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Optimal placement of Switches and Reconfiguration of Power Distribution Network for Power Quality Enhancement

Modu ABBA GANA, Adam BUKAR, Ibrahim MUSTAPHA

Department of Electrical and Electronics Engineering, University of Maiduguri, Maiduguri, Nigeria
mag1898@unimaid.edu.ng / adamb@unimaid.edu.ng / imutib@unimaid.edu.ng

Corresponding Author: mag1898@unimaid.edu.ng, +2348036495579

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Abstract: *Reconfiguration of an electrical power radial distribution network is aimed at finding a radial operating structure with minimum system active power loss and enhanced system voltage profile via reducing the active power losses whilst satisfying operating constraints. In this paper, an efficient approach to solving the problem of reconfiguration considering active power loss, total voltage deviation for a typical Nigerian distribution network is presented. The method developed is based on Modified Particle Swarm optimization to determine the optimal location of tie and sectionalizing switches, with a view to yielding an optimal performance for the network. The reconfiguration model was implemented using MATLAB R2019a and ETAP simulation environments. The effectiveness and validity of the proposed model was tested on a 69 Bus Ran distribution network in Bauchi state, Nigeria. The results showed that scenario case four was the best configuration with a reduction of 8.86% in active power loss as compared to the initial configuration. Out of the 24 buses with 300 customers isolated, 19 buses with 210 customers were restored. The bus voltages are all within the specified tolerance.*

Keywords: *System reconfiguration, switching state, power loss, MPSO, distribution system.*

1. INTRODUCTION

Reconfiguration of distribution network refers to the change of network switch combination and adjustment of the structure of network operation by closing or opening the normally closed switches and normally opened switches with constraints satisfied [1]

In the urban areas, the increase in power demand and high load density makes the operation of power systems complicated. There is a need to expand the system by increasing the substation capacity and the number of feeders to meet the load demand in the system. However, this may not be easily achieved due to various constraints. Therefore, to meet load demand for the substation, system loss minimization techniques are employed. After electric power is generated, it is sent through the transmission lines to the many distribution circuits that the utility operates. The purpose of the distribution system is to take that power from the transmission system and deliver it to the load centres. Along the line, a significant portion of the power transmitted by a utility is lost in the distribution process [2]

Losses in the distribution system occur as a result of transformers and distribution lines [3-4]. The active power that is lost in the distribution system is due to conductor material used and are a function of the square of the current flowing through the line, raising the voltage in the system reduces the power losses.

Reconfiguration of distribution system is among the different ways of decreasing losses. This condition leads to improve system voltage. For a radial distribution system, feeder reconfiguration is performed by transferring load from heavily loaded feeder to lightly loaded feeder there by balancing the load and loss reduction.

Feeder reconfiguration is a small part of distribution automation. After finding the statuses of different switches, if the result is sent to the switching control system, then the feeder can be configured from a distant place. There are two types of switches: normally open switches as tie-switch and normally close switches as sectionalizing switch. For the better planning of primary distribution system, the power distribution topology is required to change. Their aim was to obtain the minimal loss configuration [5]. Minimization of active power losses is one of the essential aims for any electrical distribution to improve system properties and meet the customer demand. As the value of loss depends on the active power, reactive power and voltage value of each node, total loss value can be reduced and percentage in power loss reduction can be minimized too. The voltage profile of the system can be improved and power factor of the substation will also be better [6].

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1.1 RECONFIGURATION OF POWER DISTRIBUTION SYSTEM

System reconfiguration means restructuring the power lines which connect various buses in a power system. Restructuring of specific lines leads to alternate system configurations. System reconfiguration can be accomplished by placing line interconnection switches into network. Opening and closing a switch connects or disconnect a line to the existing network. These switching are performed in such a way that the radiality of the network is maintained and all the loads are energized [7]. A normally open tie switch is closed to transfer a load from one feeder to another while an appropriate sectionalizing switch is opened to restore the radial structure. Branch exchange method which used to apply in this study starts with a feasible solution for distribution network operating in a radial configuration [8].

During applying reconfiguration technique, the tie switch has to be closed and on the other hand, the sectionalizing switch has to be opened in the loop created, which restores radial configuration. The switch pairs are chosen through heuristics and approximate formulas for the change in losses. Branch exchange process is repeatedly applied till no more loss reductions are available. A radial distribution network can be represented by several loops. This is because, when it is connected, one tie-line can only make one loop, the number of loops is equal to the number of tie-lines [9]. The benefits of feeder reconfiguration include: (i) restoring power to any outage partitions of a feeder, (ii) relieving overloads on feeders by shifting the load in real time to adjacent feeders, and (iii) reducing resistive line losses. There is a voltage difference across the normally open tie-switch in the tie-line. Optimal reconfiguration involves the selection of the best set of branches to be opened, one each from each loop, for reducing resistive line losses, and relieving overloads on feeders by shifting the load to adjacent feeders. However, since there are many candidate switching combinations in the system, the feeder reconfiguration is a complicated problem [10], [11].

2. MATERIALS AND METHOD

This section presents the materials, problem formulation and the solution related to the optimal location of switches. Firstly, optimal locations of the switches to be integrated were determined using modified particle swarm optimization. Secondly, 11 kV Ran feeder of Bauchi power distribution networks was modelled using both ETAP software as presented in figure 3. The networks were reconfigured to reduce the number customers affected by outage as a result of the fault and to improve the quality of the power supply (power loss reduction and improvement of voltage profile) and in other to determine the best configuration, for each of the scenario case, load flow analysis is carried out to determine the power loss and the voltage profile at each bus of the network

Figure 1 depicts the single line diagram of the 11 kV Ran feeder of JEDC power distribution company of Bauchi used in the research. It consists of 69 buses and 68 sections with total active and reactive power of 610 kW. The total power loss of the feeder under base case condition is 30 kW [12].

2.1 Materials

The materials required for the modelling of the network are presented below.

2.1.1 Required Data

In this section, we present all the pertinent system data required for this research work with respect to the Ran feeder. The data collected are as follows.

2.1.2 Data for Network Modelling

i. Active and reactive power at each bus, P & Q
ii. Line length, l
iii. Resistance, r and reactance, x of the line
iv. Transformer data such as voltage, power rating and reactance x
v. Number of customers at each bus.
vi. Single line diagram of the network.
vii Circuit breakers and directional overcurrent relays.

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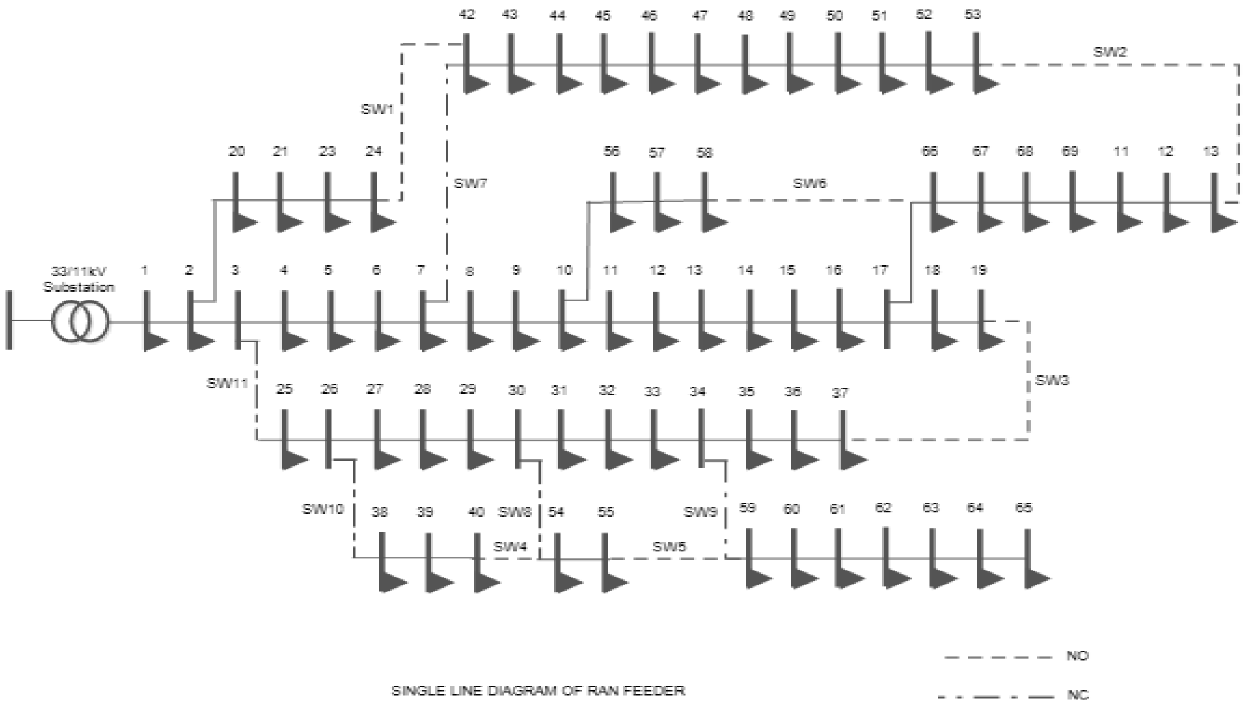

Figure 1: Single line diagram of the 11 kV Ran feeder of JEDC Distribution Company of Bauchi

2.2 Methods

2.2.1. Optimal placement of switches problem formulation

The objective function of the optimum switch number and placement problem is to minimize the sum of interruption and investment costs for distribution feeder. Here, the customers' expected outage cost (ECOST) used as an interruption cost reliability index that should be minimized is given by eqn. (1): The optimization problem is formulated as; [13],[14].

$$\min Total\ cost = ECOST\ [(x_1, x_2, x_3 \ldots . x_n, y_1, y_2, y_3 \ldots . y_m) + n \times SEC + m \times BRK] \quad (1)$$

where,

ECOST is the expected interruption cost

$$ECOST = \sum_{k=1}^{NC} \sum_{j=1}^{NIL} L_{kj}\ C_{jk(rj)} \lambda_j\ \frac{\text{N}}{\text{yr}} \quad (2)$$

NIL is the number of isolated load points due to k^{th}contingency

NC is the number of contingencies

L_{kj} is the curtailed load at load point k due to contingencies?

r_j is the average outage time

λj is the average failure rate

$C_{jk(rj)}$ is the outage cost (N/kW) of loads point k due to outage j with outage duration of rj

xi is the ith location where a switch is installed

yi is the ith location where breaker is installed

n is the number switch

m is the number of breakers

SEC is the cost associated with switch

BRK is the cost associated with breaker

It could be noted that the cost associated with switch and breakers includes capital cost, installation cost and maintenance cost. It is assumed that there are N possible locations for installing switches in the network. The cost function is therefore minimized for the optimum number and locations of switches given that m + n ≥ N.

2). Realization of Modified PSO Switch Placement

The procedure for solving the switches placement optimization using MPSO is presented to obtain the optimal number and their location in a distribution system [15]. The existence of a switch at all locations is set as a gene, and many genes constitute an individual. Each individual within the population represents a candidate solution for the switch's optimization

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problem. e.g., if n candidates are there to install switches in a distribution system at bus 'k' then the trial location vector will be X_i = [n, X_1, X_2, X_3 ……....X_n] for all candidate locations of Switch [16 - 19].
Where,
n is the number of switches
$X_1, X_2, \dots \dots \dots \dots \dots X_n$ are the candidate location of switches.
The steps are;
Step 1: Initialization
i) Actualization of power distribution network data required for computation process from the database
ii) Define MPSO parameters such as: population s, C_1, C_2 , number of iterations, W_{start}, W_{end} as in Table 1
iii) Generate a swarm with s particles randomly distributed in the design domain S
iv) Generate initial velocities randomly for each particle,
v) Evaluate fitness values for each initial particle and store the particle with less fitness value.
vi) Find the global best position Gbest
vii) Find the global worst position Gworst
Step II: Optimization process by velocity update:
a) Update switch matrix, velocity and position
i. Find the worst particles
ii. Update switch matrix k according to worst particles
iii. Update particle's velocity $v_{id}(j+1)$
iv. Update particle's position $x_{id}(j+1)$
b) Update particle's best position
Evaluate the fitness function
IF $f(x_{id}(j+1)) \leq f(p_{id}(j))$ THEN
SET $p_{id}(j+1) = x_{id}(j+1)$
ELSE
SET $p_{id}(j+1) = p_{id}(j)$
IF $f(p_{id}(j+1)) \leq f(g_{id}(j))$ THEN
SET $g_{id}(j+1) = p(j+1)$
ELSE
SET $g_{id}(j+1) = g_{id}(j)$
Step III: Check for convergence
If the generation count is less than the pre-set maximum number of iterations goes to step II otherwise
Step IV: With the optimal location of switch run the ECOST

The flow chart for the implementation of the Modified PSO based optimal switches placement is shown in Figure 2.

Table 1: Optimal MPSO parameter settings for placement of switches

S/No	Parameter	Value
1.	Maximum iteration	50
2.	Particle size	N
3.	C_1, C_3, is the cognitive acceleration coefficient	2
4.	C_2, C_4 is the social acceleration coefficient	1.5
5.	r_1, r_2, r_3, r_4 are n dimensional Colum vectors	0.8
6.	W is the static inertia weight	0.9
7.	k_1, k_2, k_3, k_4 matrix for best particle	[1, 1, 0, 0]
8.	k_1, k_2, k_3, k_4 matrix for bad particles	[0, 0, 1, 1]
9.	Maximum inertia weight	1
10.	Minimum inertia weight	0.6

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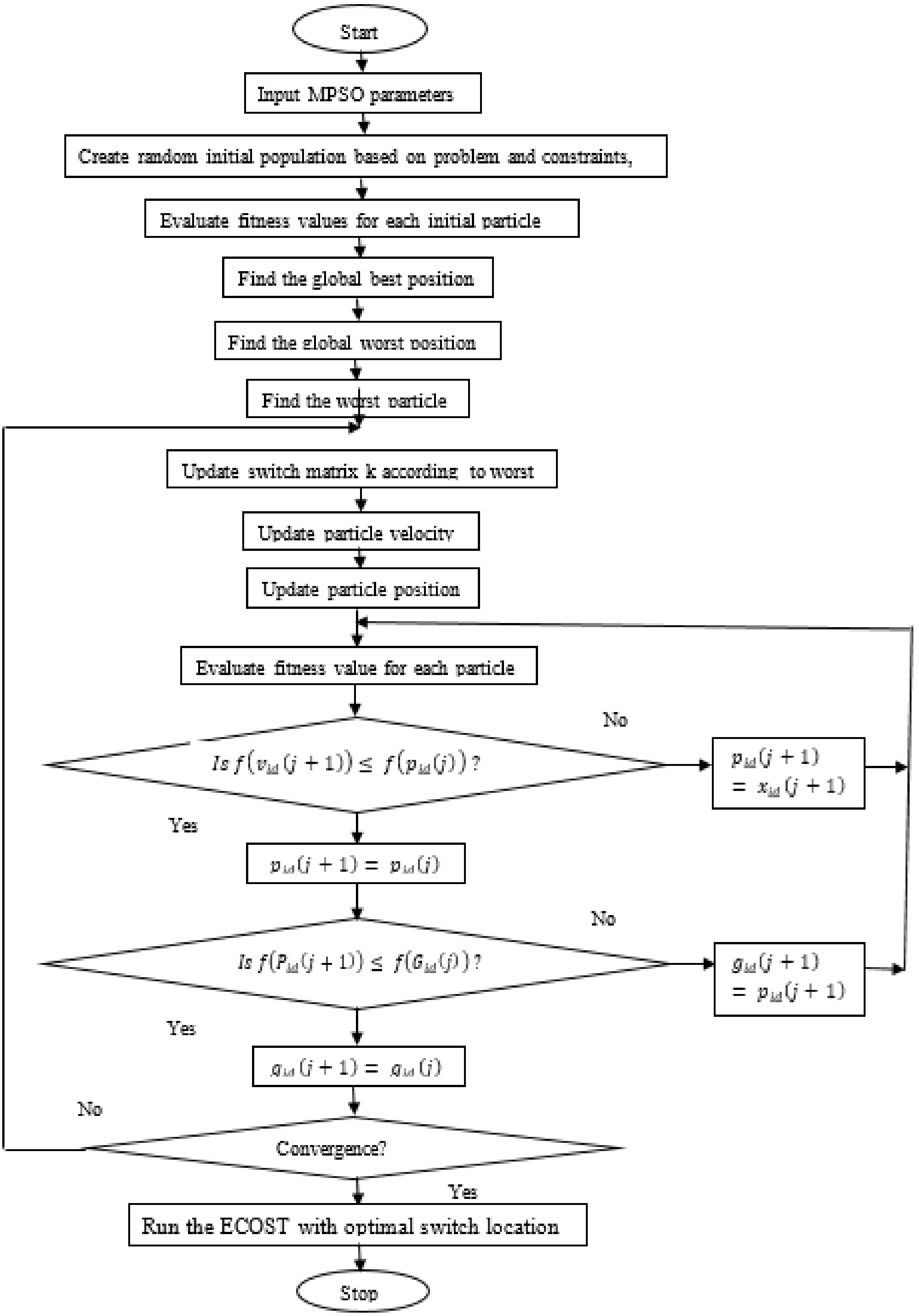

Figure 2: Flow chart for optimal placement of switches using MPSO

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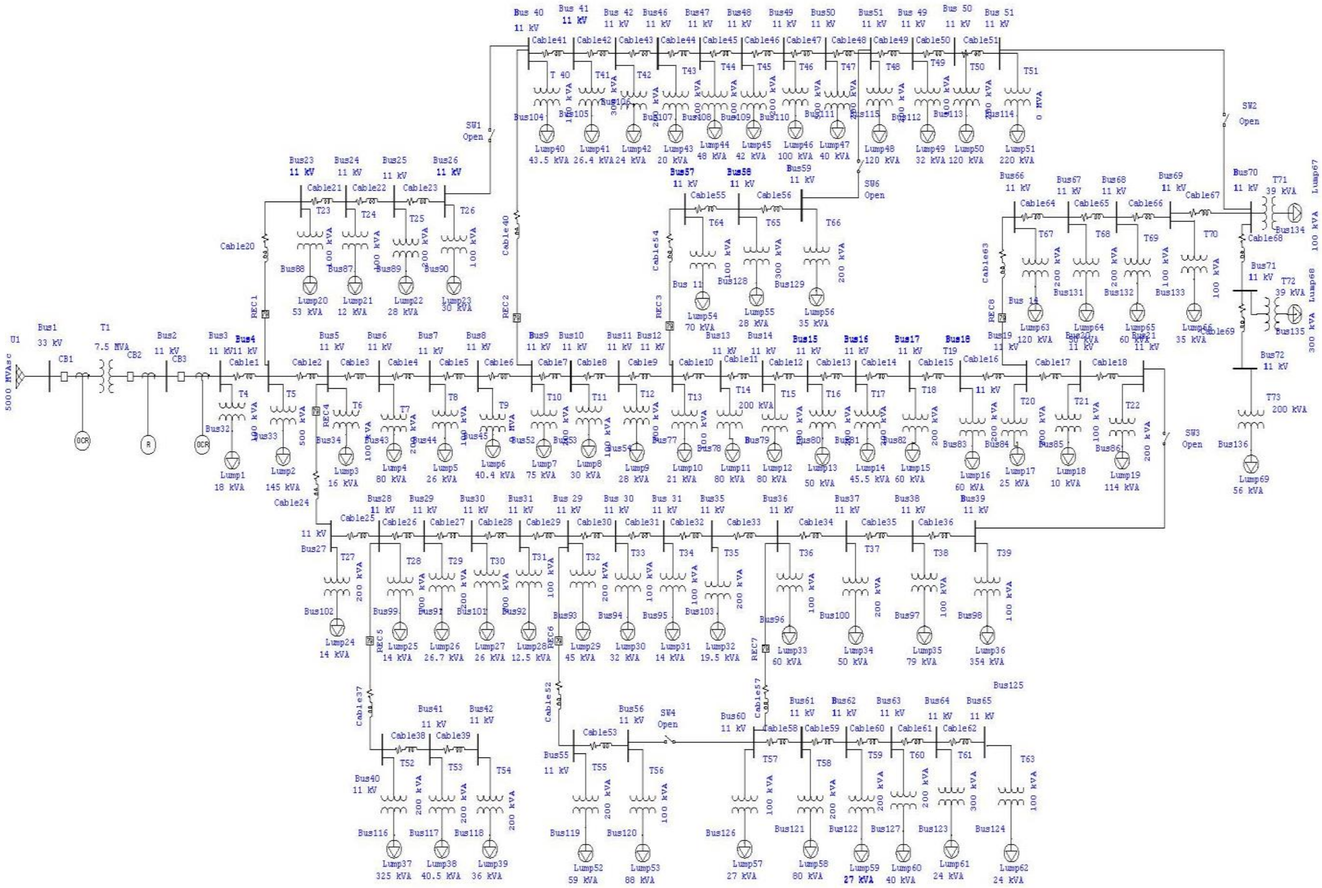

Figure 3: ETAP Model of 11 kV Ran Feeder with switches [20]

3. RESULTS AND DISCUSSION

The results for the optimal placement of switches and reconfiguration of the distribution network are presented in table 2. 11 number of switches are required for the analysis, under base case no bus in the system was isolated as a result no customer is under outage, however, when scenario case two was implemented i.e., switches 1,3 and 7 were opened 12 buses were isolated as a result 120 customers were on outage but reconfiguration of the network by closing switches 2 and 8 to 11, 80 customers were restored. For the other scenario cases i.e., Cases three, four and five, 130, 300 and 418 number of customers were isolated and 70, 210 and 203 were restored respectively. The plot of the number of buses and customers isolated and restored are presented in figures 9 and 10.

Table 2: Switch Status and Number of buses and customers isolated and restored

S/No.	Scenario Case	Opened Switch	Closed Switch	No of Buses isolated	No of buses Restored	No of Customers isolated	No of Customers Restored
1.	Base Case	Switch 1 – 6	Switch 7 - 11	-	-	-	-
2.	Case I	Switch 1& 3 – 7	Switch 2 & 8 – 11	12	10	120	80
3.	Case II	Switch 2 – 7	Switch 1& 8 - 11	12	09	130	70
4.	Case III	Switch 5,10,11	Switch 1- 4, 6 - 9	24	19	300	210
5.	Case IV	Switch 1,8,9	Switch 2 – 7, 10 & 11	28	17	418	203

Figure 4 presents the active and reactive power loss for the five scenario cases, for scenario case one which was the base case the active and reactive power losses were 30 kW and 20 KVar. After the implementation of the scenario cases 2 to 5, scenario case 4 gives the minimum loss with 15 kW and 12 KVar.

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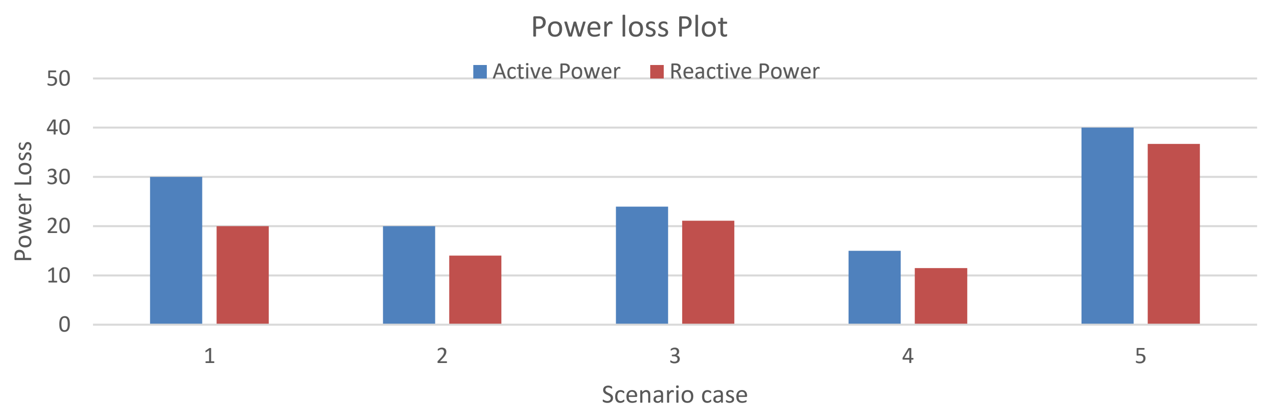

Figure 4: Power loss plot

The voltage profile for the five scenario cases were presented in figure 5 to 8 with scenario case one as the base case. i.e., A graph of base case and scenario case on each plot. Out of the four scenario cases, scenario case number four gives a good voltage profile where all the 14 bus voltages that were below 10 kV have risen to approximately 10.5 kV.

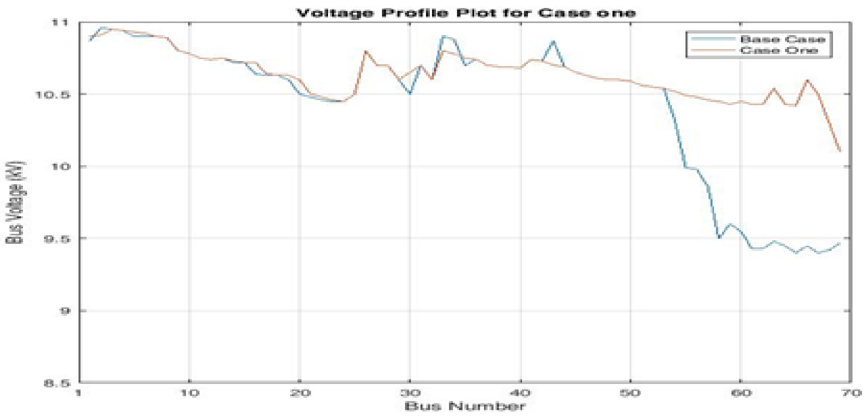

Figure 5: Voltage profile plot for Case One

Figure 6: Voltage profile plot for Case Two

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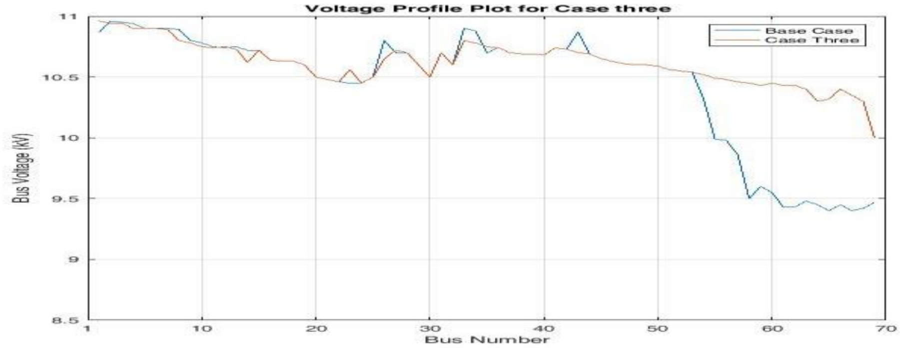

Figure 7: Voltage profile plot for Case Three

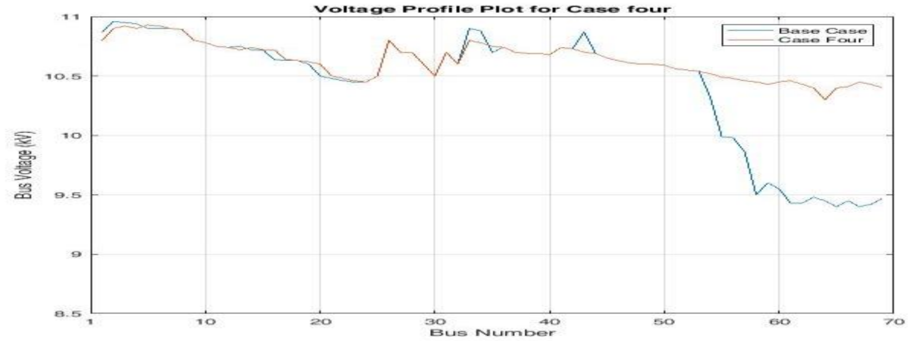

Figure 8: Voltage profile plot for Case Four

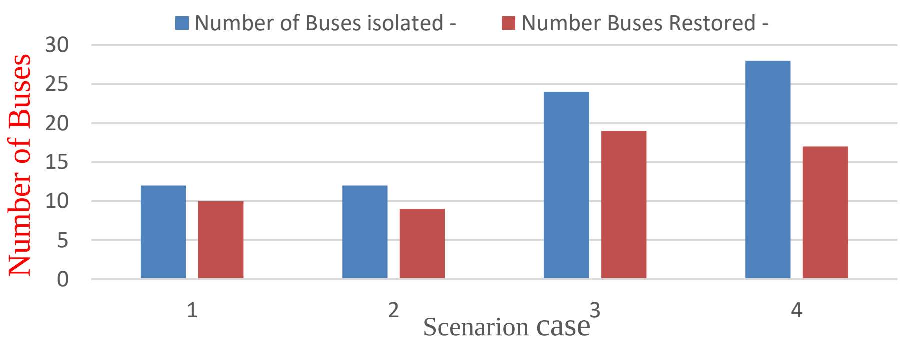

Figure 9: Plot of number of buses isolated and restored

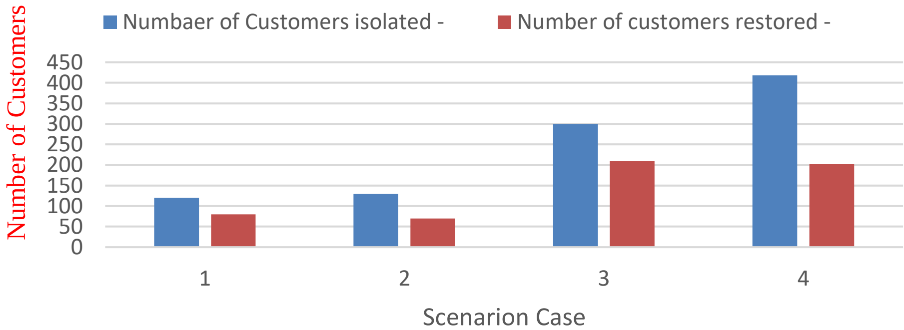

Figure 10: Plot of number of customers isolated and restored

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4. CONCLUSION

11 kV Ran feeder in Bauchi power distribution network was modelled in Electrical transient analysis platform with tie and sectionalizing switches optimally located as suggested by MPSO. The distribution network was reconfigured in four different scenarios in addition to the base case. The result for reconfiguration of Ran feeder is presented in Table 2, the number of buses isolated as a result of disturbance for cases 2 to 5 were 12,12,24 and 28 respectively but with reconfiguration of the network 10, 09, 19 and 17 buses were restored for the four cases respectively.

As a result of the reconfiguration, significant number of buses that were isolated as a result of disturbance in the system were restored which in turn reduces the number of customers isolated in the system.

Scenario case number four is the best configuration as it gives minimum power loss with all the bus voltages within the specified voltage limit.

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