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STATE OF ART FOR NETWORK RECONFIGURATION METHODOLOGIES OF DISTRIBUTION SYSTEM

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ABSTRACT

Radial Distribution is the most popular and existing type of power transmission network in the distribution system. Losses minimizations, maintenance of good voltage profile and feeder current levels minimum are the three objectives for the distribution engineer. For the past two and half decades researchers proposed different methodologies that includes heuristic and intelligent methods. This paper explores existing popular methodologies to mitigate the problem. Research publications in the popular journals, conferences and symposiums are the main source for collecting data. Popular journals like IEEE transactions, Elsevier etc., are referred. More than 300 publications are studied which are short listed to around 50. Redundancy is thoroughly avoided before short listing the paper. This paper is useful for the researchers working in this area.

Keywords- *Reconfiguration, Distribution Systems, Power loss, Heuristic methods, Optimization methods*

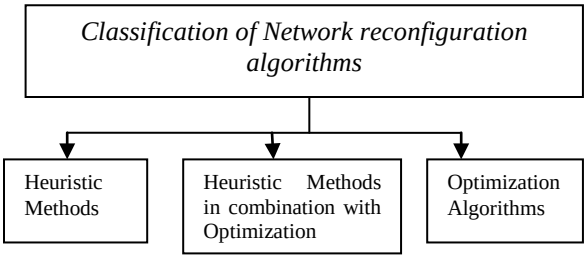
1. INTRODUCTION

Most of the distribution systems are in radial configuration. A Radial distribution system is a combination of Sectionalizing switches (Closed) and Tie switches (Open). By performing switching actions, we can alter the topology of the network and obtain the best possible configuration. The switching action depends on the number of switches, the greater the number of switches, more are the possibilities of reconfiguration. To minimize the number of switching actions, we incorporate different methods.

Though there are many options for reducing losses in a distribution system viz., reconfiguration, capacitor placement, load feeder balancing etc, reconfiguration is the most preferred method because it requires no extra equipment to be installed and is cost effective.

In recent years, considerable research has been conducted for loss minimization in the area of network reconfiguration of distribution systems. This paper makes an attempt to summarize all such methods and to analyze the best possible method for network reconfiguration of distribution system.

Popular methodologies for Network reconfiguration problem. Conventional methods such as Newton Raphson method, Langranges Method or Linear Programming method have not been applied on distribution systems because of



Classification Of Network Reconfiguration Algorithms

their slow convergence and also they fail due to inappropriate initial conditions. Heuristic methods, the second category heuristic with optimization problems have become popular for some time for the reason to avoid the problems in mathematical modeling. Many researchers advocate the use of combination of heuristics and optimization techniques. A certain degree of accuracy and convergence with acceptable solution is assured by using the combination of these two techniques. The necessity for searching optimal solution from large search area made these techniques considerably slow in convergence. To avoid above difficulties

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and due to availability of efficient optimization algorithms like Genetic Algorithm, Swarm optimization techniques, Fuzzy logic methods etc. which became popular and are recently used.

2. PROBLEM FORMULATION

Distribution system consists of two types of switches: tie switch and sectionalizing switch. As shown in Fig.1, the branches between nodes 5-11, 10-14, 7-16 are the tie switches which are open and the remaining continuous switches are called sectionalising switches which are generally closed. When operating conditions are abnormal or undergo a change, reconfiguration of the system is performed during which, one of the tie switch is closed and a part of the load is transferred to another feeder and to maintain the radiality, simultaneously a sectionalized switch must be opened. For example if the network is reconfigured and the tie switch closed is the one between 5-11, then to maintain radiality say switch between 4-5 is opened.

The objective of the reconfiguration is to minimize the distribution losses with turning on / off sectionalizing switches. The reconfiguration problem has the following constrains:

1. Power flow equations.
2. Upper and lower bounds of nodal voltages.
3. Upper and lower bounds of line currents.
4. Feasible conditions in terms of network topology.

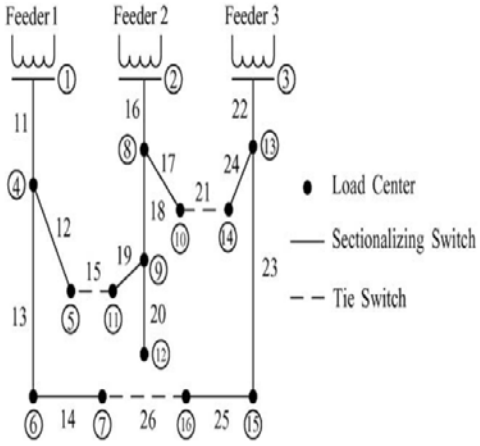

Fig.1 IEEE 16 BUS System

Mathematically, the problem can be formulated as follows:

Cost function:

$$MinZ = \frac{\sum_{i=1}^{L} r_i (P_i^2 + Q_i^2)}{V_i^2} \quad (1)$$

Subject to:

$$g(x) = 0 \quad (2)$$

$$V_i^{min} < V_i < V_i^{max} \quad (3)$$

$$I_i^{min} < I_i < I_i^{max} \quad (4)$$

det(A) = 1 or -1 radial system (5)

det(A) = 0 not radial

Where,
Z: Cost function
L: No. of transmission lines
P_i: Active power loss at bus *i*
Q_i: Reactive power at bus *i*
V_i: Voltage at bus *i*
I_i: Line current at line *i*
g(x):Power flow equations
V_i^{min} : Lower voltage limit
V_i^{max} : Upper voltage limit
I_i^{min} : Lower current limit
I_i^{max} : Upper current limit
A: Bus incidence matrix
r_i : Section resistance

The non-linear nature of the distribution system necessitates that at each iteration of an optimization algorithm a load flow operation be performed to determine a new system operating point. With the facilities available today, load flow analysis can be performed in a time efficient manner, but numerous successive load flows could represent a time-consuming procedure. To reduce the solution time of the problem, some researchers have derived empirical formulas to assess the loss reduction afforded by a particular switching operation.

Definition of the reconfiguration problem in this manner is typical of reconfiguration algorithms proposed to date. The proposed reconfiguration techniques make use of similar problem formulations, but employ different solution methods and introduce simplifications through the use of heuristics, heuristics with combination of optimization algorithms and optimization algorithms respectively. Numerous efforts were made to exploit anomalies in the behaviour of the distribution system.

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3. ALGORITHMS BASED ON HEURISTIC METHODS

These involve the algorithms in which distribution system reconfiguration has been made by using techniques based on only heuristic algorithm methods. The heuristic methods involve development of empirical formulas to assess the loss reduction related with switching operations and also rules to minimize the number of switching operations. They are mainly based on the assumption that improvement in voltage profile at buses would minimize the losses of the system to a great extent. Though the execution time is less, these methods considers approximate system behavior and used only for loss reductions problem.

3.1 Purely Heuristic methods

➢ Based on the method of Merlin and Back in [1], S. Civanlar, J. J. Grainger and S. H. Lee [2], developed a branch-exchange method which considers the on-off conditions of the sectionalizing switches in discrete numbers.

The heuristic rules were based upon typical system operation requirements by analysing voltage drop at system buses. Civanlar et al.[2] were able to find out if a particular switching operation would increase or decrease losses. The rules were defined to eliminate certain switching operations.

The rules civanlar et al.[2] defined were as follows:

Rule 1: *Open tie switches.* Loss reduction can only be attained if there is a significant voltage difference across an open tie switch.

Rule 2: *Open switches.* Loss reduction will be achieved if loads on the higher voltage drop side of the tie switch are transferred to the other side.

Once the two heuristic rules were applied, the relative loss reduction afforded by the remainder of the switching options could be determined using an empirical formula:

$$\Delta P = \mathrm{Re}\left[2\left(\sum_{i\in D} I_i\right)(E_m - E_n)^*\right] + R_{loop}\left|\sum_{i\in D} I_i\right|^2 \quad (6)$$

D: set of buses disconnected from one feeder (I) and connected to another (II)

m: tie bus of feeder I to which loads of feeder II are to be connected

n: tie bus feeder II that will be connected to bus m via a tie switch.

I_i: Complex bus current at bus i

R_{loop}: Series resistance of path connecting two substation buses of feeder I and II via closure of a specified tie switch.

E_m: Component of $E= I_{Bus}*R_{Bus}$ corresponding to bus m

R_{Bus}: Bus resistance matrix of feeder I before load Transfer.

I_{Bus}: Vector of bus currents for feeder I

E_n: similar to E_n but defined for bus n of feeder II

Eq.(6) was derived through perturbation analysis for a UDLM, and was demonstrated to be reasonably accurate for a small sample system. A major drawback of the method of Civanlar et al. was that the behaviour of this formula for a more representative system was unknown. The search procedure for a minimal spanning tree involved evaluating a series of candidate switching options, and then proceeding with only the option which offered the greatest reduction in losses (best-fit search). This procedure would be iterated until no option was untried (Fig.2).

Civanlar et al. used 'branch exchange' operation for switching operations: the open of any switch required closure of any other switch to maintain the radial of the distribution network.

The ***advantages*** of the algorithm of civanlar et al.[2] are:

- The definition of heuristic rules to minimize the number of switching operations.
- The formulation of an equation to determine the relative reduction in losses due to a particular switching operation.
- Better determination of switching configuration with reduced losses and reduced number of switching operations.
- Reasonably accurate approximations to load flows.

The ***disadvantages*** of method presented in [2] are :

- Only one pair of switching operations can be considered at a time.
- Since the method is based on heuristics, it is not so easy to take a systematic way to evaluate an optimal solution.
- The method is only suitable for reduction of losses.
- This method approximates the system behaviour.

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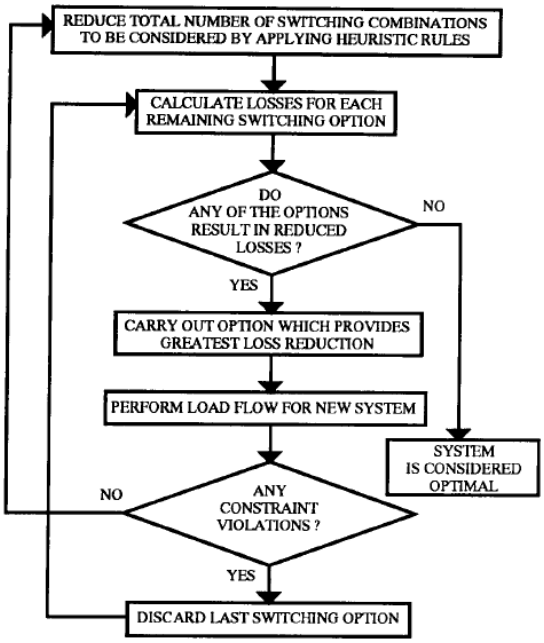

Fig 2. Algorithm of Civanlar et al.[2]

3.2 Other Heuristic algorithms

After great efforts of Civanlar et al in [2]. Several heuristic algorithms were proposed by many other authors. The attempts were made to offer better solutions or to make use of more advanced loss estimation/approximation formulas.

- Baran and Wu [3] made an attempt to improve upon the method of civanlar et al [2], by introducing two approximation formulas for power flow in the transfer of system loads [3]. The power flow equations used by them were defined by the recursive approximation of P, Q and V at each bus. Through this algorithm it was possible to verify important parameters even before the final reconfigured system was established. As baran and Wu [3] represented the system on a per phase basis, they asserted that their algorithm could be employed for reducing losses by load balancing as well.

Baran and Wu [3] tried to overcome the difficulties of 'branch exchange' method by stating that more complex switching operations could be accounted for by a series of 'branch exchanges'. The method of Baran and Wu [3] considered the possible spanning trees which represents local minima. It depends on the feasible initial configuration of the system and divides it into levels; at each stage switching option which doesn't violate the system constraints would be selected. While the solution obtained by heuristic method would offer loss reduction, convergence by using optimization algorithms is uncertain for larger systems.

- Castro and Watanabe [4] extended the work of Civanlar et al. by making use of a more extensive search strategy [4]. The main drawback of Civanlar et al. of that of branch exchange is that it considers the most significant switching options and helps in solution time reduction but increase the likelihood of obtaining a local minimum. The modified search technique of Castro and Watanabe increases the likelihood of obtaining a better solution to the reconfiguration problem. Though this method promises so much, the proposed technique doesn't assure the Global optimum and has not been proven for larger systems.

But over a period of time the methods using blend of heuristics and optimization algorithms have taken over methods which used only heuristics owing to their drawbacks and unreliability for higher bus systems.

Advantages of Heuristic methods:

- Heuristic methods help us in reducing the number of iterations.
- They perform minimal switching actions and help in reducing the time taken for arriving at the solution

Disadvantages of Heuristic methods:

- There are few approximations in the solution which may not be very accurate at times
- The computation time becomes more for higher bus systems

4. Blend of Heuristic and Optimization Algorithms

Distribution system reconfiguration for loss reduction was first proposed by Merlin and Back [1]. They made use of blend of heuristics and optimization to find the minimal loss operating configuration for a distribution system which was represented by a spanning tree structure. The use of heuristics is justified because of the need to reduce the number of iterations and also the convergence in large non linear networks becomes difficult without heuristic rules. Though Civanlar et al. proposed a method solely based on the heuristics, by and large, a blend of heuristics with optimization algorithms was used.

(a)The algorithm of Merlin and Back

Merlin and Back modelled the distribution system by a spanning tree structure [1]. The line sections of

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the distribution network were represented by arcs of the graph and buses with nodes. As a spanning tree problem, the optimal network configuration could be determined from the values found for binary variables associated with switch status. The system constraints were neglected by Merlin and Back for the purposes of the algorithm.

The initial algorithm of Merlin and Back was accounted for only the contribution of the real component of the current in loss calculation and assumed that the voltage angles were negligible. Typical of earlier distribution analysis, Merlin and Back approximated the behaviour of the distribution system by performing a DC power flow operation. The strength of the algorithm of Merlin and Back was that an optimal solution was obtained which was independent of the initial switch status. The distribution system was assumed to be balanced, and losses associated with line equipment were not considered.

Merlin and Back asserted that simultaneous solution of Kirchhoff's current and voltage laws (KCL and KVL) for distribution system, represented as a meshed network, would ensure power flow which presented minimal system losses. The algorithm of Merlin and Back required an iterative process of removing the branch with the lowest power flow and then performing a minimal loss power flow, until a radial network was obtained. The branch-and-bound algorithms used for the problem solution proved to be very time consuming.

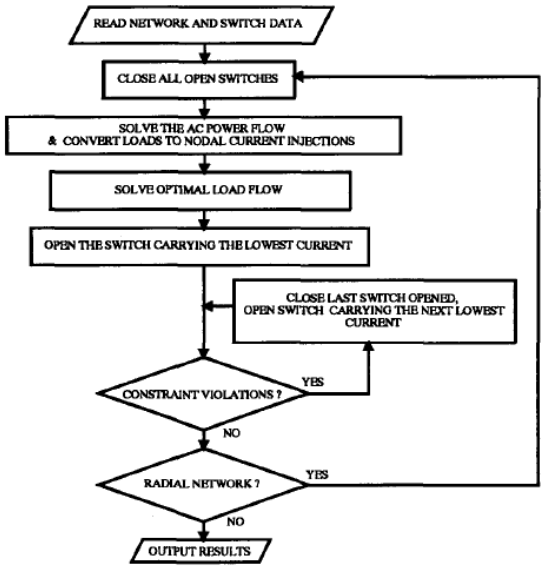

Fig.3 The algorithm of Merlin and Back as modified by Shirmohammadi and Hong.

Fig.3 shows the algorithm of Merlin and Back which was later modified by Shirmohammadi and Hong [5]. The algorithm of Fig.3 as modified by Shirmohammadi and Hong differs from the original proposed by Merlin and Back only in the inclusion of feeder voltage and current constraints. Shirmohammadi and Hong made use of compensation based power flow technique to ensure that the behaviour of the weakly meshed distribution network was more accurately modelled. Few advantages of this method are:

- The convergence is relatively quick
- The achieved solution is very nearer to the optimal solution

The disadvantages with this method are:

- The multiphase, unbalanced nature of the distribution system was not efficiently modelled
- Line equipment losses were not included in the problem formulation
- Despite the use of heuristics, the search strategy represents a time consuming process.

4.2 Other algorithms involving a blend of heuristic and optimization algorithms

Numerous researchers advocated the use of a blend of heuristics and optimization techniques. The blend of the types of technique permits the problem to retain a certain degree of accuracy, while assuring convergence and an acceptable solution time. Although more promising recent work offers considerable advantages over initial efforts, real-time implementation of the reconfiguration method has yet to be performed. Consideration of the cost, transient effect, and influence on the reliability of the switches must be accounted for prior to wise scale implementation.

Liu et al. offered two algorithms that they asserted would ensure a global optimal solution [6]. They recognized that this type of algorithm could be of considerable benefit in both operational and planning contexts. They were able to demonstrate that, by considering the loads as current sinks, the current flowing through an are (regardless of configuration) could be represented by the sum of a basic current y_k and constant a_k. If the current sinks are represented in this way, the current profile from the source is a continuous, monotonically decreasing function. Through the use of the current sink model, their reconfiguration problem was transformed into a positive-definite quadratic programming problem (Eqs. (7) and (8). A global optimal solution would be assured. The problem

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would be solved by a piecewise linearization of the objective function:

Minimize

$$\frac{1}{2}\sum_{k-1}^{na}\int_{o}^{l_k} r_k(x)[y_k(x)-a_k]dx \quad (7)$$

Subject to

$$\sum_{m\varepsilon B1i}(y_{m,\max}-a_m)+\sum_{m\varepsilon B2_i} a_k = 0 \quad (8)$$

$$i = 1,2,.....,nn$$

Where B_{1i} is a set of arcs whose basic current profiles have the highest value at mode i, and B_{2i} is a set of arcs whose basic current profiles have the lowest value at mode i; na and nn are the total number of arcs and nodes, respectively, in the system.

The first algorithm proposed by I.iu et al. Dealt only with the uniformly distributed load model (UDLM) this algorithm served to identify which sectionalizing points were required to be open for a minimal loss configuration. Global optimality could not be assured when practical constraints such as line voltage drop were considered. In this algorithm, if the system was assessed to be 'nonoptimal (failure to meet set criteria) nonoptimal feeder pairs would be selected and minimum loss positions determined until a tolerance was satisfied. The second algorithm of liu et al. Was related to determining the actual switch positions for the optimal system configuration. For this variant of their algorithm, both the UDIM and concentrated load model (CLM) could be used. Formulas to estimate the loss reduction associated with particular switching operation were developed for both load models. This algorithm differed from the first in that all nonoptimal pairs were assessed using the loss estimation formulas and only the pair with the greatest loss reduction was selected. Although promising results were obtained through the use of the second proposed algorithm. Identification of load zones required for the loss estimation would be computationally awkward in an operational environment.

Glamocanin formulated the reconfiguration problem as a transhipment problem with quadratic costs[7]. In this proposed method, it is necessary to obtain an initial 'optimal' configuration by linear zing power losses. Using the 'optimal' initial configuration as the starting basic solution, the quadratic simplex method was used to improve the solution. The ladder network technique was employee for the distribution load flow analysis. Although the unbalanced multiphase nature of the distribution was not included, an increased sensitivity to the requirements for accurate distribution level modelling was developed. Efforts were made to include the influence of line equipment and to consider crucial operating constraints. The algorithm of glamocanin was deficient in that the quadratic simplex algorithm is known to be greedy, which would increase the likelihood of obtaining a local optimal solution. Algorithm inclusion of all crucial system criteria is not difficult task, solution would entail combinatorial explosion if all required criteria were considered.

Huddleston et al. Offered a reconfiguration algorithm based on a linearly constrained quadratic programming problem [8]. Included in this proposed method was reduction of end circuit segments to spot loads in order to decrease the burden of distribution system analysis. A key feature if this algorithm is the assumption that the distribution systems power factor approaches Unity the loss function can be expressed as a DC Model. By exploiting the structure of the distribution network, Huddleston et al. were able to put forth a continuous representation of the reconfiguration problem where the voltage dependence of the loads was considered.

Wagner et al. presented a reconfiguration algorithm based on solution of a linear transportation problem [9]. Quadratic feeder line section losses were approximated by a piecewise linear function, permitting solution using the stepping-stone algorithm Feeder voltage and thermal constraints could be included due to the simplification introduced by the linearization. Using a working 44 kv distribution network, a comparison of method offered by Wagner et al. Was performed with the method proposed by shirmohammadi and Hong [5] and Civanlar et al. [2] for a small-efficient manner. Analysis of larger networks (those in excess of 1000 buses) using any of the described methods would result in an excessive computational burden for real-time implementation.

Goswami and basu [10] were of the belief that it was inappropriate to initially represent the distribution network as a meshed network and then open switches until a radial system is obtained (the method described by refs [2, 5] in Ref [10], Goswami and basu introduced an algorithm similar to that of Merlin and back [1], differing in that the distribution network was never represented as a meshed system. In the method proposed by Goswami and babu, any switch closure is complemented by the opening of another switch to ensure a radial network. Although suitable for smaller systems, the algorithm proposed by

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goswami and babu is deficient as the solution becomes prohibitive for larger network.

Several Recent efforts have attempted to make use of more progressive optimization methods for the solution of the reconfiguration problem. Chaian and Jean-Juneau developed a two-stage algorithm based on a modified simulated annealing technique and the epsilon constrained method [11,12]. The algorithm of chiang and jean-jumeau proposed to include both optimal loss reduction and load balancing in a multiobjective, nondifferentaible objective optimization problem with both equality and inequality constraints. Although mathematically rigorous, this algorithm was, by the admission of change and jean-jumeau, too time consuming for any practical purpose. Cherkaoui et al. Made use of the TABU search strategy to perform the branch exchange method of reconfiguration [13]. This formulation of the reconfiguration problem would account for the presence of distribution transformers and include line security constraints, but the unbalanced multiphase nature of the system was not considered.

The TABU search method used in Ref.[13] is a popular solution technique in combinatorial optimization problem. Although the use of TABU for the test network used by Cherkaoui et al. Yiclded impressive solution times, the nature of their 0 1 optimization problem would become more cumbersome for systems of more realistic size with added system constraints. Sarfi et al. Offered a method of overcoming the size limitations imposed by previously published techniques [14]. Through the use of network portioning techniques, the distribution network was partitioned into smaller subsystems which can be solved in a more time-efficient manner this application the partitioning also served to reduce the inter subsystem losses. The method presented in Ref.[11-13] are particularly suited to parallel implementations, making them attractive for real-time application.

[15] An Efficient Algorithm for Minimum Loss Reconfiguration of Distribution System Based on Sensitivity and Heuristics by G. K. Viswanadha Raju and P. R. Bijwe.

This paper presented a very efficient, two-stage method for the distribution system reconfiguration for loss minimization. The efficiency of the method stems from the use of real power loss sensitivity with respect to the impedances of the candidate branches. The proposed method used these sensitivities in the first stage. A branch exchange procedure was used in the second stage to refine the solution.

The main **advantages** of Heuristic techniques with combination of optimization algorithms are:

- The solutions achieved are very close to optimal solution
- The computation is time is improved when compared to heuristic method based methods
- The search path is cut short to certain extent which allows in reducing the no. of switching actions being performed

The main **disadvantages** with these methods are:

- Though the solution obtained is close to the optimal solution, the degree of accuracy of the solution is approximated to certain extent
- When applied for systems with large buses, the computation time is high.
-

5. AI BASED TECHNIQUES

With popularity of AI methods increasing day by day and the availability of advanced and fast commercial development packages have resulted in a plethora of AI based power engineering applications [16]. Artificial neural networks (ANNs), genetic algorithm (GAs), and expert systems (ESs), Ant colony methods, Fuzzy based methods, Particle Swarm Optimization methods have been used to implement the distribution reconfiguration procedure. Although the use of AI based methods has proven them to be valuable in a wide variety of applications, the caution is that they do not represent the best solution in some implementations. AI based methods are currently figuring prominently in reconfiguration efforts as more sophisticated methods are becoming readily available. Hybrid algorithms based methods offer the potential of significant reductions in solution times.

5.1 Use of ANNs for distribution reconfiguration

ANNs are particularly useful in the reconfiguration procedure as they can be used to map the relationship between the highly nonlinear nature of a load pattern to a network topology which offers minimal line losses. Although the use of ANNs can offers reduced solution times for even larger problem, three factors make their use father awkward for implementation in a utility.

- A considerable amount of time is required for training.
- Training must be performed for each utility's network and subsequent changes in the system must be accounted

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- Accurate training data must be acquired to ensure that the ANN offers meaningful results.

Kim et al. proposed a two-stage algorithm based upon ANNs for distribution system reconfiguration for loss minimization [17]. To avoid the difficulties associated with training large sets of data, it was proposed that the distribution network be divided into load zones. Each load zone would have a distinct set of two ANNs trained to classify the loading level and to reconfigure, based upon the loading level assignment. The use of an ANN in this application offered fast solution as no load flow operations were required within the solution algorithm. A multilayered feed forward network topology was selected for the ANN in view of the adaptive learning capability of this structure. Training data were obtained by solution of a quadratic programming problem, whose constraints included line voltage drop and thermal limitations. AI though very respectable results are obtained by this algorithm; the solution obtained by the ANN is only as accurate as the training data provided.

5.2 Reconfiguration by GA

The characteristics of genetic algorithms make them particularly suited to ill-structured optimization problems. Based upon the mechanics of natural selection and natural genetics, the GA combines the evolutionary process with functional optimization. The coded discrete information of artificial strings used by the GA lends itself favourably to the binary status of switches in the distribution reconfiguration problem. An interesting feature of the GA is that it searches from a population of points and not from a particular search point, so that there is the possibility of obtaining an optimal solution very rapidly. The features of GA algorithms are:

1. GAs work with a coding of the parameters set, not the parameters themselves. Therefore GAs can easily handle the integer or discrete variables.
2. GAs search with in a population of points, not a single point. Therefore GAs can provide a globally optimal solution.
3. GAs use only objective function information, not derivatives or other auxiliary knowledge. Therefore GAs can deal with non-smooth, non-continuous and non-differentiable functions which are actually exist in a practical optimization problem.
4. GAs use probabilistic transition rules, not deterministic rules. We use GS because the features of GA are different from the other search techniques in several aspects, such as:
5. The algorithm is a multipath that searches many peaks in parallel and hence reducing the possibility of local minimum trapping.
6. GA works with a coding of parameters instead of the parameter will help the genetic operator to evolve the current state into next state with minimum computations.

GA evaluates the fitness of each string to guide its search instead of the optimization function.

Nara et al. proposed a method of distribution system reconfiguration for loss reduction using a simple GA [18]. 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 15 min). The encouraging results obtained by nara et al. would lead one to believe the future implementations employing faster computer platforms and more sophisticated Gas could be viable for online, real-time implementation.

[19] Implementation of Genetic Algorithm for Distribution Systems Loss Minimum Reconfiguration by Koichi Nara et al.

A distribution systems loss minimum reconfiguration method by genetic algorithm was proposed in this paper. The problem is a complex mixed integer programming problem and is very difficult to solve by a mathematical programming approach. A genetic algorithm (GA) is a search or optimization algorithm based on the mechanics of natural selection and natural genetics. Since GA is suitable to solve combinatorial optimization problems, it was successfully applied to problems of loss minimum in distribution systems.

[20]Genetic Algorithm Based Network Reconfiguration for Loss Minimization in Distribution Systems by Kng-Yi Hong et al.

This paper presented a method based on Genetic Algorithms (GAS) using a vertex encoding/decoding to determine the network configuration. The vertex based number was used in GAS for encoding/decoding the chromosomes (strings). The Prufer number ensured that the system structure will be radial for the distribution system.

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[21]Optimal reconfiguration of electrical distribution network using the refined genetic algorithm by J.Z. Zhu

This paper proposed an improved method to study distribution network reconfiguration (DNRC) based on a refined genetic algorithm (GA). The DNRC model, in which the objective is to minimize the system power loss, was set up. In order to get the precise branch current and system power loss, a radiation distribution network load flow (RDNLF) method was presented in the study. The refined genetic algorithm was also set up, in which some improvements were made on chromosome coding, fitness function and mutation pattern. As a result, premature convergence was avoided.

[22] The Improved Clonal Genetic Algorithm & Its Application in Reconfiguration of Distribution Networks by Ji Wang, An Luo, Mingjun Qi, Maojun Li

In this paper, a kind of genetic algorithm aiming to power system, i.e. pre-digestion of distribution networks, chromosome encoding strategy & improved clonal genetic algorithm, was proposed, based on the main genetic operator of clonal genetic algorithm & its nature. It can be used, to reduce the unsolvable code of the distribution system reconfiguration, to enhance the rate of the solvable code and to accelerate the calculating process, by the kind of genetic algorithm.

[23] Enhanced genetic algorithm-based fuzzy multi-objective approach to distribution network reconfiguration by Y.-C. Huang

An enhanced genetic algorithm (EGA)-based fuzzy multi-objective approach to solve a network reconfiguration problem in a radial distribution system was presented in this paper. Maximising the fuzzy satisfaction allows the operator to simultaneously consider the multiple objectives of the network reconfiguration to minimise power loss, ,violation of voltage and current constraints, as well as switching number, while subject to a radial network structure in which all loads must be energised.

[24] Minimal Loss Reconfiguration Using Genetic Algorithms With Restricted Population and Addressed Operators: Real Application by Jorge Mendoza et al.

This paper proposes and evaluates a method that improves the adaptability and efficiency of genetic algorithms (GAs) when applied to the minimal loss reconfiguration problem. This research reduces the searching space (population) when a new codification strategy and novel genetic operators, called accentuated crossover and directed mutation, are used. This allows a drastic reduction of the computational time and minimizes the memory requirements, ensuring a efficiency search when compared to current GA reconfiguration techniques. The reduced population was created through the branches that form “system loops.”

Advantages and Disadvantages of Genetic Algorithm

Advantages:

- GAs can handle the integer or discrete variables well
- GAs can provide a globally optimum solution as it can avoid the trap of local optima
- GAs can deal with the non-smooth, non continuous, non-convex and non differentiable functions which actually exist in practical optimization problems.
- GAs have the potential to find solutions in many areas of search space simultaneously, there by multiple objectives can be achieved in single run.
- GAs are adaptable to change, ability to generate large number of solutions and rapid convergence.
- GAs can be easily coded to work on parallel computers.

Disadvantages:

- GAs are stochastic algorithms and the solution they provide to reconfiguration is sometimes not the optimum one
- The execution length increases with increase in chromosome length
- It converges into infeasible solutions sometimes with increase in size of system.

5.3 Reconfiguration by expert system

Several efforts have been made to use expert systems in the solution of the distribution system reconfiguration problem. As with the algorithms based upon heuristics, the rules used for the proposed expert systems are based upon system operation constraints and not directly upon loss reducing measures. Expert systems have many of the same limitations as the heuristic based methods.

Taylor and lubkeman [25] proposed an expert system for distribution system configuration based upon extensions of the rules of Civanlar et al. Taylor and Lubkeman described the primary objective of their work as being to avoid transformer overloads, feeder thermal overloads, and abnormal, voltages; they asserted that satisfying these criteria would simultaneously result in loss minimization. They justified the use of a best-first search strategy by the need to reduce the solution time. Five different rule sets were

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developed to drive the inference of the expert system developed. Following each decision, a load flow operation was necessary to update the networks operating status. The use of heuristic rules was demonstrated to reduce the search space considerably. The work of Taylor and Lubkcman identified the need to address the issues of protection coordination and voltage control strategies within reconfiguration efforts.

Change et al. Introduced the requirements for a knowledge based software package for analysis and control of distribution systems [26]. The knowledge base would employ tools specific to distribution analysis to ensure precise, representative modelling. Reconfiguration for loss reduction figures prominently in their proposed package and would be driven by an expert system. They highlight the need for sophisticated load modelling as outlined in Ref.[27].

5.4 Reconfiguration by Simulated Annealing Method

The background for simulated annealing comes from the relation between the physical annealing of solids and combinatorial optimization problems. Physical annealing refers to the process of finding low energy states of a solid by initially melting the substance and then lowering the temperature slowly, spending a long time at temperatures close to the freezing point. The recent interest began with work of Kirkpatrick (1983) and Cerny (1985). They showed how a model for simulating the annealing of solids, as proposed by metropolis et al. (1953) could be used for optimization problems, where the objective function to be minimized corresponded to the energy of states of the solid. The simulated annealing method resembles the cooling process of molten metals through annealing. At high temperature, the atoms in the molten metal can move freely with respect to each other, but as the temperature is reduced, the movement of the atoms gets restricted. The atoms start to get ordered and finally form the crystals having least possible energy.

[28] Optimal Network Reconfigurations in Distribution Systems: Part 1 : A New Formulation and A Solution Vlethodology Hsiao-Dong Chiang, RenC Jean-Jumeau

A new formulation of the network reconfiguration problem for both loss reduction and load balancing taking into considerations load constraints and operational constraints was presented. The number of switch on/ switch-off operations involved in network reconfiguration were put into a constraint. The new formulation was a constrained, multi-objective and non-differentiable optimization problem with both equality and inequality constraints. A two-stage solution methodology based on a modified simulated annealing technique and the €-constraint method for general multi-objective optimization problems was developed. A salient feature of the solution methodology is that it allowed designers to find a desirable, global non-inferior solution for the problem.

[29] Optimal Network Reconfigurations in Distribution Systems: Part 2 : Solution Algorithms and Numerical Results Hsiao-Dong Chiang, Renk Jean-Jumeau

This paper was based on a two-stage solution methodology and a modified simulated annealing technique. A solution algorithm to the network reconfiguration problem which is a constrained, multi-objective, non-differentiable optimization problem was developed. This solution algorithm allowed the designer to obtain a desirable, global non-inferior point in a reasonable computation time. Also, given a desired number of switch on/ switch-off operations involved in the network reconfiguration, the solution algorithm could identify the most effective operations. In order to speed up the computation time required, the idea of approximate calculations was explored and incorporated into the solution algorithm, where two efficient load flow methods were employed; one for high temperature and the other for low temperature.

[30] An Efficient Algorithm for Network Reconfiguration in Distribution System A. Young-Jae Jeon, B. Jae-Chul Kim

This paper presented an eficient algorithm for loss reduction of distribution system by sectionalizing switch operation in distribution system. Simulated annealing can avoid escape from local minima by accepting improvements in cost, but the use of this algorithm is also responsible for an excessive computation time requirement. To overcome this major limitation of simulated annealing, they have used modified simulated annealing. The polynomial-time cooling schedule is used which is based on the statistics calculation during the search. This approach resulted in saving CPU time.

[31] Performance of the Simulated Annealing-based Algorithms for the Optimal Reconfiguration of Distribution Systems

In this paper, Simulated Annealing-based algorithms have been proposed as a useful technique for computing near-optimal solutions. The performance of these algorithms depends on the choice of several parameters. This paper dealt with the effects of the parameter choice on the

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computation time and on the effectiveness of the solutions.

Advantages of Simulated Annealing:

- Simulated annealing can deal effectively with arbitrary systems and cost functions
- It statistically guarantees finding an optimal solution
- It is relatively easy to code, even for complex problems
- It generally gives a good solution

Disadvantages of Simulated Annealing:

- For a large temperature rise, it takes too many iterations and the search sometimes may not be optimum
- Sometimes the computational time is high
- Selection of initial parameters is trial and error process which can be time consuming in case of large systems.

5.5 Reconfiguration by Ant Colony Method

Ant colony algorithm is a member of swarm intelligent methods family. It was initially proposed by Marco Dorigo in 1992, the first algorithm was aiming to search for an optimal path in a graph, based on the behaviour of ants seeking a path between their colony and a source of food. The original idea has since diversified to solve a wider class of numerical problems, and as result, several problems have emerged, drawing on various aspects of behaviour of ants.

[32] Ant-Colony Search-Based Minimum Losses Reconfiguration of Distribution Systems by Enrico Carpaneto and Gianfranco Chicco

This paper presented a new application of the Ant Colony Search method to the minimize the losses by reconfiguration of distribution systems. The optimization problem was formulated by taking into account the operational constraints of the distribution systems. The results of the proposed approach were compared to the ones obtained from other deterministic and heuristic methods.

[33]Distribution System Reconfiguration for Loss Reduction Based on Ant Colony Behavior by F. S. Pereira, K. Vittori, G. R. M. da Costa.

The problem of reconfiguration of distribution systems to minimize power loss was formulated as an optimization problem. This formulation took into account the operational constraints on line flows and voltages and the radial topology. To solve this problem, the authors proposed a method to optimize the reconfiguration of the distribution system, based on the behaviour of colonies of ants.

[34] Ant Colony Search - based Loss Minimum for Reconfiguration of Distribution Systems by T.Q.D.Khoa and B.T.T.Phan

This paper presented one of applications of the Ant colony search method to reduce the minimum losses of distribution network. The configuration of distribution network was defined by the tie switches and sectionalized switches. The configuration optimization problem of distribution network is a combination optimization with a large search space involved the operational constraints of the distribution. The results of the ACS were compared to the ones obtained from other heuristic methods (Heuristic Simulated Annealing, Genetic).

[35] Loss Reduction in Distribution Network Using Simultaneous Capacitor Placement and Reconfiguration with Ant Colony Algorithm by M. J. Kasaei and M. Gandomkar

This paper introduced an ant colony algorithm to solve the optimal network reconfiguration and capacitor placement problem for power loss reduction and voltage profile enhancement in distribution networks. The proposed approach demonstrated employing one distribution network.

[36]Distribution Network Reconfiguration Based on Ant Colony System Algorithm by Zhijian Hu, Xixiong He, Yang Gao, and Dong Liu

In this paper, a novel algorithm based on Ant Colony System Algorithm (ACSA) was presented which was used for the reconfiguration of distribution network in order to reduce the power energy losses under normal operation conditions. Combined with the features of distribution network, it applied the Ant Colony Algorithm (ACA) to solve the problem of distribution network reconfiguration. The main drawbacks of the basic ACA are the slow convergence and stagnation behaviour, so some new measures to overcome these shortcomings were proposed in this paper.

[37] An AIS-ACO Hybrid Approach for Multi-Objective Distribution System Reconfiguration by Ashish Ahuja, Sanjoy Das and Anil Pahwa.

This paper proposed a hybrid algorithm based on artificial immune systems and ant colony optimization for distribution system reconfiguration, which was formulated as a multi-objective optimization problem. The algorithm maintained a population of candidate solutions called antibodies. The search space was explored by means of the hyper-mutation operator that perturbs existing antibodies to produce new ones. A table of pheromones were used to reinforce better edges during hyper-mutation. An added innovation was the use of the pheromones to obtain quick solutions to restore the distribution system under contingency situations.

Advantages and disadvantages of Ant Colony method

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Advantages:

- There is an inherent parallelism in the case of ant colony optimization
- The presence of positive feedback accounts for rapid discovery of good solution
- It is highly efficient for solving problems like travelling salesman problem and other complicated problems
- Can be employed in dynamic applications since it easily adapts to changes such as new distance etc

Disadvantages:

- The analysis of ant colony optimization theoretically is highly difficult
- The probability distribution changes by iteration by iteration only
- Research in the case of ant colony optimization is experimental rather than theoretical
- Time taken by the algorithm to converge is uncertain even though it definitely converges.

5.6 Reconfiguration by Fuzzy based Methods

In real world there are a lot of uncertainties. Electric power systems are large, complex, geographically widely distributed systems and are influenced by a lot of uncertainties. This makes it very difficult to deal with distribution system problems through conventional methods. Fuzzy provides a model free description of control system and does not require any model identification. In past few years many researchers have tried to emulate human way of thinking into optimization algorithms. Fuzzy logic is one such algorithm.

[38] Distribution network reconfiguration for loss reduction using fuzzy controlled evolutionary programming by Y.H song et al.,

In this paper, a new type of evolutionary search technique, evolutionary programming (EP), has been adopted and improved for the particle application. To improve the performance of EP, a fuzzy controlled EP (FCEP), based on heuristic information, was proposed. The mutation fuzzy controller adaptively adjusts the mutation rate during the simulated evolutionary process. The status of each switch in distribution systems is naturally represented by a binary control parameter 0 or 1. The length of string is much shorter than those proposed by others. A chain-table and combined depth-first and breadth-first search strategy is employed to further speed up the optimisation process. The equality and inequality constraints were imbedded into the fitness function by penalty factors which guarantee the optimal solutions searched by the FCEP were feasible.

[39] A Fuzzy Multi-objective Approach for Network Reconfiguration of Distribution Systems by Debapriya Das

In this paper, an algorithm for network reconfiguration based on the heuristic rules and fuzzy multi objective approach was proposed. Multiple objectives were considered for load balancing among the feeders and also to minimize the real power loss, deviation of nodes voltage, and branch current constraint violation, while subject to a radial network structure in which all loads must be energized. These four objectives were modelled with fuzzy sets to evaluate their imprecise nature and one can provide his or her anticipated value of each objective. Heuristic rules were also incorporated in the algorithm for minimizing the number of tie-switch operations.

[40] Network Reconfiguration of Distribution System Using Fuzzy Preferences Multi- Objective Approach by Hongbin Sun and Yongsheng Ding

In this method the network reconfiguration optimal control in distribution networks is modelled as a multi-objective combinational optimization. Multiple objectives are considered for load balancing among the feeders, minimum deviation of the nodes voltage, minimize the power loss and branch current constraint violation. Based on the objectives evaluated by membership functions respectively, These objectives were modelled with fuzzy sets to evaluate their imprecise nature and one can provide the anticipated value of each objective

[41]Distribution Network Reconfiguration starting from Fuzzy Multicriteria Decision Making Algorithms by D. P. Bernardon et al.

In this paper involves important objectives: power losses reduction, enhancing the voltage profile and increasing the reliability levels. This paper implied the developing of a new fuzzy multi-criteria decision making algorithm and software to distribution network reconfiguration, aiming at the adequate processing of the information sources available at the utilities.

[42] Optimal radial distribution system reconfiguration using fuzzy adaptation of evolutionary programming by B. Venkatesh, Rakesh Ranjan

This paper proposed a method that uses fuzzy adaptation of Evolutionary Programming (FEP) as a solution technique. FEP technique was chosen as it is particularly suited while solving optimization problems with discontinuous solution space and when the global optimum is desired. Fuzzy

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adaptation of EP is necessitated while considering optimization of multiple objectives.

Optimal Reconfiguration of Radial Distribution Systems

[43] Using a Fuzzy Mutated Genetic Algorithm by K. Prasad et al.

A new method based on a fuzzy mutated genetic algorithm for optimal reconfiguration of radial distribution systems (RDS) was presented in this paper. The proposed algorithm overcomes the combinatorial nature of the reconfiguration problem and dealt with non-continuous multi-objective optimization. The attractive features of the algorithm are: preservation of radial property of the network without islanding any load point by an elegant coding scheme and an efficient convergence characteristic attributed to a controlled mutation using fuzzy logic.

Advantages and disadvantages of Fuzzy Logic methods

Advantages:

- Fuzzy logic is an effective algorithm which can emulate human thinking in certain ways
- The problem solution arrives quickly as the boundary conditions are clearly defined

Disadvantages:

- The membership functions need to be defined for every problem which becomes very extensive for a big problem
- The problem formulation becomes complex in big network systems.

5.7 Reconfiguration by PSO

Particle Swarm optimization (PSO) is a population based stochastic optimization technique inspired by social behaviour of bird flocking or fish schooling. It was introduced in the year 1995 by Kennedy and Eberhart. PSO searches the optimal solution by using population of particles in which each of the solution represents a candidate solution to the optimization problem. Particles change their position and velocity components and move in multi-dimensional space until a relatively unchanged position is obtained or if computational limits are not exceeded. The concept of pbest (local best) and gbest (global best) in PSO allow it to adjust quickly and very accurately providing fast convergence. It is a very efficient optimization algorithm and has gained a lot of interest and attention in network reconfiguration applications in the recent past.

[44] Particle Swarm Optimization by Yuhui Shi

Describes various developments in PSO algorithms and techniques and also explains in detail about the functioning of the PSO.

[45] An Improved Particle Swarm Optimization Algorithm by Lin Lu, Qi Luo, Jun-yong Liu, Chuan Long

A hierarchical structure poly-particle swarm optimization (HSPPSO) approach using the hierarchical structure concept of control theory was presented in this paper. In the bottom layer, parallel optimization calculation was performed on poly-particle swarms, which enlarges the particle searching domain. In the top layer, each particle swam in the bottom layer was treated as a particle of single particle swarm. The best position found by each particle swarm in the bottom layer is regard as the best position of single particle of the top layer particle swarm. The result of optimization on the top layer particle swarm was fed back to the bottom layer. If some particles trend to local extreme in particle swarm optimization (PSO) algorithm implementation, the particle velocity was updated and re-initialized.

[46] A Modified Particle Swarm Algorithm for Distribution Systems Reconfiguration by A.Y. Abdelaziz et al.

The proposed PSO algorithm was introduced with some modifications such as using an inertia weight that decreases linearly during the simulation. This setting allowed the PSO to explore a large area at the start of the simulation. A modification in the number of iterations and the population size was also presented in this paper.

[47] A Novel Particle Swarm Method for Distribution System Optimal Reconfiguration by Florentin Batrinu et al.

In this paper the conventional PSO was revisited in order to develop an efficient heuristic algorithm which will be able to take into account the system radial configurations and the various operational constraints of real time distribution systems. This system made some changes in the iterations and has been able to develop a hybrid PSO.

[48] An Improved Particle Swarm Optimization for Reconfiguration of Distribution Network by Lin Lu, Qi Luo et al.

To deal with distribution network reconfiguration, a hierarchical structure poly-particle swarm optimization (HSPPSO) approach using the hierarchical structure concept of control theory was presented in this paper. In the bottom layer, parallel optimization calculation was performed on poly-particle swarms. In the top layer, each particle swam in the bottom layer was treated as a particle. The best position found by each particle swarm in

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the bottom layer was regarded as the best position of single particle of the top layer particle swarm. The result of optimization on the top layer particle swarm is fed back to the bottom layer. Considering the features of distribution network, the probability of producing feasible solutions was improved by modifying the rule of position updating.

[49] FDR Particle Swarm Algorithm for Network Reconfiguration of Distribution Systems by Kiran et al.

This paper proposed a novel particle swarm optimization algorithm for reconfiguration of distribution system named Fitness Distance Ratio Particle Swarm Optimization Algorithm (FDR-PSOA) to reduce the power loss of the system. In Conventional PSO all the solutions damps towards local pbest and thoroughly ignore other pbest points due to the convergence criteria and targets mainly on local optima than global optima. The proposed FDR-PSOA in contrast, considers local pbest points as well as neighbouring pbest called nbest values before arriving to gbest.

[50] Global Optimal Solution for Network Reconfiguration Problem using AMPSO Algorithm by Kiran et al.

This paper presented a new Adaptive Mutation Particle Swarm Optimization algorithm for minimization of losses of a Reconfigured Distribution Network. The tendency of solution being struck up to local optima or premature convergence as in the case of conventional PSO was thoroughly avoided using this new proposed technique. The algorithm was based on variance of population's fitness. During running time, the mutation probability was mainly based on variance of population's fitness and current optimal solution.

Advantages and disadvantages of PSO methods :

Advantages:

- PSO methods are stochastic in nature and also are very quick and accurate when compared to other optimization technique
- PSO algorithms have self learning capability. By taking pbest and gbest position values they tend to learn from the local best solutions and then incline the solution convergence in global path so that the obtained solution is the most optimum solution.

Disadvantages:

- In PSO algorithms if the rules are not properly framed, the solution's tendency to get into local optima and to get stuck up increases thus giving out the local best solution instead of the global best.

6. CONCLUSION

This paper explores existing popular methodologies for the network reconfiguration of radial distribution systems. The literature survey is carried over the past two and half decades published in various popular journals like IEEE transactions, Elsevier etc. This paper is useful for ready reference for researchers and students. The merits and demerits of all the methods are furnished for the purpose of having better idea over the methods.

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