, real power loss, Particle Swarm Optimization, voltage profile.

1. INTRODUCTION:

Power Generation and Transmission is a complex process, wherever power is to be transferred, the two main components are active and reactive power. In a three phase ac power system active and reactive power flows from the generating station to the load through different transmission lines and networks buses. The active and reactive power flow in transmission line is called power flow or load flow. Power flow analysis is also used to determine the steady state operating condition of a power system. For the planning, operation and future expansion of power distribution system, Power flow analysis is used.

Due to uncertainty of system loads on different feeders, which vary from time to time, the operation and control of distribution systems is more complex particularly in the areas where load density is high. Power loss in a distributed network will not be minimum for a fixed network configuration for all cases of varying loads. Hence, there is a need for reconfiguration of the network from time to time.

Network reconfiguration is the process of altering the topological structure of feeders by changing open/closed status of sectionalizing and tie switches. In general, networks are reconfigured to reduce real power loss and to relieve overload in the network. However, due to dynamic nature of loads, total system load is more than its generation capacity that makes relieving of load on the feeders not possible and hence voltage profile of the system will not be improved to the required level. In order to meet required level of load demand, DG units are integrated in distribution network to improve voltage profile, to provide reliable and uninterrupted power supply and also to achieve economic benefits such as minimum power loss, energy efficiency and load leveling. However, in the proposed method, network reconfiguration for improved loss minimization and voltage profile at some level.

Since network reconfiguration is a complex combinatorial, non-differentiable constrained optimization problem, many algorithms are proposed in the past. Merlin and Back [1] first proposed network reconfiguration problem and they used a branch and bound-type optimization technique. The drawback with this technique is the solution proved to be very time consuming as the possible system configurations are 2^n, where *n* is line sections equipped with switches. Based on the method of Merlin and Back [1], a heuristic algorithm has been suggested by Shir-mohammadi and Hong [2]. The particle swarm optimization algorithm is proposed [3]. The references [4-8] presents the different configurations in distribution system.

2. PROBLEM FORMULATION:

A. Power Flow Equations:

The power losses in the distribution systems are real power loss and reactive power loss. The total real power loss (I^2R loss) in a balanced distribution system consisting of *b* branches can be written as

$$P_{LT} = \sum_{i=1}^{b} I_i^2 R_i \qquad (1)$$

Where I_i is the branch current and *R* is the resistance of the i^{th} branch of the network.

$$I_i = I_a + j * I_r \qquad (2)$$

The branch current I_i is the active part of the branch Current I_a and reactive part of branch current I_r in the network can be obtained from the load flow solution of the network. The total I^2R loss P_{LT} can be separated in to two components P_{LA} and P_{LR} based on the active and reactive components of branch currents. The power loss components can be defined as

$$P_{LA} = \sum_{i=1}^{b} I_{ai}^2 R_i \qquad (3)$$

$$P_{LA} = \sum_{i=1}^{b} I_{ri}^2 R_i \qquad (4)$$

The power loss in the line section connecting buses and *k+1* may be computed as

$$P_{Loss}(k, k+1) = R_k . \frac{(P_k^2 + Q_k^2)}{|V_k|^2} \qquad (5)$$

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 distribution system.

B. Objective Function:

The objective function of the problem is formulated to maximize the power loss reduction in distributed system, which is given by

$$fitness\ function = min\ \{\ P_{Loss}\ \} \qquad (6)$$

C. Voltage Violations:

The next proposed goal is to minimize voltage violations at load nodes. Permissible limits of voltage is defined as

$$0.90 < V < 1.10 \qquad (7)$$

3. PSO METHOD:

Particle swarm optimization (PSO) method is a population based evolutionary computation technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by a social behavior of bird flocking or fish schooling. The Particle swarm concept originated as a simulation of simplified social system, and has been found to be robust in solving linear and nonlinear problems. PSO technique can generate high quality solutions within shorter calculation time and have more stable convergence characteristic than other stochastic methods. PSO based approach is considered as one of the most powerful methods for resolving the non-smooth global optimization problems.

PSO shares many similarities with evolutionary computation technique such as Genetic Algorithms. Both algorithm start with a group of a randomly generated population and both have fitness values to evaluate the population. Both update the population with random techniques. However, PSO does not have genetic operators like crossover and mutation. Particles update themselves with the internal velocity. The mechanism of information sharing is significantly different compared to genetic algorithms. In genetic algorithms, chromosomes share the information with each other.

Inertia weight:

The main purpose of a standard continuous optimization technique is to find the best of all feasible solutions to a optimization problem minimizing or maximizing a continuous function with respect to several constraints.

$$\underset{x}{\text{minimize}} = f(x), \quad f(x): R^n \to R$$

subject to $g_i(x) \le 0, i = 1,2 \dots, m$

$$h_i(x) = 0, i = 1,2 \dots, p$$

Where f(x) is called objective or fitness function and gi(x) and hi(x) respectively define the inequality and equality constraints.

Then the personal best position $P_{best,t}$ at the next time step, $t+1$, where $t \in [0, \dots, n]$, is calculated as

$$P_{best,t}^{t+1} = \begin{cases} P_{best,t}^{t} & if\ f(x_i^{t+1}) > P_{best,i}^{t} \\ x_i^{t+1} & if\ f(x_i^{t+1}) \le P_{best,i}^{t} \end{cases}$$

Where $f: R^n \to R$ is the fitness function. The global G_{best} at next time step, t is calculated as

$$G_{best} = min\ \{P_{best,t}^{t}\}$$

$$where\ i\ \epsilon\ [1, \dots, n]\ and\ n > 1$$

The global best position G_{best} is the best position discovered of the particles in the entire swarm.

For gbest method, the velocity of particle i is calculated by

$$V_{ij}^{t+1} = V_{ij}^{t} + c_1 r_{1j}^{t}[P_{best,i}^{t} - x_{ij}^{t}] + c_2 r_{2j}^{t}[G_{best,i}^{t} - x_{ij}^{t}]$$

$$X_i^{k+1} = X_i^{k} + V_i^{k+1}$$

V_{ij}^t is the velocity vector of particle i in dimension j at time t;

x_{ij}^t is the position vector of particle i in dimension j at time t;

$P_{best,i}^t$ is the persona best position of particle i in dimension j

From initialization through time t;

$G_{best,i}^t$ is the global best position of particle i in dimension j

From initialization through time t;

c_1, c_2 are positive acceleration constants;

X_i^k Position of Particle in K^{th} iteration

$r_{1j}^t\ r_{2j}^t$ are random numbers from uniform distribution $\cup\ (0,1)$ at time t.

C. Inertia weight:

The inertia weight 'w' will at every step be multiplied by the velocity at the pervious step, i.e. V_{ij}^t. Therefore, in the gbest PSO, the velocity equation of the particle i with the inertia weight equation changes to

$$V_{ij}^{t+1} = \omega V_{ij}^{t} + c_1 r_{1j}^{t}[P_{best,i}^{t} - x_{ij}^{t}] + c_2 r_{2j}^{t}[G_{best,i}^{t} - x_{ij}^{t}]$$

The inertia weight can be implemented either as a fixed value or dynamically changing value. Initial implementations ω used a fixed value for the whole process for all particles.

Usually the large inertia value is high at first, which allows all particles to move freely in the search space at the initial steps and decreases over time. The decreasing inertia weight ω has produced good results.

$$\omega^{t+1} = \omega_{max} - \left(\frac{\omega_{max} - \omega_{min}}{t_{max}}\right) t\ ,$$

$$\omega_{max} > \omega_{min} \qquad (3.29)$$

$\omega_{max}\ and\ \omega_{min}$ are the initial and final value of the inertia weight respectively.

t_{max} is the maximum iteration number.

t is the current iteration number.

Constraints considered are,

$$\left.\begin{array}{l} V_i^{min} \leq V_i \leq V_i^{max} \\ X_i^{min} \leq X_i \leq X_i^{max} \end{array}\right\} \quad (3.30)$$

4. TEST RESULTS:

The new solution vectors are generated and updated using (18). Using new solution vectors, inferior vectors of previous iteration will be replaced with a new randomly generated vector selected from the population that has lesser objective function value. This procedure is repeated until termination criteria is satisfied. In order to demonstrate the effectiveness of the proposed method using HSA, it is applied to two test systems consisting of 33. In the simulation of network, nine scenarios are considered to analyze the superiority of the proposed method.

Scenario I: The system is without reconfiguration and distributed generators (Base case);
Scenario II: same as Scenario I except that system is reconfigured by the available sectionalizing (32) switches and tie (5) switches.

Table 1: Different Scenarios in Network Reconfiguration at Distribution Level

Scenario		**Load level**		
		Light (0.5)	**Normal (1.0)**	**Heavy (1.5)**
Base Case (Scenario 1)	Tie Switches	33,34,35,36,37	33,34,35,36,37	33,34,35,36,37
	Power Loss(kW)	47.0766	202.7069	496.4391
	Minimum voltage (p.u)	0.9582	0.9130	0.8634
Only Reconfiguration (Scenario 2)	Tie Switches	6, 12, 32, 33, 37	6, 12, 32, 33, 37	6, 12, 32, 33, 37
	Power Loss(kW)	42.6646	182.9718	446.2550
	Minimum voltage (p.u)	0.9547	0.9049	0.8492
Only Reconfiguration (Scenario 3)	Tie Switches	6, 10, 14, 30, 37	6, 10, 14, 30, 37	6, 10, 14, 30, 37
	Power Loss(kW)	39.7603	170.7829	418.2332
	Minimum voltage (p.u)	0.9503	0.8954	0.8333
Only Reconfiguration (Scenario 4)	Tie Switches	7, 9, 36, 33, 37	7, 9, 36, 33, 37	7, 9, 36, 33, 37
	Power Loss(kW)	38.5943	163.5938	392.7124
	Minimum voltage (p.u)	0.9646	0.9267	0.8855
Only Reconfiguration (Scenario 5)	Tie Switches	7, 9, 14, 28, 30	7, 9, 14, 28, 30	7, 9, 14, 28, 30
	Power Loss(kW)	36.8208	156.7013	378.7834
	Minimum voltage (p.u)	0.9551	0.9061	0.8514

Only Reconfiguration (Scenario 6)	Tie Switches	6, 9, 14, 28, 36	6, 9, 14, 28, 36	6, 9, 14, 28, 36
	Power Loss(kW)	35.4740	149.1719	354.4711
	Minimum voltage (p.u)	0.9701	0.9386	0.9051
Only Reconfiguration (Scenario 7)	Tie Switches	9, 28, 33, 34, 36	9, 28, 33, 34, 36	9, 28, 33, 34, 36
	Power Loss(kW)	34.8293	146.3930	347.7328
	Minimum voltage (p.u)	0.9692	0.9367	0.9020
Only Reconfiguration (Scenario 8)	Tie Switches	7, 9, 14, 31, 37	7, 9, 14, 31, 37	7, 9, 14, 31, 37
	Power Loss(kW)	33.9012	142.6113	339.2798
	Minimum voltage (p.u)	0.9633	0.9239	0.8812
Optimal Reconfiguration (Scenario 9)	Tie Switches	7, 9, 14, 32, 37	7, 9, 14, 32, 37	7, 9, 14, 32, 37
	Power Loss(kW)	33.2703	139.5585	330.7409
	Minimum voltage (p.u)	0.9698	0.9378	0.9038

From table 1, Scenario 1 represents the results of 33-bus system before reconfiguration. This test system is a 33-bus radial distribution system with 5 tie-switches and 32 sectionalizing switches. In the network configuration, the base case represents 32 sectionalize switches (normally closed) are numbered from 1 to 32, and 5 tie-switches (normally open) are numbered from 33 to 37.

Scenario 3 represents the results of 33-bus system after reconfiguration, consider as average case. This test system is a 33-bus radial distribution system with 5 tie-switches and 32 sectionalizing switches. In the network, this average case represents 32 sectionalize switches and 5 tie-switches are 6, 10, 14, 30, 37 .

Scenario 9 represents the results of 33-bus system optimal reconfiguration. This test system is a 33-bus radial distribution system with 5 tie-switches and 32 sectionalizing switches. In the network, this optimal case represents 32 sectionalize switches (normally closed) and 5 tie-switches (normally open) are 7, 9, 14, 32, 37

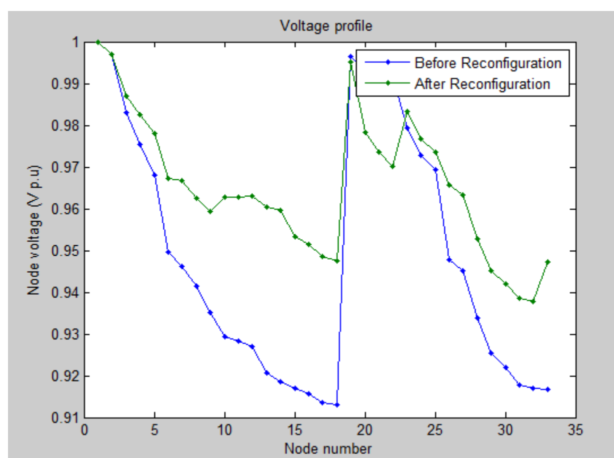

Fig: Voltage Profile before and Optimal Reconfiguration

Table II: Summary of Network Reconfiguration

Scenario		**Load level**		
		Light (0.5)	**Normal (1.0)**	**Heavy (1.5)**
Base Case (Scenario 1)	Tie Switches	33,34,35,36,37	33,34,35,36,37	33,34,35,36,37
	Power Loss(kW)	47.0766	**202.7069**	496.4391
	Minimum voltage (p.u)	0.9582	0.9130	0.8634
After Reconfiguration (Scenario 2)	Tie Switches	6, 10, 14, 30, 37	6, 10, 14, 30, 37	6, 10, 14, 30, 37
	Power Loss(kW)	39.7603	170.7829	418.2332
	Minimum voltage (p.u)	0.9503	0.8954	0.8333
Optimal Reconfiguration (Scenario 3)	Tie Switches	7, 9, 14, 32, 37	7, 9, 14, 32, 37	7, 9, 14, 32, 37
	Power Loss(kW)	32.2703	**139.5585**	330.7409
	Minimum voltage (p.u)	0.9698	0.9378	0.9038

It is observed from Table II, at light load, the power loss (in kW) in the system is 47.06 which is reduced to 39.76 and 32.27 using scenario 2 (After Reconfiguration) and scenario 3 (Optimal Reconfiguration) respectively. The percentage loss reduction for scenario III and IX is 15.74%, and 30.92%, respectively. The base case power loss (in kW) at light, nominal, and heavy load conditions is 47.0766, 202.7069 and 496.4391 respectively. similarly for optimal configuration, the power loss (in kW) at light, nominal, and heavy load conditions are 32.2703, 139.5585 and 330.7409 respectively.

The proposed PSO method iteratively searches for maximum loss reduction which gives the optimal reconfiguration. The coding of PSO method is simple because the PSO method has no evolution operators such as crossover and mutation, which appears in genetic algorithm.

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