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RECONFIGURATION OF A RADIAL DISTRIBUTION NETWORK THROUGH WHALE OPTIMIZATION ALGORITHM

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ABSTRACT

In this work, an innovative algorithm is addressed for the reconfiguration of an electrical radial distribution network such that it can lower the active power loss and enhance the voltage profile while satisfying the operating constraints. A nature-based motivated metaheuristic optimization algorithm that is Whale Optimization Algorithm (WOA) has been proposed. This novel algorithm is motivated by a special foraging strategy of the humpback whales. The proposed algorithm (WOA) is successfully simulated on IEEE standard 33 bus and 69 bus system. To validate the effectiveness of WOA, a benchmark comparison has been done with the previously existing algorithm.

Keywords: metaheuristic, whale optimization algorithm, reconfiguration, active power loss, voltage profile.

1. INTRODUCTION

Electrical distribution systems are becoming larger and being extended too far, which causes higher system losses and inferior voltage regulation. So there is a necessity for a suitable and sustainable distribution system for operation. Distribution system normally having a combination of loads i.e. industrial, commercial, residential and agricultural loads. Now a day, a constant attempt is being made to reduce the losses of the distribution networks. Generally, distribution systems are setup radially for productive supervision of switchgear protection. The radiality emphasizes that there is no loops formation in the network and each bus is connected to the source via exactly one path. Active power loss is lowered by modifying the position of sectionalising and ties switches, which is popularly known as reconfiguration of the network.

Network reconfiguration is a way by which the network topological architecture is altered by modifying the position (open/close) of sectionalising and tie switches. Reconfiguration is basically applied to obtain the optimal combination of switches so that it can reduce the line losses for specific types of loads of a network. It meets the various objectives such as the service restoration to dark areas, curtailment real power loss, and load stabilization with feeders. Therefore, reconfiguration helps electrical distribution system to increase reliability, quality, and security levels of operation. In the past decades, researches have been done in order to settle down distribution network reconfiguration problems. Initially Merlin and Back [1] were successful to minimize feeder loss. Now a days, artificial intelligence technique is most commonly and universally used for the reconfiguration to avoid the complexity of the optimization problem. These techniques are artificial neural networks (ANN) [2], Tabu search [3], Refined GA (RGA) [4], Simulated annealing (SA) [5], Ant colony optimization (ACO) [6] and so on. Apart from this, there are plenty of heuristic methods [7, 8] which have obtained the best or global result with minimum computational effort. These heuristic methods help to reduce the search space and are depended greatly on the proficiency of the operator.

Civanlar [9] has formulated a simple model and developed the formula to determine power loss changes which result due to the exchange of the branch. Ankush Tandon [10] has stated a significant drop in power loss with enhancement in voltage magnitude and enhanced convergence output. The additional changes are included in the existing PSO to accelerate the algorithm by Inji Ibrahim Atteya [11]. This paper proposed a novel method that is WOA. This method is basically used to determine the best suitable switching combination for network configuration to lower the power losses.

2. WHALE OPTIMIZATION ALGORITHM (WOA)

It is a new population dependent optimization algorithm. It has been popularized by S. Mirjalili [12]. WOA mimic the unique foraging technique of humpback whales. Basically, the humpback whale used to prefer to search for small fishes in the sea. Their special hunting method makes them smarter. This foraging behaviour is known as a bubble-net hunting method. Here they whirl over to the prey and forma typical circular round shape.

The mechanism of WOA with mathematical formulation is as follows:

- Encircling the prey
- bubble net hunting strategy
- search the prey

2.1 Encircling the prey

The area of the prey is recognized by the whale and finally encircles them. Initially, assume that the present best candidate response is the target location. Meanwhile, all other whales will readjust their spot towards the updated target area. The following equations represent this behaviour:

$$\vec{X}(t+1) = \overrightarrow{X^*}(t) - \vec{A} - \vec{D} \tag{1}$$

$$\vec{D} = \left|\vec{C} \cdot \overrightarrow{X^*}(t) - \vec{X}(t)\right| \tag{2}$$

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$$\vec{A} = 2 \cdot \vec{a} \cdot \vec{r} - \vec{a} \tag{3}$$

$$\vec{C} = 2 \cdot \vec{r} \tag{4}$$

Where $\vec{X}$ is the position vector, $\vec{X}^*$is for best obtained position vector. 't' refers to the present iteration. $\vec{A}$,$\vec{C}$represents vector coefficients. In the course of iteration,$\vec{a}$ is linearly dropped from 2 to 0. The random vector $\vec{\boldsymbol{r}}$ lies in [0, 1].

2.2 Bubble-net hunting strategy

The mathematical modelling of bubble-net behaviour consists of:

I. Shrinking encircling mechanism

It is obtained by lessening the numerical value of $\vec{a}$ in the Eq. (3). Here $\vec{A}$refers to anarbitrary value in the range [-a, a]. The shifting of the spot from (X, Y) over (X^*, Y^*) can be obtained by $0 \leq A \leq 1$ in a search zone as shown in Figure-1.

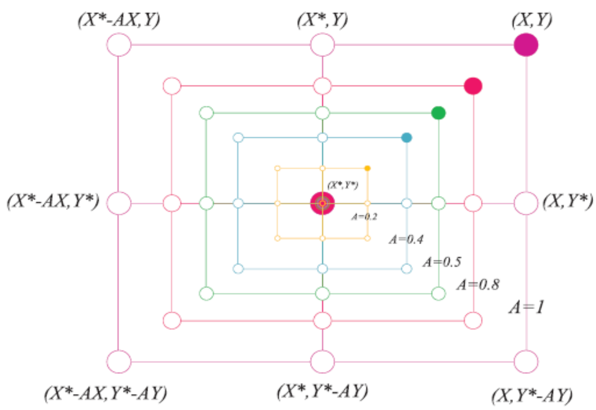

Figure-1. Shrinking encircling mechanism.

I. Spiral updating

This procedure is based on the measured gap between the position of the whale (X, Y) and prey (X^*, Y^*). This behaviour is shown in Figure-2. The spiral equation to copy the helix-shaped motion of whale is:

$$\vec{X}(t+1) = \vec{D'} \cdot e^{bl} \cdot \cos(2\pi l) + \vec{X^*}(t) \tag{5}$$

Where $\vec{D'} = \left|\vec{X^*}(t) - \vec{X}(t)\right|$ represents the gap between the whale and prey represents constant for defining the logarithmic gyrate shape, l refers to an arbitrary value in the range [-1, 1].

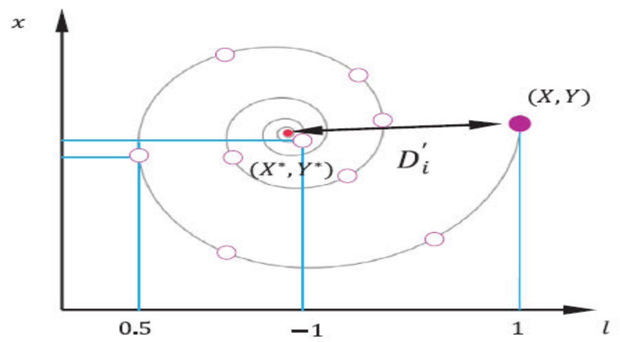

Figure-2. Bubble net Spiral behaviour.

Whales search for the prey simultaneously in a shrinking loop or in a spiral course. So assume that there is a likelihood of 50% to opt either shrinking encircling behaviour or the spiral-shaped, to readjust their spot during the optimization process. It can be expressed mathematically as:

$$\vec{X}(t+1) = \begin{cases} \vec{X^*}(t) - \vec{A} \cdot \vec{D} & \text{if } p < 0.5 \\ \vec{D'} \cdot e^{bl} \cdot \cos(2\pi l) + \vec{X^*}(t) & \text{if } p > 0.5 \end{cases} \tag{6}$$

Where p refers to the arbitrary value in [0, 1]

2.3 Search the prey

In this process, the humpback whale used to randomly seeking for the prey. The global search of prey is basically used by varying the $\vec{\mathbf{A}}$vector. $|\vec{A}|$ **>1** indicates exploration which permits WOA for the global search. Mathematically the behaviour can be expressed by:

$$\vec{D} = \left|\vec{C} \cdot \vec{X}_{rand} - \vec{X}\right| \tag{7}$$

$$\vec{X}(t+1) = \vec{X}_{rand} - \vec{A} \cdot \vec{D} \tag{8}$$

where $\vec{X}_{rand}$ represents the position of random whale in the current iteration. The flow chart for the WOA is presented in Figure-3.

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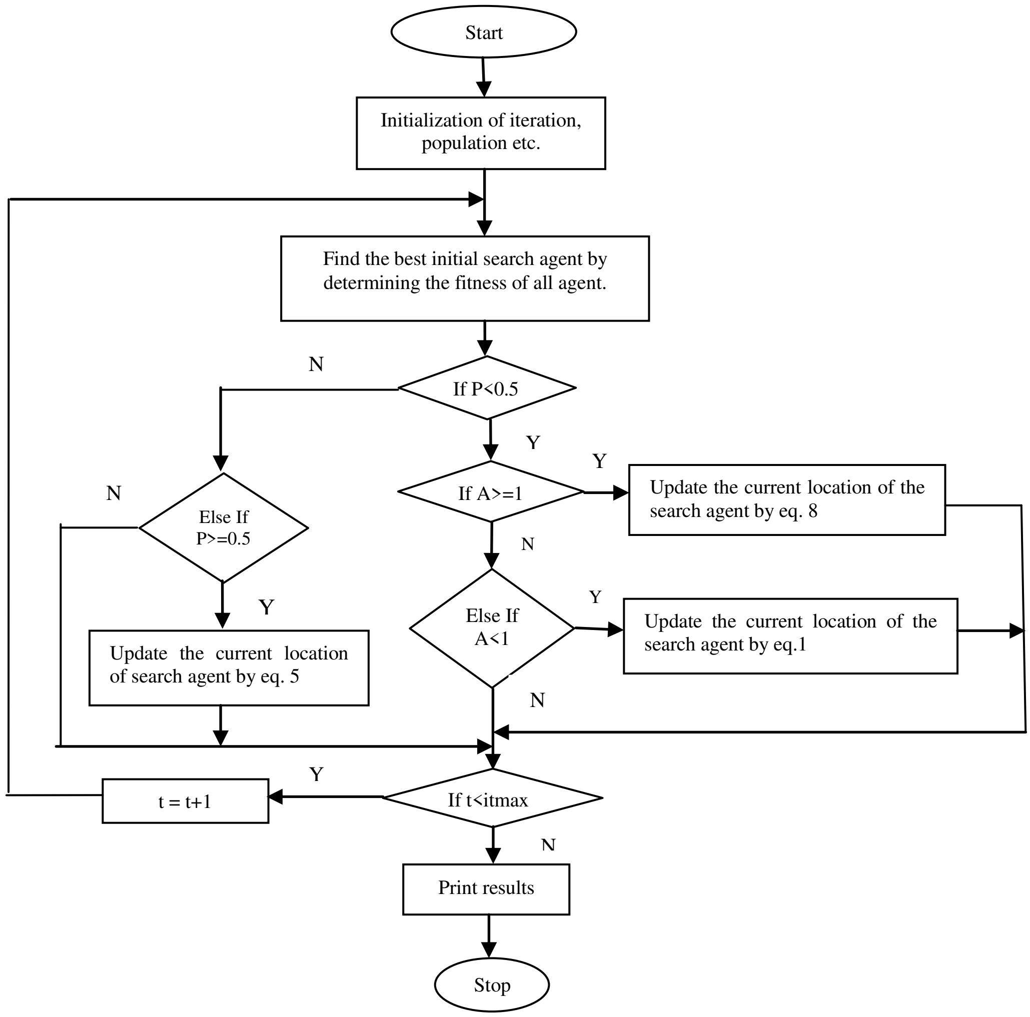

Where
Y---Yes
N---No

Figure-3. Proposed WOA flow diagram.

3. SIMPLIFIED POWER FLOW EQUATION

The network reconfiguration is achieved by switching the sectionalizing and ties switches. Here the main problem is to choose the best combination of the switches (sectionalising and tie switches), to obtain maximum loss reduction. By performing a line flow study, the loss reduction before and after reconfiguration can be easily determined. Consider the one line diagram of a radial system which is taken from Hong-Chan Chang [13] is shown in Figure-4.

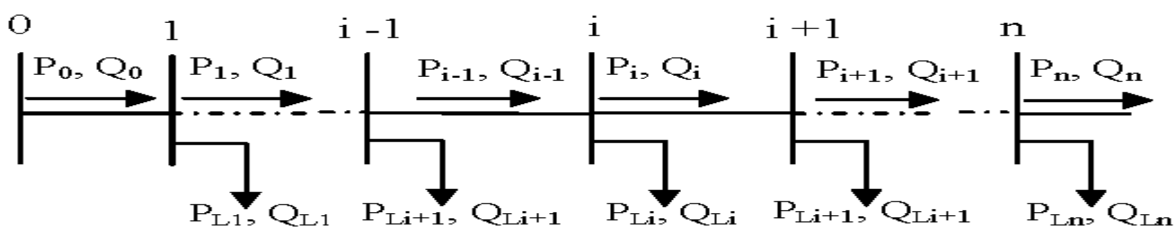

Figure-4. One-line diagram of a radial system.

The power flow equation is calculated by:

$$P_i = P_{i+1} + P_{Li+1} + r_i \frac{P_i^2+Q_i^2}{|V_i|^2} \tag{9}$$

$$Q_i = Q_{i+1} + Q_{Li+1} + x_i \frac{P_i^2+Q_i^2}{|V_i|^2} \tag{10}$$

$$|V_i|^2 = |V_{i+1}|^2 + 2(r_i P_i + x_i Q_i) - (r_i^2 + x_i^2)\frac{P_i^2+Q_i^2}{|V_i|^2} \tag{11}$$

where P_i and Q_i refers to active and reactive power of the source end bus i, P_{Li} and Q_{Li} is the real and reactive load power for bus i, $\boldsymbol{V_i}$ is bus i voltage, $\boldsymbol{r_i}$ *and* $\boldsymbol{x_i}$ is the resistance and reactance.. $|V_{i+1}|$ denotes voltage magnitude at $i+1^{th}$ bus.

4. PROBLEM FORMULATION

The purpose of the paper is to lessen the active power loss and to maintain a healthy voltage profile at each bus of a network. This is achieved by optimally selecting the location and combination of the switches.

$$MinPower_{\boldsymbol{losses}} = \sum_{i=1}^{n} (I_i^2)R_i \quad (12)$$

Where N refers to total branch number, $I_i$indicates branch current at i^{th} node, and $R_i$represents the resistance of i^{th}branch.

The system limitations are:

a) voltage limit

$$V_{min} \leq V_{bus} \leq V_{max} \quad (13)$$

b) Power flow limit

The line power flow (PF_l) should be always below the maximum limit of power flow (PF_l^{max}) as:

$$|PF_l| < PF_l^{max} \quad (14)$$

5. THE PROPOSED METHOD AND TEST SYSTEM RESULTS

The correlation between the natural behaviour of whale and real time distribution network is quite important for a better understanding of this method. The position of prey refers to the identification of weak bus in a given test system. The best defined agent indicates the opted optimal switch combination. Later on, the update of their spot is done as per the best defined searched location, which refers to the update of the switch combination for the further steps.

5.1 33-Bus System

The opted base value for voltage and power of a 33-bus system are 12.66 kV and 100 MVA. The main substation is the slack bus and the rest of the buses are load buses. The one line diagram of 33-bussystem is displayed in figure 5, which comprises of 5 tie lines and 32 sectionalising switches. The net load of the network is 3715 kW and 2300 kVar. The suggested method is run successfully on IEEE 33-bus system and the tabulated results are shown in Table-1.

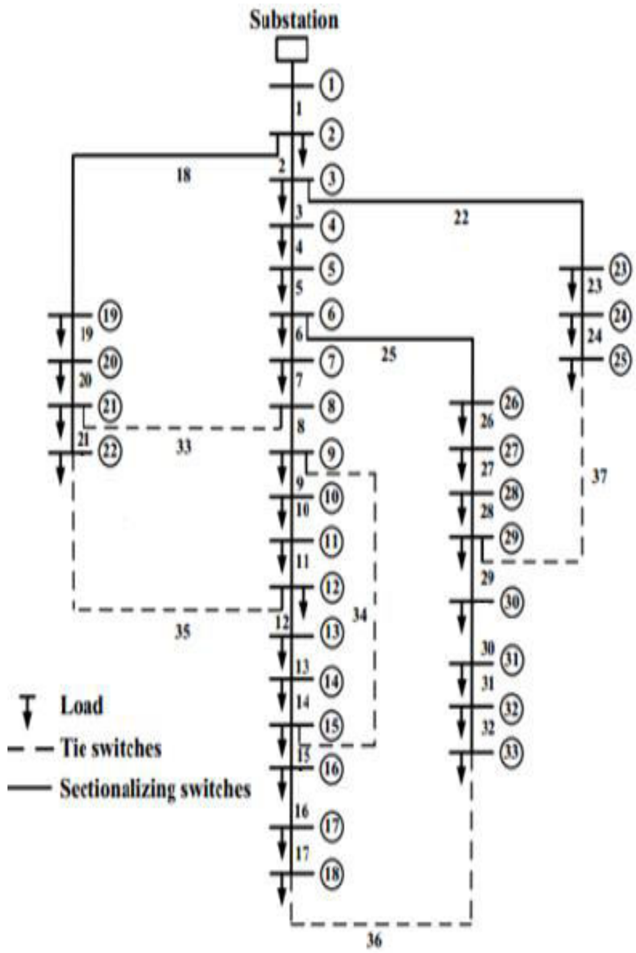

Figure-5. IEEE 33 Bus Network.

Table-1. Various switch combination for 33 bus network.

Test system	open switch	total power loss (kW)
Case1	9,28,33,35,36	133.4569
Case2	9,27,33,35,36	131.8424
Case3	9,26,33,35,36	128.5790

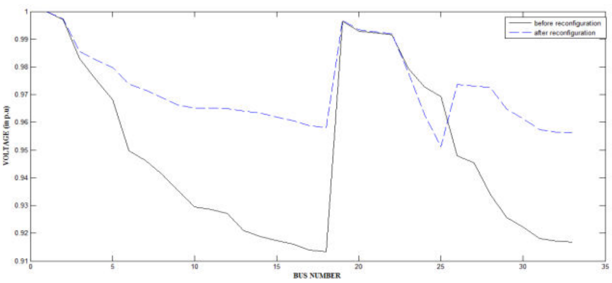

Figure-6. Voltage status for 33 bus system.

5.2 69-bus system

The one line diagram of 69-bus network is depicted in Figure-6. It comprises of 69 buses, 5 tie and 68 sectionalizing switches. The net load of the network is 21.5162kW and 11.0551 kVar. The opted base power and base voltage for a power flow study are 100MVA and

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12.66 kV respectively. The suggested method is simulated on the 69-bus network and the obtained values are shown in Table-2.

Table-2. Various switch combination for IEEE 69- bus system.

Test system	Open switch	Total power loss (kw)
Case1	13,42,52,71,72	28.2750
Case2	14,42,52,71,72	25.7901
Case3	14, 52, 46, 71, 72	21.5162

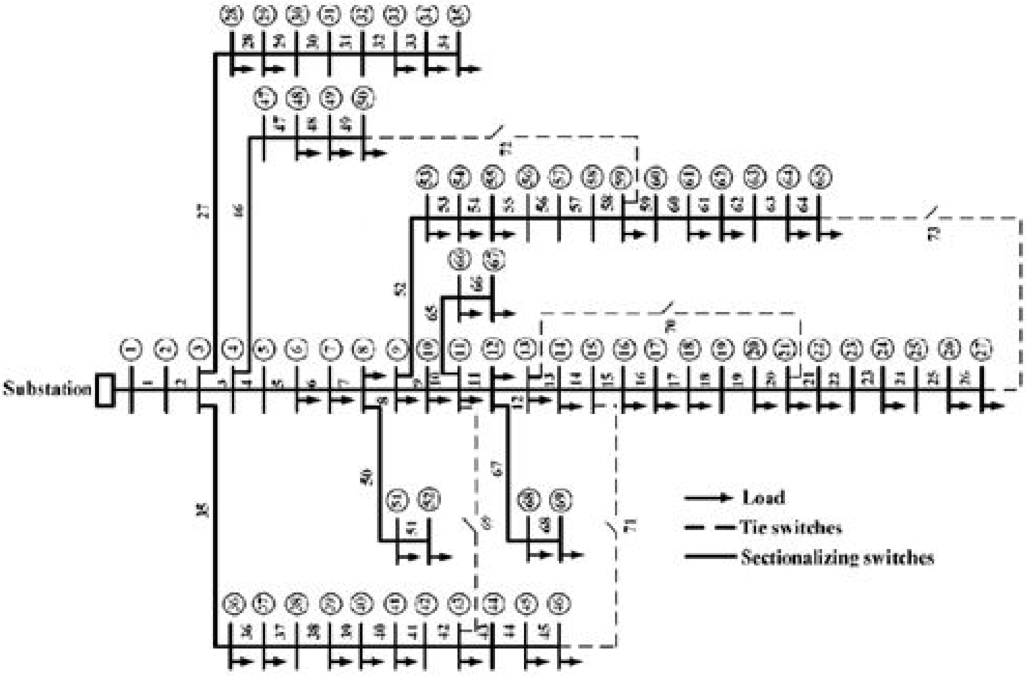

Figure-7. IEEE 69 Bus Network.

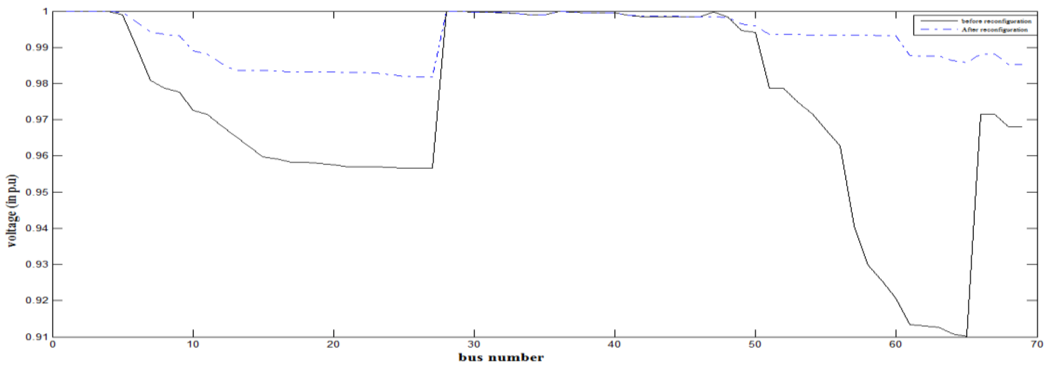

Figure-8. Voltage profile for 69 bus system.

It has been found that for 33 bus standard system the losses are less when the switches [9, 26, 33, 35, 36] and for the 69 bus system when the switches [14, 52, 46, 71, 72] are in open position. The suggested method is analysed with the already pre-existing method and it has been found that for the 33 bus network, active power loss is lowered by 36.31 % and for 69 bus network 90.41% respectively.

The WOA is programmed in MATLAB and the effectiveness of this method for the loss minimization of a radial network is successfully tested on standard IEEE 33-bus and 69-bus system.

Table-3. Results Validation of 33 bus network.

Technique	Tie Switch	Total power loss (kW)	(%) Loss reduction
Initial state	33,34,35,36,37	201.8969	--
RGA	7,10,14,33,37	139.5320	30.88
CSA [14]	7,9, 14, 32, 37	138.8700	31.21
Fuzzy-ACO	37,32,14, 10,7	136.8064	32.23
BFOA [15]	7,14,28,32, 36	134.5200	33.37
Proposed method	9,26,33,35,36	128.5790	36.31

Table-4. Results Validation of 69 bus network.

Method	Tie Switch	Total power loss (kW)	(%) Loss reduction
Initial state	69,70,71,72,73	224.5723	---
CSA	14,57,61,69,70	98.5680	56.10
BFOA	18, 43, 56, 61, 69	98.5600	56.11
Proposed method	14, 52, 46, 71, 72	21.5162	90.41

6. CONCLUSIONS

This paper suggested a nature inspired Whale Optimization Algorithm for the reconfiguration of distribution network. It helps to raise the superiority of the supplied power to the terminal ends and minimize the system power loss.WOA is suggested to choose the best switch combination for reconfiguration of network and is successfully executed on IEEE standard 33 and 69 bus network and found with effective results. Therefore, the suggested technique can be implemented for a large radial network.

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