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# Network Reconfiguration of Distribution System Using Artificial Bee Colony Algorithm

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***Abstract*—**Power distribution systems typically have tie and sectionalizing switches whose states determine the topological configuration of the network. The aim of network reconfiguration of the distribution network is to minimize the losses for a load arrangement at a particular time. Thus the objective function is to minimize the losses of the network by satisfying the distribution network constraints. The various constraints are radiality, voltage limits and the power balance condition. In this paper the status of the switches is obtained by using Artificial Bee Colony (ABC) algorithm. ABC is based on a particular intelligent behavior of honeybee swarms. ABC is developed based on inspecting the behaviors of real bees to find nectar and sharing the information of food sources to the bees in the hive. The proposed methodology has three stages. In stage one ABC is used to find the tie switches, in stage two the identified tie switches are checked for radiality constraint and if the radilaity constraint is satisfied then the procedure is proceeded to stage three otherwise the process is repeated. In stage three load flow analysis is performed. The process is repeated till the losses are minimized. The ABC is implemented to find the power flow path and the Forward Sweeper algorithm is used to calculate the power flow parameters. The proposed methodology is applied for a 33–bus single feeder distribution network using MATLAB.

***Keywords*—**Artificial Bee Colony (ABC) algorithm, Distribution system, Loss reduction, Network reconfiguration.

## I. Introduction

THE electric utility system is usually divided into three subsystems which are generation, transmission, and distribution. A fourth division, which sometimes made, is called sub transmission. However, sub transmission can really be considered as a subset of transmission since the voltage levels and protection practices are quite similar.

The distribution system is commonly broken down into three components: distribution substation, distribution primary and secondary. At the substation level, the voltage is reduced and the power is distributed in smaller amounts to the customers. Consequently, one substation will supply many customers with power. Thus, the number of transmission lines in the distribution systems is many times that of the transmission systems. Furthermore, most customers are connected to only one of the three phases in the distribution system. Therefore, the power flow on each of the lines is different and the system is typically ‘unbalanced’. This characteristic needs to be accounted for in load flow studies related to distribution networks.

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Electric power distribution is the portion of the power delivery infrastructure that takes the electricity from the highly meshed, high-voltage transmission circuits and delivering it to customers. Primary distribution lines are “medium-voltage” circuits, normally thought of as 600V to 35kV. At a distribution substation, a substation transformer takes the incoming transmission- level voltage (35 to 230kV) and steps it down to several distribution primary circuits, which gets regulated from the substation. Close to each end user, a distribution transformer takes the primary-distribution voltage and steps it down to a low-voltage secondary circuit (commonly 120/240V; other utilization voltages are used as well). From the distribution transformer, the secondary distribution circuits connect to the end user where the connection is made at the service entrance. Functionally, distribution circuits are those that feed customers.

The distribution system is fed through distribution substations. These substations have an almost infinite number of designs based on consideration such as load density, high side and low side voltage, land availability, reliability requirements, load growth, voltage drop, cost and losses, etc.

In practice, the following distribution circuits are generally used. According to connection scheme the distribution system has two types as given below:

i. Radial System.
ii. Ring Main System.

A radial system has only one power source for a group of customers. A power failure, short circuit, or a downed power line would interrupt power in the entire line which must be fixed before power can be restored. Radial distribution system is widely used because it is cheap and has easy maintenance.

## II. Feeder Reconfiguration

In a distribution system, each feeder has a different mixture of commercial, residential, and industrial type loads. These load types have different daily patterns which make the peak load of feeders occur at different times. In normal operating conditions, part of loads can be transferred from heavily loaded to relatively less heavily loaded feeders by network reconfiguration.

Distribution feeders contain number of switches that are normally closed (sectionalized switches) and switches that are normally open (tie switches). Distribution network reconfiguration is the process of altering the topological structure of distribution network by closing the open/ close status of sectionalizing and tie switches. When the operation conditions change, network reconfiguration is performed by the opening/closing of the network switches under the constraints of transformer capacity, feeder thermal capacity, voltage drop and radiality of the network. The distribution network is reconfigured for the following objectives:

1. Reducing power losses.
2. Relieving overload (balance loading).
3. Reducing voltage deviations.
4. Restoring the system

One important area in which distribution automation is being applied is the area of network reconfiguration. Network reconfiguration refers to the closing and opening of switches in a power distribution system in order to alter the network topology, enabling the flow of power from the substation to the customers. There are two primary reasons to reconfigure a distribution network during normal operation.

1) Depending on the current loading conditions, reconfiguration may become necessary in order to eliminate overloads on specific system components such as transformers or line sections. In this case it is known as load balancing.
2) As the loading conditions on the system change it may also become profitable to reconfigure in order to reduce the real power losses in the network. This is usually referred to as network reconfiguration for loss reduction.

Network reconfiguration in both of the above cases can be classified as a minimal spanning tree problem, which is named as NP–complete combinatorial optimization problem. A method is needed to find the network configuration quickly which minimizes the total real power loss of the network while satisfying all system constraints. Several approaches have been applied to the solution of this problem with varying degrees of success.

Distribution system reconfiguration for loss reduction was first proposed by Merlin and Back [1]. They employed a blend of optimization and heuristics to determine the minimal–loss operating configuration for the distribution system represented by a spanning tree structure at a specific load condition. The strength of the algorithm is that an optimal solution can be obtained which is independent of the initial switch status. But the shortcomings in the paper are: 1) contribution of only real component of current was considered while calculating power loss and assumed that the voltage angles are negligible; 2) the losses associated with line equipment are not considered; and 3) the solution proved to be very time consuming as the possible system configurations are, where is line sections equipped with switches.

Baran and Wu [2] presented a heuristic reconfiguration methodology based on the branch exchange to reduce losses and balance the loads in the feeders. To assist in the search, two approximated load flows for radial networks with different degrees of accuracy are used. They are simple Dist flow method and back and forward update of Dist flow method. This method is very time consuming due to the complicated combinations in large scale system and converges to a local optimum solution, because convergence to the global optimum is not guaranteed.

Safri and Chikhani [3] defined a new set of heuristic rules for distribution system reconfiguration problem. The rules have been developed with the objective of reducing losses directly and make an effort to quantize the suitability of switching options. The proposed method serves as a preprocessor to a reconfiguration algorithm removing undesirable switching options without the need to perform a complex load flow analysis.

Chiang and Darling [4] proposed an efficient algorithm for real network reconfiguration on large unbalanced distribution networks where the aim is to change the network topology as needed for loss reduction and load balancing in response to system and load variations.

Zhou [5] refined the GA method by modifying the string structure and used approximated fitness function which leads directly to unreliable solutions. Some improvements are made on chromosome coding (real coding), fitness function and mutation patterns. Among these improved features, an adaptive process of mutation is developed not only to present premature convergence but also to produce smooth convergence.

Lin and Cheng [6] proposed a Refined GA (RGA) that takes advantage of the optimal flow pattern, GA and the Tabu Search (TS). Cross over and mutations were combined in RGA.

Parsad and Ranjan [7] proposed a fuzzy mutated GA which overcomes the combination nature of the reconfiguration problem and deals with non continuous multi objectives optimization. The attractive features of the algorithm are: presentation of radial property in the network without isolating any load points by an elegant coding scheme and an efficient convergence characteristics attributed to a controlled mutation using fuzzy logic.

Kim [8] presented the strategy of feeder reconfiguration to reduce the power loss by Artificial Neural (ANN) Network. In this approach the load transfer and the corresponding load flow solution during the search process are not required. The training set of ANN is the optimal system topology corresponding to various load patterns which minimizes the load under given conditions.

Lin [9] presented a rule based expert system with a Colored Perti Net (CPN) algorithm for load balancing of distribution system. CPN models of the distribution components such as four ways line switches are proposed to derive the proper switching operation.

Li and Chen [10] introduced an efficient and robust method based on Tabu Search (TS) technique which is a recent member in the family of modern heuristics methods to solve the problem of network reconfiguration in distribution system to reduce the line losses under normal operating conditions. TS is a heuristic optimization technique which obtains the optimal solution of combinatorial optimization problem.

Based on the above literature survey, the application of graph theory to address the PSR problem was identified as a potential research area. Further, confining the scope of hybrid algorithm is increasing. The network reconfiguration problem in a distribution system is to find a best configuration of radial network that incurs minimum power loss while the imposed operating constraints are satisfied. So, in this paper Artificial

Bee Colony (ABC) is proposed for the minimization of power loss in the distribution system. The aim of this paper is to find the optimal power flow paths by using the ABC method. The role of ABC is to generate a sequence of switching combinations for finding the power flow path.

Feeder reconfiguration problem belongs to a category of optimization and graph theory problems known as “Spanning Tree”. It means having nodes of a graph; branches of that graph are determined so that a well–defined objective function is optimized. It can also be used to satisfy the constraints. The operating constraints considered are voltage profile of the system, and radial structure of the distribution system. So, to check the voltage profile constraint load flow analysis is used. Spanning tree concept is used for radiality constraint. The proposed method is tested on 33 – bus system and the results are obtained using MATLAB.

## III. Formulation of the Problem

The network reconfiguration problem in a distribution system is to find a best configuration of radial network that gives optimum power paths while the imposed operating constraints are satisfied. The constraints are (i) voltage constraints and (ii) radiality constraints. This is a combinatorial problem since the solution involves the consideration of all possible spanning trees. The objective function is to minimize the power loss.

The constraints are;

1. Radiality
2. Voltage Limits

$$V_{i\min} < V_i < V_{i\max} \quad (1)$$

where

$V_i$ : Voltage at receiving end of the branch

$V_{i\min}$ : Minimum Voltage at receiving end of the branch

$V_{i\max}$ : Maximum Voltage at receiving end of the branch

The network reconfiguration has to obey the following rules:

1) No feeder section can be left out of service
2) Radial network structure must be retained.

Power flow in a radial distribution network can be described by a set of recursive equations called distribution flow branch equations that use the real power, reactive power and voltage. Fig. 1 shows the single line diagram of radial distribution network.

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

$$Q_{i+1} = Q_i - x_i \frac{(P_i^2 + Q_i^2)}{V_i^2} - Q_{L(i+1)} \quad (3)$$

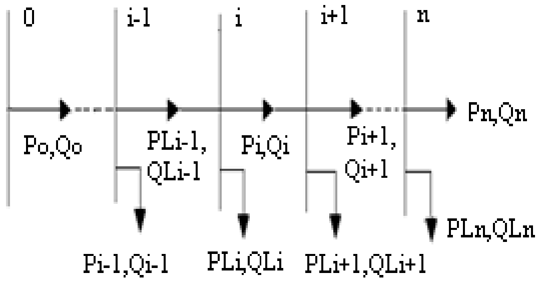


Fig. 1 One line diagram of a radial network

$$V_{i+1}^2 = V_i^2 - 2(r_i P_i + x_i Q_i) + \frac{(r_i^2 + x_i^2)(P_i^2 + Q_i^2)}{V_i^2} \quad (4)$$

The power loss in a branch is expressed as

$$LP_i = \frac{r_i (P_i + Q_i)}{V_i^2} \quad (5)$$

where

| | | |
|---|---|---|
| $LP_i$ | – | Power loss in the i[th] branch |
| N | – | Number of buses |
| $r_i$ | – | Resistance of the branch |
| $P_i$ | – | Real power flowing through the branch |
| $Q_i$ | – | Reactive power flowing through the branch |

## IV. Artificial Bee Colony (ABC)

Karaboga developed a new optimization algorithm called the ABC algorithm [11]. The ABC algorithm was first introduced for numerical optimization problems based on the foraging behavior of a honey bee swarm. Further improvements of the ABC algorithm have been carried out by [12].

ABC is developed based on inspecting the behaviors of real bees to find nectar and sharing the information of food sources to the bees in the hive.

Agents in ABC

- The Employed Bee
- The Onlooker Bee
- The Scout

The Employed Bee:

- It stays on a food source and provides the neighborhood of the source in its memory.

The Onlooker Bee:

- It gets the information of food sources from the employed bees in the hive and select one of the food source to gathers the nectar.

The Scout:

- It is responsible for finding new food, the new nectar, and sources.

The colony of artificial bees consists of three groups of bees: employed bees, onlookers and scouts. The first half of the colony consists of the employed artificial bees and the second half includes the onlookers. For every food source, there is only one employed bee. In other words, the number of employed bees is equal to the number of food sources around the hive. The employed bee whose food source has been exhausted by the bees becomes a scout.

Each cycle of the search consists of three steps: moving the employed and onlooker bees onto the food sources, calculating their nectar amounts and determining the scout bees and directing them onto possible food sources. A food source position represents a possible solution to the problem to be optimized. The amount of nectar of a food source corresponds to the quality of the solution represented by that food source [13].

Onlookers are placed on the food sources by using a probability based selection process. As the nectar amount of a food source increases, the probability value with which the food source is preferred by onlookers increases, too. [13] Every bee colony has scouts that are the colony's explorers. The explorers do not have any guidance while looking for food. They are primarily concerned with finding any kind of food source. As a result of such behavior, the scouts are characterized by low search costs and a low average in food source quality. Occasionally, the scouts can accidentally discover rich, entirely unknown food sources. In the case of artificial bees, the artificial scouts could have the fast discovery of the group of feasible solution. In this work, one of the employed bees is selected and classified as the scout bee. The selection is controlled by a control parameter called "limit". If a solution representing a food source is not improved by a predetermined number of trials, then that food source is abandoned by its employed bee and the employed bee is converted to a scout. The number of trials for releasing a food source is equal to the value of "limit" which is an important control parameter of ABC [13].

In a robust search process exploration and exploitation processes must be carried out together. In the ABC algorithm, while onlookers and employed bees carry out the exploitation process in the search space, the scouts control the exploration process. In the case of real honey bees, the recruitment rate represents a "measure" of how quickly the bee swarm locates and exploits the newly discovered food source. Artificial recruiting process could similarly represent the "measurement" of the speed with which the feasible solutions or the optimal solutions of the difficult optimization problems can be discovered. The survival and progress of the real bee swarm depends upon the rapid discovery and efficient utilization of the best food resources [13].

Similarly the optimal solution for difficult engineering problems is connected to the relatively fast discovery of "good solutions" especially for the problems that need to be solved in short time.

### *A. ABC – Procedure*

Step1. Initialize the population.
Step2. Modify positions.
Step3. Apply selection criterion.
Step4. Repeat (cycle).
Step5. Allow the employed bees to share the food information with onlooker bees.
Step6. Allow the onlooker bees to choose the best food source based on the probability calculation.
Step7. Apply selection criterion.
Step8. Check for an abundant solution, any (if exists) initiate a new food-source position. Otherwise, follow the next step.
Step9. Retain best solution so far.
Step10. Until the results are obtained.

## V. Proposed Methodology

In the proposed methodology, parameters are initialized and a New Bee Colony population is generated. The colony population is filled with many randomly generated solution vectors. Then the radiality constraints are checked, if the radiality constraints are satisfied then the load flow analysis is performed and voltage constraints are checked. If the number of iterations is violated then the optimal switching sequence is displayed, otherwise a new population is improvised based on the worst case, the colony population is updated and the stopping criterion are checked. If stopping criterion is achieved then display the optimal switching sequence. The following steps are involved in the proposed methodology

The following steps are involved in the proposed methodology.

Step1. Start
Step2. Generate a new Bee Colony population
Step3. Check for radiality constraints using Brute Force technique
Step4. If satisfied go to step 5 otherwise go to step 2
Step5. Perform load flow analysis
Step6. Check for voltage limits
Step7. If no of iterations is over, go to step 9 otherwise go to step 8
Step8. Improvise a new population using The Employed Bee, The Onlooker Bee, The Scout, Update the colony population and Check the stopping criterion
Step9. Display the optimal switching sequence

## VI. Test Problem

The proposed Artificial Bee Colony (ABC) is applied to 33–bus network. The resultant power flow path is shown along with new tie switches. The results are also compared with existing method. The proposed method is also used to find optimal power flow path.

To demonstrate the efficiency of the ABC, the proposed method is tested on the 33–bus system. The details of the 33–bus system are given below:

| | | |
|---|---|---|
| Number of buses | – | 33 |
| Number of branches | – | 37 |
| Number of tie lines | – | 5 |
| Tie lines | – | S33, S34, S35, S36, S37 |
| Total real power | – | 3525 MW |
| Total reactive power | – | 2300 MVAR |

The proposed method is tested on the 33–bus system. A single line diagram of a 33–bus system is shown in Fig. 2. The distribution network of a 33–bus system has two types of switches, dark lines are sectionalizing switches which are normally closed and dot lines are tie switches which are normally open.

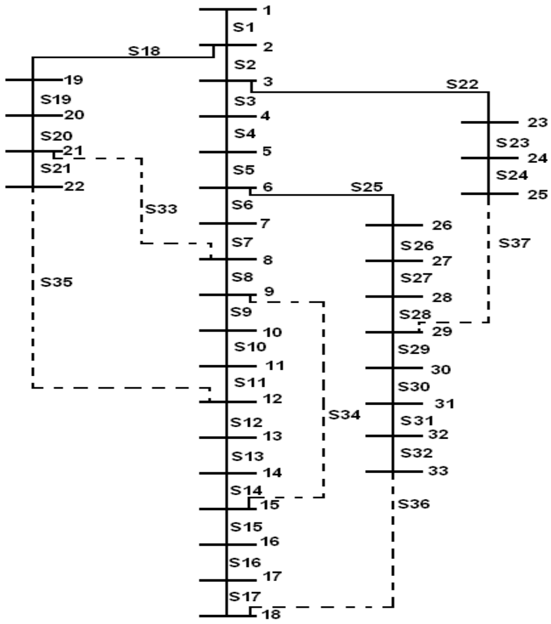


Fig. 2 33–Bus test Network

TABLE I
ABC RESULT FOR 33–BUS SYSTEM

| Tie switches | | | | | Total real power loss kw | Minimum p.u. voltage |
|---|---|---|---|---|---|---|
| S2 | S5 | S12 | S15 | S35 | 404.45 | 0.9527 |
| S6 | S9 | S21 | S27 | S37 | 262.61 | 0.9624 |
| S7 | S10 | S12 | S20 | S23 | 390.68 | 0.9789 |
| S4 | S11 | S12 | S16 | S19 | 377.52 | 0.9782 |
| S2 | S8 | S13 | S26 | S33 | 416.91 | 0.9816 |
| S4 | S9 | S21 | S24 | S29 | 352.06 | 0.9563 |
| S5 | S13 | S22 | S29 | S35 | 256.61 | 0.9772 |
| S7 | S9 | S14 | S26 | S37 | 379.93 | 0.9801 |
| S2 | S5 | S9 | S12 | S15 | 212.07 | 0.9861 |
| S10 | S12 | S20 | S23 | S34 | 730.52 | 0.9641 |
| S4 | S14 | S26 | S33 | S35 | 1047.0 | 0.9371 |
| S7 | S12 | S26 | S32 | S35 | 277.38 | 0.9771 |
| S5 | S11 | S23 | S32 | S34 | 214.29 | 0.9783 |
| S4 | S9 | S14 | S24 | S29 | 169.83 | 0.9748 |
| S4 | S10 | S19 | S25 | S35 | 134.26 | 0.9853 |

The results obtained during various time of execution are tabulated in Table I. The node voltage of 33 bus system is compared before and after reconfiguration. Before reconfiguration the lowest bus bar voltage is 0.9052p.u, which occurs at node 18. After reconfiguration, the minimum node voltage of the system has improved to 0.9853p.u, which occurs at node 33. The performance of the proposed methodology and node voltages are shown in Tables II and III.

TABLE II
PERFORMANCE OF THE PROPOSED METHODOLOGY

| Algorithm | Maximum total loss (KW) | Minimum total loss (KW) | Average total loss (KW) |
|---|---|---|---|
| ABC | 1047.4 | 134.26 | 375.01 |

The ABC is executed four times and the best result is obtained for the switching sequence having the tie switches, which S4, S10, S19, S25, S35 are as follows. The ABC Result for 33–bus system is shown in Fig. 3.

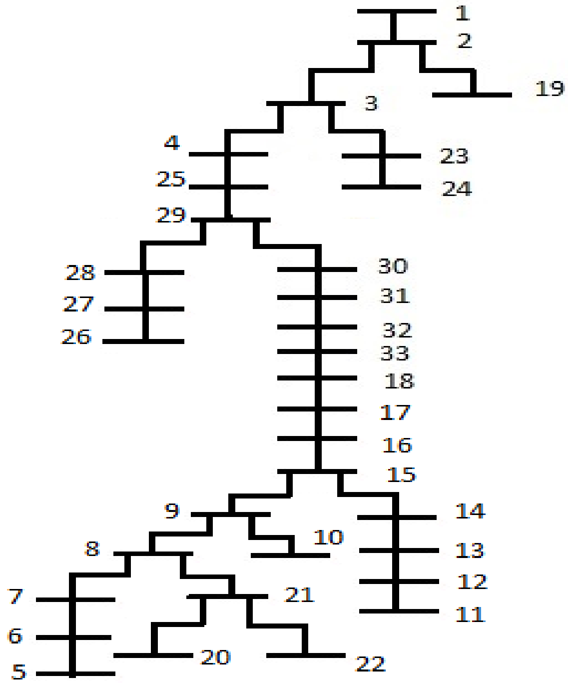

Fig. 3 ABC Result for 33–bus system

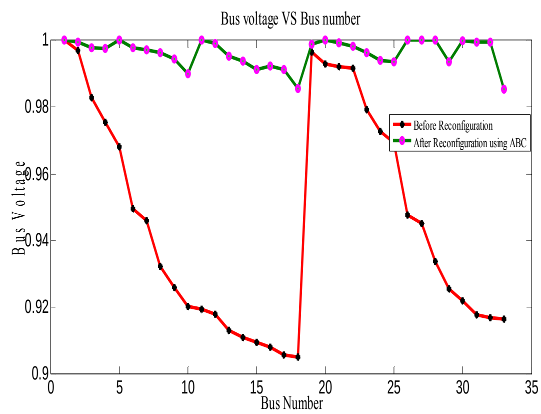


Fig. 4 Voltage profile for 33 bus system

The voltage profiles of the system before and after reconfiguration are shown in Fig. 4. The minimum voltage in the system after reconfiguration is improved by 8.1%.

TABLE III
NODE VOLTAGE OF 33–BUS SYSTEM

| Bus No | Before Reconfiguration Voltage | After Reconfiguration Using ABC Voltage |
|---|---|---|
| 1 | 1.0000 | 1.0000 |
| 2 | 0.9970 | 0.9995 |
| S3 | 0.9829 | 0.9978 |
| S4 | 0.9754 | 0.9975 |
| S5 | 0.9680 | 1.0000 |
| S6 | 0.9496 | 0.9978 |
| S7 | 0.9461 | 0.9972 |
| S8 | 0.9324 | 0.9964 |
| S9 | 0.9261 | 0.9944 |
| S10 | 0.9203 | 0.9901 |
| S11 | 0.9194 | 1.0000 |
| S12 | 0.9179 | 0.9991 |
| S13 | 0.9131 | 0.9953 |
| S14 | 0.9110 | 0.9938 |
| S15 | 0.9095 | 0.9912 |
| S16 | 0.9080 | 0.9923 |
| S17 | 0.9058 | 0.9912 |
| S18 | 0.9052 | 0.9856 |
| S19 | 0.9965 | 0.9989 |
| S20 | 0.9929 | 1.0000 |
| S21 | 0.9922 | 0.9992 |
| S22 | 0.9916 | 0.9982 |
| S23 | 0.9793 | 0.9963 |
| S24 | 0.9727 | 0.9941 |
| S25 | 0.9693 | 0.9936 |
| S26 | 0.9477 | 1.0000 |
| S27 | 0.9451 | 1.0000 |
| S28 | 0.9337 | 1.0000 |
| S29 | 0.9255 | 0.9936 |
| S30 | 0.9220 | 0.9998 |
| S31 | 0.9178 | 0.9995 |
| S32 | 0.9169 | 0.9995 |
| **S33** | 0.9166 | 0.9853 |

The results obtained using ABC method is compared with other various existing methods and the results are shown in Table IV.

## VII. CONCLUSION

The ABC has been used to find the network reconfiguration of the distribution network through which optimum power flow path (optimum switching sequence) has been found by satisfying the distribution network constraints. The various constraints are radiality and voltage limits.

The proposed methodology has three stages. In stage one power flow path (tie switches) has been found using ABC. In stage two the identified tie switches has been checked for radiality constraint and if the radilaity constraint is satisfied then the procedure proceed to stage three. Otherwise the process has to be repeated. In stage three load flow analysis is done. The Forward Sweeper algorithm has been used to calculate the power flow parameters. The distribution constraints are checked based on the load flow analysis results. The option which has minimum losses is selected as the best solution. The proposed methodology has been applied to a 33–bus single feeder distribution network using MATLAB.

TABLE IV
COMPARISON OF RESULTS 33–BUS

| Algorithms | Tie Switches | | | | | Total Impedance Ω | Total Real power loss KW | Minimum p.u. Voltage | Bus No of Min p.u. Voltage |
|---|---|---|---|---|---|---|---|---|---|
| INITIAL | S33 | S34 | S35 | S36 | S37 | 26.3247 | 2104.3 | 0.9052 | 18 |
| RGA[14] | S7 | S10 | S14 | S36 | S37 | 33.7917 | 1123.3 | 0.9345 | 33 |
| TSA[14] | S7 | S9 | S14 | S32 | S37 | 32.5863 | 1061.2 | 0.9340 | 32 |
| ABC | S4 | S10 | S19 | S25 | S35 | 30.4932 | 134.26 | 0.9853 | 33 |

***** RGA - Refined Genetic Algorithm, ***** TSA - Tabu Search Algorithm

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