Optimizing Loss Reduction through Distribution Network Restructuring using the PSO Algorithm

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Abstract:-In this study, the research delves into the intricate process of formulating and restructuring Radial Distribution Networks (RDN) using loop matrices. The conventional analytical method employed to determine optimal restructuring demands significant computational time, a duration that escalates in direct proportion to the number of buses within the system. Consequently, the necessity for an optimization algorithm becomes paramount to identify the optimal restructuring strategy for radial distribution systems. The primary objective of this optimal restructuring lies in minimizing network losses. To achieve this, the research employs advanced optimization algorithms, specifically Genetic Algorithm and Particle Swarm Optimization. This work utilizes metaheuristic methods for optimal restructuring, incorporating organic optimization techniques such as the PSO algorithm. The study rigorously investigates the reorganization issue within a conventional large-scale 135-node network, exploring various scenarios in both the presence and absence of optimization approaches.

Keywords*: PSO, RDN, Bus System.*

1. Introduction

Power system engineers face the formidable task of meeting escalating load demands within existing generating capacities. Expanding these capacities involves substantial investments and time. Therefore, optimizing the operation of the current power network is essential. To achieve this goal, systematic planning methods and effective control strategies are crucial to minimize energy losses, enhancing the quality of power delivered to consumers [1-2]. The fundamental components of a power system include generating stations linked through high voltage transmission networks and low voltage distribution networks that supply electricity to various points of use. The planning, design, and operation of generating and transmission systems have been meticulously analyzed, integrating suitable control strategies to optimize performance. In particular, meticulous attention is required in the systematic planning and design of distribution systems to enhance the power quality provided to consumers. Reconfiguration refers to the process of altering the distribution network's topology without disrupting its radial configuration. It stands out as an economical method to curtail system losses without introducing additional compensating devices. Optimizing the topology modification to minimize losses constitutes the essence of optimal reconfiguration of Radial Distribution Systems (RDS) [3]. The primary challenge lies in determining the number of tie-line switches, a value contingent upon the RDS's loop count. This chapter explores the optimal selection of main switches and tie line switches. The optimization objective is to minimize system losses through judicious reconfiguration. To achieve this, a heuristic algorithm is employed, focusing on the strategic opening or closing of switches. The switching decisions for tie lines and sectionalized switches are based on the loop matrix (LM) [4-6].A crucial application of reconfiguration is loss reduction within the system. Initially, radial distribution systems are designed through meticulous power system planning and load allocation. However, as system load escalates over time, the existing planned grid struggles to meet the heightened demand, leading to increased losses. Consequently, the system losses intensify with rising load.

Reconfiguration plays a pivotal role in adapting the planned distribution system's structure to accommodate higher loads, thereby addressing this challenge.

2. Optimizing techniques

The main objective of optimization is to minimize undesirable things (e.g., cost, energy loss, errors, etc.) or maximize desirable things (e.g. profit, quality, efficiency, etc.) since its mathematical model, subject to some constraints. Optimization is a commonly encountered mathematical problem in all engineering disciplines. It literally means finding the best possible/desirable solution.Optimization problems are wide ranging and numerous, hence methods for solving these problems. From the view of optimization, the various techniques including traditional and modern optimization methods, which have been developed to solve power system operation, control and planning problems [7-10].

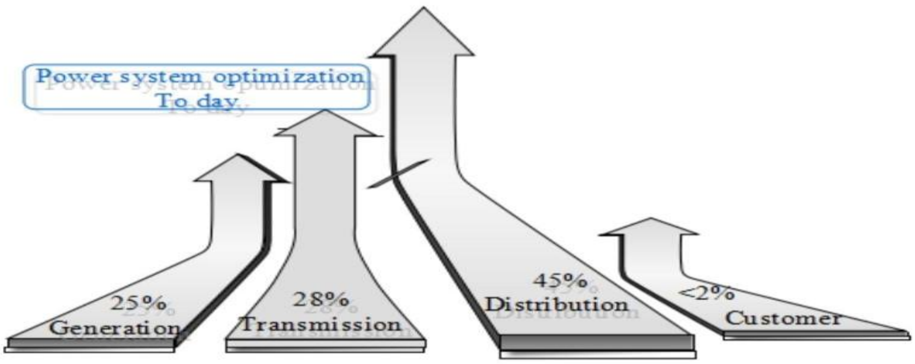

Fig.1 Power system optimization today

Optimization techniques percentage applicability on power systems today. Optimization techniques are applicable on different power system stages such as generation, transmission, distribution and customer's side for minimizing different problems, and its percentage applicability. Fig.1 shows Power system optimization today. Fig .2 shows Some Optimization methods with its invention years [11].

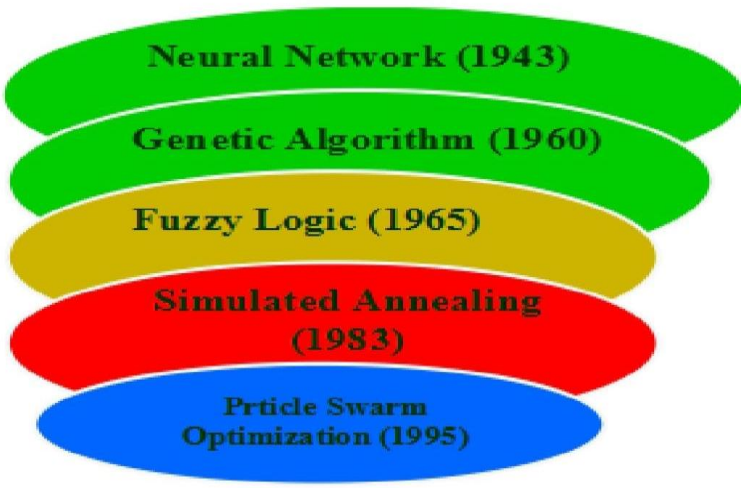

Fig.2 Some Optimization methods with its invention years

3. Network Reconfiguration

Network Reconfiguration (NR) of a power distribution system is an operation for altering the topological structure of distribution feeders or feeder laterals by changing closed status of sectionalizing and open status of tie switches. Network reconfiguration balances feeder loads and helps in managing overload situations of the network by transferring part of their load from heavily loaded feeders to lightly loaded feeders [12-14]. The main advantages of the radial system over meshed systems are simplicity of analysis, lower short circuit currents, simpler switching, simpler protection schemes, lower cost and useful when the generating is at low voltage. Such networks are more economical which have a small load condition for some regions and involve fewer amounts of cables.

On the other hand, the radial structure provides lower reliability. Most of the primary distribution networks are designed as radial, which is provided exclusively one path from substation to the consumer and if it is interrupted resulting in a complete outage of power to the consumers. An efficient operation of distribution networks can be achieved by reconfiguring the system to reduce the power losses as the operating conditions altered. Network reconfiguration can also be used in planning studies for determining the optimal configuration of the network. Furthermore, online reconfiguration management becomes a crucial part of distribution automation [15-18].

Generally, network reconfiguration is proposed herein considers the following aspects

i). Provide service to as many customers as possible during planned outages for maintenance purpose.

ii). No feeder section can be left out service, except the faulty line section.

iii). Radial structure of the distribution network must be retained in which all loads must be energized.

iv). The unwanted switching operations are discarded to make simple the dimensionality problem.

v). Loss allocation to consumers before and after network reconfiguration.

vi). A desirable solution technique capable of reducing the computational requirements and the change in power losses.

vii). Reduce network resistive line losses and balance the loads to avoid overload of network line sections.

Two most important aspects to reconfigure the distribution networks are Minimization of real power losses and Maximization of the load balancing Feeder reconfiguration is a very important function of automated distribution systems to reduce distribution feeder losses, load balancing and improve system security. Loads can be transferred from feeder to feeder by changing the open and close status of the feeder high speed switches. The optimal reconfiguration model responds to changes in the network topology by switching the automatic breakers installed in the network [19-21]. Effective combination of switches that are to be opened, can significantly improve the performance of radial distribution networks. Reconfiguration not only involves discovering all concerned trees consisting of the nodes analogous to supply points but also all loads in the reduced network by satisfying voltage and current constraints. For identification of optimal switches in the network by testing different combinations in switching using loop vectors.

4. Particle Swarm Optimization

Particle swarm optimization (PSO) method is a population based evolutionary computation technique developed by Eberhart and Kennedy in 1995,inspired by a social behavior of bird flocking or fish schooling is shown in Fig.The Particle swarm concept originated as a simulation of a simplified social system, and has been found to be robust in solving linear and nonlinear problems. PSO technique can generate high quality solutions within less calculation timeand have more stable convergence characteristic than other stochastic methods. The PSO based approach is considered as one of the most powerful methods for resolving the non-smooth global optimization problems. The life cycle of PSO algorithm is exposed in Fig.3 [22].

Fig.3 Social Behavior of Bird Flocking and Fish Schooling

The mechanism of information sharing is significantly different compared to genetic algorithms. In genetic algorithms, chromosomes share the information with each other. In PSO, only, g best gives out the information to others. The evolution only looks for the best solution [23].

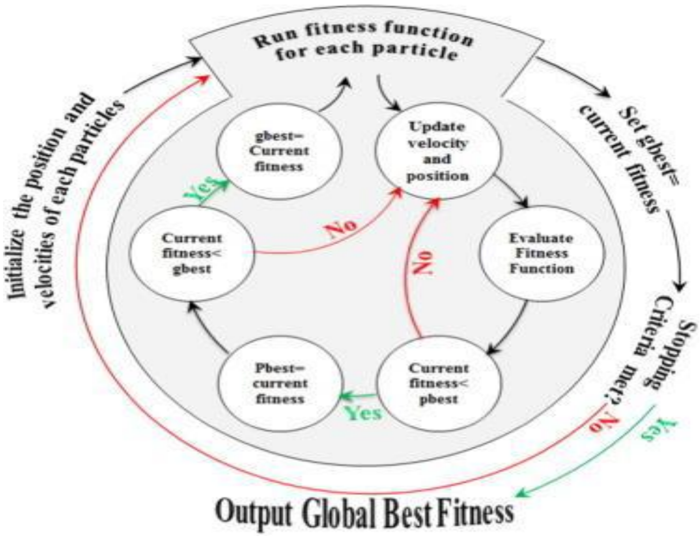

Fig.4 Cycle Process of Particle Swarm Optimization

The PSO was originally inspired by the social behavior of bird flocks and fish schools. It was observed that they take into consideration the global level of information to determine their direction. Hence, the global and the local best positions are computed at each instant of time (iteration), and the output is the new direction of search. Once this direction is detected, it is followed by the cluster of birds.Cycle Process of Particle Swarm Optimization is shown in Fig.4 [24-26].

1) Each individual particle i has the following properties: A current position in search space, xi , a current velocity, vi , and a personal best position in search space, yi .

2) The personal best position, yi , corresponds to the position in search space where particle i presents the smallest error as determined by the objective function f, assuming a minimization task.

3) The global best position represents the position yielding the lowest error among all the yi. Equations define how the personal and the global best values are updated at time t, respectively. In the following, it is assumed that the swarm consists of s particles, thus i∈ 1 . . . s.

$$yi(t + 1) = \{yi(t) \text{ if } f(yi(t) \leq f(xi(t + 1)))\}$$

$$\{xi(t + 1) \text{ if } f(yi(t) > f(xi(t + 1)))\}$$

$$y\hat{}(t) = \min \{f(y), f(\hat{}y(t))$$

$$y \in \{y0(t), y1(t), . . . ,ys(t)$$

Algorithm:

Reconfiguration of radial distribution system with PSO, the following steps are to be followed:

Number of variables=number of dimensions.

Step 1: Firstly, initialize the positions and velocity of the particles in the swarm within their respective limits.

Step 2:Then initialize the historical best p best.

Step 3: If Maximum number of iterations is reached or algebraic difference meet the minimum limit, then choose the optimal solution.

Step 4: If not, set pbest to all particles and select gbest among pbest.

Step 5: Then evaluate the particle swarm.

Step 6: Now update achieve, update gbest, update pbest and choose the optimal solution.

Step 7:The best switches that should be operated are found using this algorithm.

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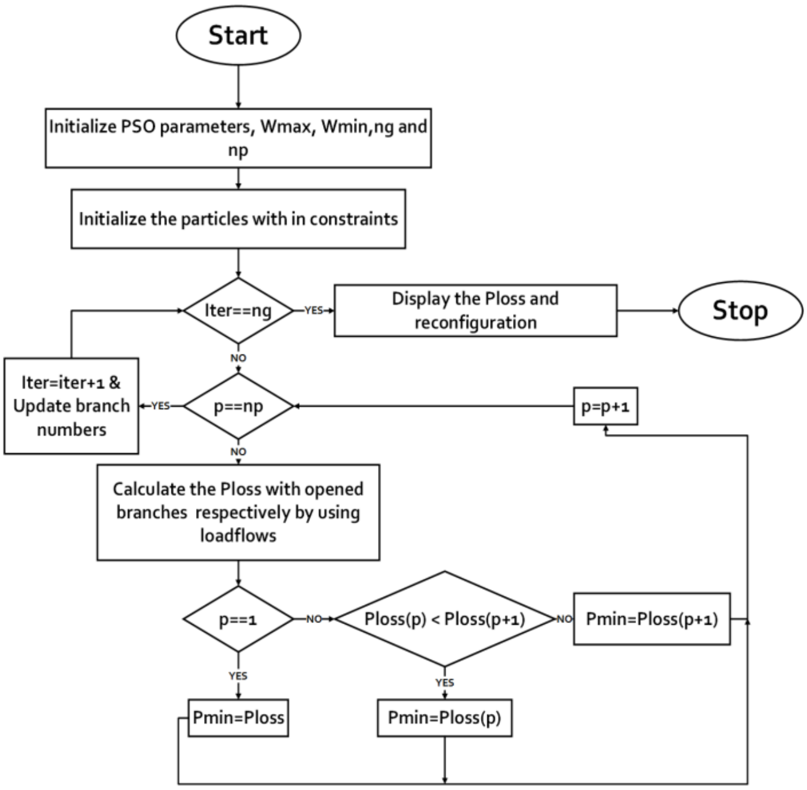

Fig.5 flow chart for PSO

5. Simulation Results

Test Case-: 135-RDN

A. without Reorganization:

The voltage profile of the 135 bus is shown in Fig.6.The number of tie-line switches of 135 bus system is 21. The real power losses of 135 bus RDS are 306.01 kW.

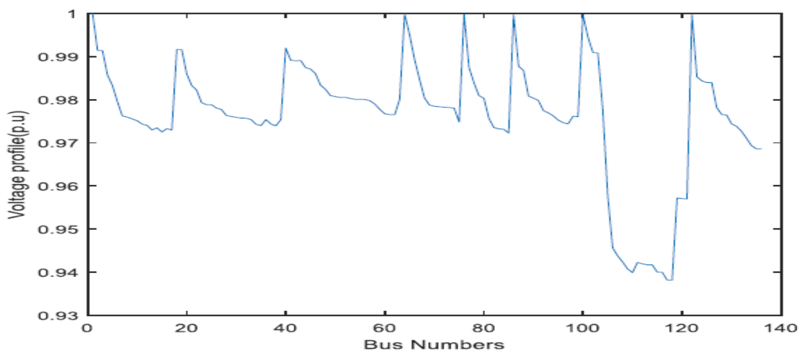

Fig 6. Voltage profile of 135 bus system

B. with Reorganization:

The number of tie-line switches of 135 bus system is 21.The reorganization switches are 141,146, 116, 150, 34, 94, 144, 138, 139, 137, 154, 152, 155, 149,148, 145, 153, 143, 147, 151, 128 and losses are 288.02 kW. The effect reorganization of 135 bus system is shown in fig.7 the voltage profile improvement.

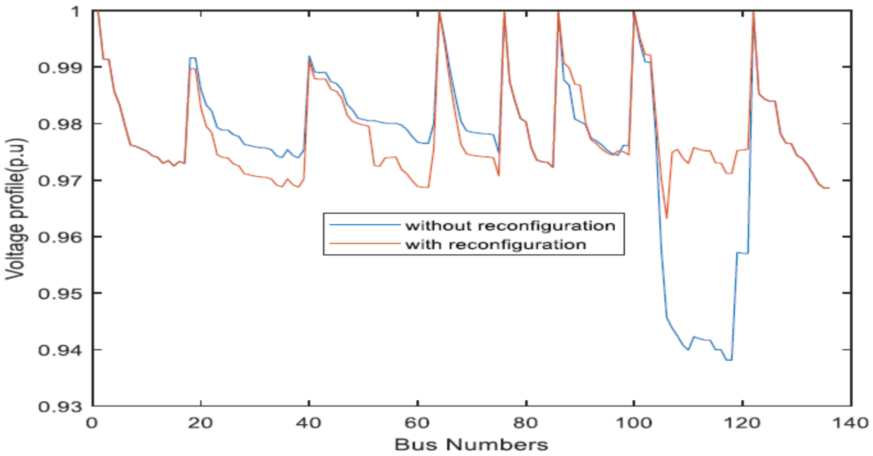

Fig .7 Voltage outline of 135 bus system with reorganization

C. Optimal Reorganization using PSO:

The proposed algorithms are used to study the high rated RDN which is in high rated size of the load and size of the bus system. The bus system has 21 tie-line switches. These switches are used for optimizing the 135 bus radial distribution system. The 135-node system reorganization with PSO is shown in figure .8. The tie-line switches which are used to optimize the RDS are 7 35 51 90 96 106 118 126 135 137 138 141 142 144 145 146 147 148 150 151 155. The losses of the system are reduced from 306.01 kW to 281.011 kW. The comparative analysis of the system is given in Table II. Comparative analysis of voltage profiles of 135 bus RDS with proposed optimization techniques shown in fig.9. Figure.10 shows the real power losses of various algorithms.

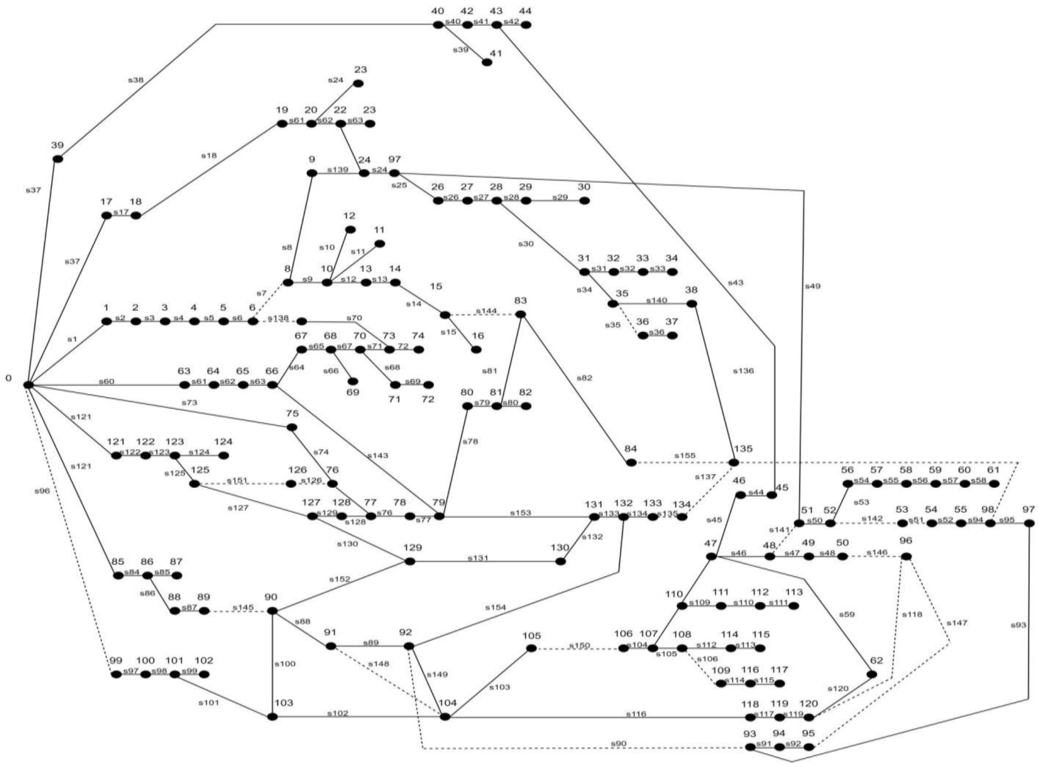

Fig .8 135- bus system reorganization using PSO.

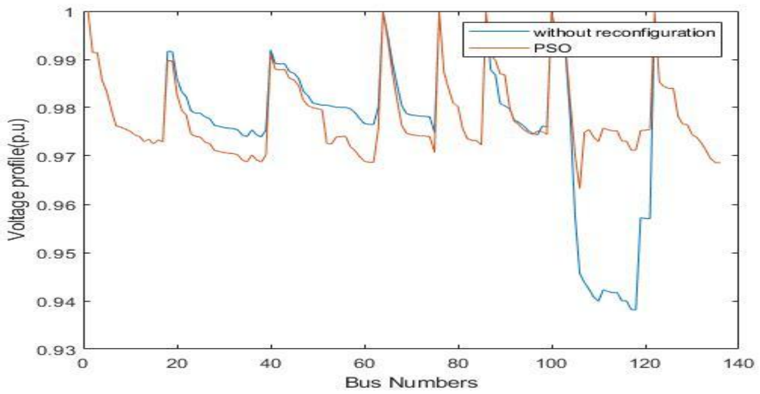

Fig .9 Voltage outline of 135 bus system with reorganization using PSO.

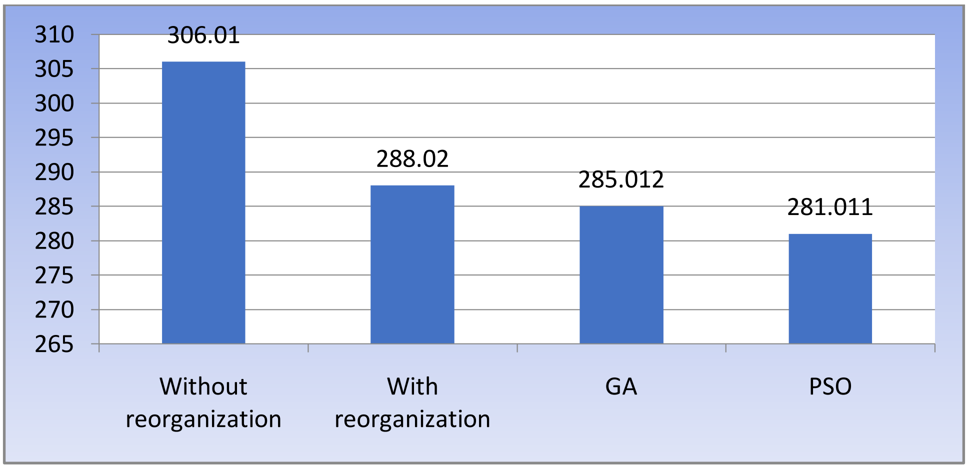

Fig .10. Real power losses of various algorithms

Table I shows the Comparative analysis of 135 bus system parameters using optimizing techniques.

Table I. Comparative analysis of 135 bus system parameters using optimizing techniques.

Content	Without reorganization	With reorganization	PSO
Switches open	136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156	141,146, 116, 150, 34, 94, 144, 138, 139, 137, 154, 152, 155, 149,148, 145, 153, 143, 147, 151, 128	7 35 51 90 96 106 118 126 135 137 138 141 142 144 145 146 147 148 150 151 155
Losses (kW)	306.010	288.02	281.011
%Reduction of losses	---		30.14
Minimum voltage(p.u)	0.938	0.935	0.952

6. Conclusions:

The optimization algorithm PSO is used to optimize the 135 bus system. The dimensions of the optimization algorithm are similar with 33 bus and 69 bus system which are five in each case. The losses are less with PSO optimization of reorganization of 135 bus system. In this research work, Particle Swarm Optimization algorithm is used for reorganization, it reduced both the power losses and computational time compared to GA and load flow methods to solve the same distribution networks. Using reorganization for a existing bus system, 793 KW of maximum reduction in loss is obtained i.e. almost 30.14% of losses are reduced and for a 135 bus system, losses are reduced from 306.01KW to 281.011KW. The results obtained after reorganization suggests that the proposed Particle Swarm Optimization algorithm is capable for finding the best solution using simultaneous switching.

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