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Reliability Improvement of Distribution System Network using Network Reconfiguration

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Abstract

This work focuses on carrying out reliability and network reconfiguration of the NAF base Kaduna 33kV distribution network system. Outage data was collected from the utility company Kaduna Electricity Company, Kaduna Nigeria (KAEDCO) from 2017 to 2020. This data was evaluated using some reliability parameters like SAIDI, SAIFI, CAIDI, AENS, ENS, Reliability, Availability, and Unavailability. The values obtained was analyzed in order to ascertain reliability of network in the case study. Using Fault Tree Analysis (FTA), the events; Transient fault, Ring Main Unit RMU fault, Damage on the J&P fuses, Breaking of cross arm , Thunder lightening , Crossing of two or all three phases, Weather condition, Isolation due to fault, Human activities, Animal encroachment, Wire twist, Wire cut, Jumper cut, Pull out of conductor, broken pole, maintenance due to fault and some fault conditions leading to failure which cause reliability problems on the network was analyzed. From the results of the fault, 7.094558e − 06 failure/yr as achieved as the top failure rate that occurred on the network. In order to minimize the loss on the network, the network was optimized using the Particle Swam Optimization (PSO) algorithm and eventually reconfigured using the information from the PSO algorithm. The network reconfigured, simulated and its performance enhanced for effective power delivery ultimately. All results were presented and discussed. From the network reconfiguration process, with tie switches located at (17-20) and (11-31) of the chosen network, the active power loss experienced by the network was reduced from 63.4004 kW and 20.3689 kW, indicating a percentage reduction of active loss: 63.0791 %, percentage improvement in reliability of 1.7955 % with a reliability of 1.4628 int/cost-yr was also achieved and this was validated using the IEEE standard test 33 bus system.

1. Introduction

Electrical power system has a main function to deliver power to the end users reliably and economically. In recent times, power distribution networks have exponentially grown in size and technology. As a result, utility companies must harness areas in order to ensure that the reliability requirements of customers are met with the peak of strategic planning and lowest cost possible. The ability of a power system to provide adequate electricity is determined by the term reliability. Reliability is one major indicator in the quality of power supply, but recently; it's being treated as a standalone problem in the power system. The other factor that determines the power system reliability is the quality of electricity delivered to customers. Moreover, the capability of a power system to regularly deliver quality electricity means that the customers are satisfied and the electricity providers are having good returns on their investment [1]. Electric power system is therefore set up in order to supply [2] to the end users' electricity with a minimal or no interruptions. The rate at which these interruptions occur while the system performs its dedicated function is part of what determines the overall system's reliability. Electricity consumption has become an important stake in the drive needed for technological growth and to facilitate the modern society developmental growth as well. It is however necessary to assess and evaluate the reliability of power system networks with the aim of achieving the most accurate and effective ways in decision making especially in planning, operation, and maintenance [3, 4-5]. The basic subsystems of an electric power system are the generating, transmission and distribution. Electricity is generated at the generating station and then transmitted through the high voltage transmission lines to the distribution substations for continuity of supply [6, 7]. A lot of empirical study and research work have been conducted due to the increasing cost of blackouts and fault outages. Analysis of the customer failure statistics of most electricity companies shows that the distribution system makes the greatest individual contribution to the unavailability of supply to a customer [8, 9]. In effect, the resolve of establishing generating stations and the hurdles overcome in transmitting electricity is defeated when it does not get to the user end as a result of distribution system failure. This makes distribution system to be of high importance. The distribution systems account for up to 90% of all customer reliability problems, improving distribution reliability is the key to improving customer reliability [10]. Moreover, distribution reliability is very important considering its high impact on the cost of electricity and its corresponding effect on customer satisfaction. Interruptions are however inevitable in power systems across the world; but from country to country, the manner as to how it's been handled makes it different [11]. For instance, in the United States, there is nearly an uninterrupted delivery of quality electricity to its numerous customers which makes it rank among the most dependable in the world [12].

2. Review of Related Literature

In [13], the authors carried out reliability prediction using neural network to estimate the behaviour of the network with respect to time. The work however did not consider the components that made up the system but rather treated the system as a single entity. Furthermore, the work also did not consider network reconfiguration as a means of improving system reliability. Reliability Evaluation of Al_Mansour 11kV Distribution Network in Baghdad City was conducted [14]. The authors discovered that Reliability is a key aspect network in Baghdad city. The minimal cut set method was adopted for the reliability evaluation. Evaluating the reliability requires calculating and evaluating a set of reliability indices. In their research, the reliability indices were calculated for Al_Mansour 11kV distribution network in Baghdad city. According to these indices, several improvements was proposed and simulated on the network as follows: Adding N/C (Normally Closed) manual switches in the network for isolating fault area and restoring the service to the remaining parts. Adding N/O (Normally Open) manual switches to interconnect feeders and provide alternative supply. Replacing the manual switches by remotely controlled or fully automated switches with fault indicators to reduce interruption times. Replacing the overhead lines by underground cables to reduce the fault rates. The software CYMDIST version 7.1 has been used as a tool for the simulation of the distribution network and performing the required analysis. The authors did not of power system design and planning. Their work was aimed at evaluating and improving the reliability of a power distribution make analysis on the causes of the faults in the network. Most developing countries' distribution systems including Ethiopia's distribution systems have considerably received less attention as the generating or transmitting systems. In research conducted by [15]; Enhancement of Distribution system of Debre Berhan distribution network. The authors carried out reliability assessment on four feeders of 15kv and 33kv so as to assess the performance of the existing system and to predict the reliability analysis for the future. The interruption data of two years 2017-2018 was used as a base year. They discovered that uncertainty of the input data was a major issue. Reliability indexes used are SAIDI (system average interruption duration index), SAIFI (system average interruption frequency index) and EENS (Expected Energy Not Served). The authors used ETAP 12.6.0 to simulate and enhance the network. SAIFI was reduced by 77.33% as compared with the average reliability indices values of the system in the base years. In the like manner SAIDI and EENS was also decreased by 80% and 77.77% respectively. The reason as to the uncertainty of the data was justified. Reliability Assessment of Electrical Energy Distribution System in Port Harcourt [16] using the Analytical Technique and ETAP software as the simulation tool to run the reliability assessment of the System. The authors carried out the analysis using 2014 and 2015 historical data of Secretariat, Silver Bird, Water Works, UST and School of Nursing Injection Substations obtained from the Port Harcourt Electricity Distribution company [PHEDC]. From the results of their analysis, they established that the Secretariat Injection Substation was the most reliable in the network when compared to the other four substations as it recorded system indices of ASAI: 99.90, SAIFI: 0.877, SAIDI: 8.11, CAIDI: 9.25 in 2014 and ASAI: 99.9 1, SAIFI: 0.873, SAIDI: 8.13, CAIDI: 9.14 in 2015. However, the overall reliability indices of the five substations under review as obtained from the analysis, revealed that the reliability of the distribution system is far below the set benchmark. System re-configuration and introduction of Photovoltaic Systems to re- supply interrupted loads at a shorter time were therefore recommended. In a paper to address the reliability of distribution systems in Nigeria [17], using the monthly fault report data of the load points. Using the analytical method and network reduction technique, the substation reliability was analyzed based on the outage data gotten from the utility company. The authors extracted faults data from the PHCN fault report logbook and classified it under seven types of faults (blown of fuses in the feeder pillar and J & P fuses holders, damages to poles and underground cables, low tensions lines cut down, breakdown of insulation and cross arms, service wire cut down, tripping of circuit breaker, burning of transformer windings). The authors attempted to solve these problems, through making use of these monthly fault report data at the load point (system interruption records) on a given electrical distribution system to evaluate the system reliability indices. The reliability indices evaluated in this work include SAIDI, SAIFI, ASAI, ASUI, CAIFI and CAIDI. The systems failure rate, MTTR, MBTF and availability were also determined. They established that transformers followed by fuse problem and the outgoing feeders gave rise to the low reliability level that was experienced in the system but the analysis into the causes of the faults were stated. In a paper to investigate the reliability of a power distribution system using Fault Tree Analysis (FTA) technique, [18] carried out research is to evaluate or assess the reliability of the 33/11kv injection substation of Rivers State University. Data used for the study was obtained from the university substation. The reliability analysis included assessing the failed power components of the substation in terms of the frequency and durations of their failures. The physical translation of the substation line diagram into the reliability block diagram or fault tree diagram was constructed. The FTA diagram showed the logical arrangement of the power equipment and fault path leading to the system failure. With the FTA diagram, the qualitative analysis was carried out using logic symbols AND-GATE and OR-GATE to determine the minimal cut sets that indicated the root-cause of the system failure and the Boolean algebra was obtained. The quantitative analysis was also carried out to determine the reliability parameters such as Mean Time Between Failures (MTBF), Mean Time To Repair (MTTR) and Unavailability of each the power equipment in the substation by using reliability indices. Using the Fault Tree Analysis (FTA) technique in their research, it was identified that the substation feeders such as 11kv UST Feeder, 11kv Federal Feeder and especially 11kv Wokoma Feeder were the power equipment that contributed majorly to the system failure of the substation. The authors did not went further to improve on the system after the respective feeders were discovered to be major contributing factor to entire system failures. In a paper [19] which surveys on a reliability technique which is called Fault Tree Analysis (FTA). FTA is a top-down approach to failure analysis, starting with a potential undesirable event (accident) called a TOP event, and then determining all the ways it can happen. The analysis proceeds by determining how the TOP event can be caused by individual or combined lower-level failures or events. In power system analysis this approach could maintain the static analysis of the system. The causes of the TOP event are “connected” through logic gates and modeling of the corresponding system. The paper went further to discuss the features and application of FTA with the power system being the center of consideration. The electrical power system, especially that of the Electric Distribution Network (EDN) is more complex for the rapid deployment and penetration of Distributed Generation (DG). According to [20], the DGs in the EDN are vulnerable to faults, and the reliability index considered is a critical factor in the work continuation of the EDN. The Particle Swarm Optimization (PSO) was modified to restrict the particle velocities when it runs to obtain the optimum solution for DG placement and capacity in the distribution network. This modification prevents the velocities from reach an acceptable level within a few iterations. This paper presents a new approach and good analysis to the evaluation of reliability and estimates the optimal location and capacity of the DGs units with multi-objective functions for power loss reduction and improves voltage profile. The optimization approach is based on the new Modified Particle Swarm Optimization (MPSO) for decision-making on strategic distribution system points for location and capacity of DGs using MATLAB software. In their study, reliability was evaluated using the "ETAP" and applied on the IEEE 33-bus test system. The obtained results of the proposed approach show superior on the other methods a reduction in real power losses by (60.13%) and an improvement in voltage profile by (88.34%). In research carried out by [21], a distribution network reconfiguration scheme for active power loss minimization and reliability improvement using particle swarm optimization technique was developed. In their work, the Backward Forward Sweep (BFS) algorithm was used to determine the power loss before and after reconfiguration, while also the System Average Interruption Frequency Index (SAIFI) was used for the reliability evaluation. The PSO based reconfiguration algorithm was also used to determine the optimum positions of the tie and sectionalizing switches. This proposed method was applied on IEEE 33 and 69 test bus systems. For the standard IEEE 33 test bus system, the proposed PSO based method produced a power loss reduction of 49.12 % when compared with the network before reconfiguration. The optimal tie switches were found to be (4-5), (11-12), (16-17), (19-20), and (21-22). For the standard IEEE 69 test bus system, the proposed method produced a power loss reduction of 66.25% when compared with the un-reconfigured network. The optimal tie switches were found to be (10-11), (14-15), (17-18), (24-25) and (54-55). The proposed method was applied to Ungwan Boro Injection sub-station in Kaduna State, Nigeria consisting of the Sabo, Pama and Mahuta 11kV feeders.

3. Material and Method

Data was collected from the utility company between 2017 and 2020. The reliability indices with the aid of MATLAB R2020a were used to evaluate the reliability of the network. PSO on MATLAB environment was used for the simulation of the case study so as to obtain the reliability and minimize the losses of the network; the results were therefore presented. The reliability values obtained was compared to 0.9900 [22] value for IEEE standard value for reliability to ascertain the level of reliability of this network and others alike. Finally, the simulated values obtained for the network was validated by the IEEE standard 33 bus system.

Materials

The case study considered in this work is the NAF base 33/11KV distribution network system. In this network we carried out reliability evaluation, validating the values with the IEEE standard benchmark values, analyzing the fault events as well as conducting a reconfiguration on the network. The materials used are as thus: The single line diagram which was used to simulate the network on MATALB/PSO environment is presented in Figure 1.

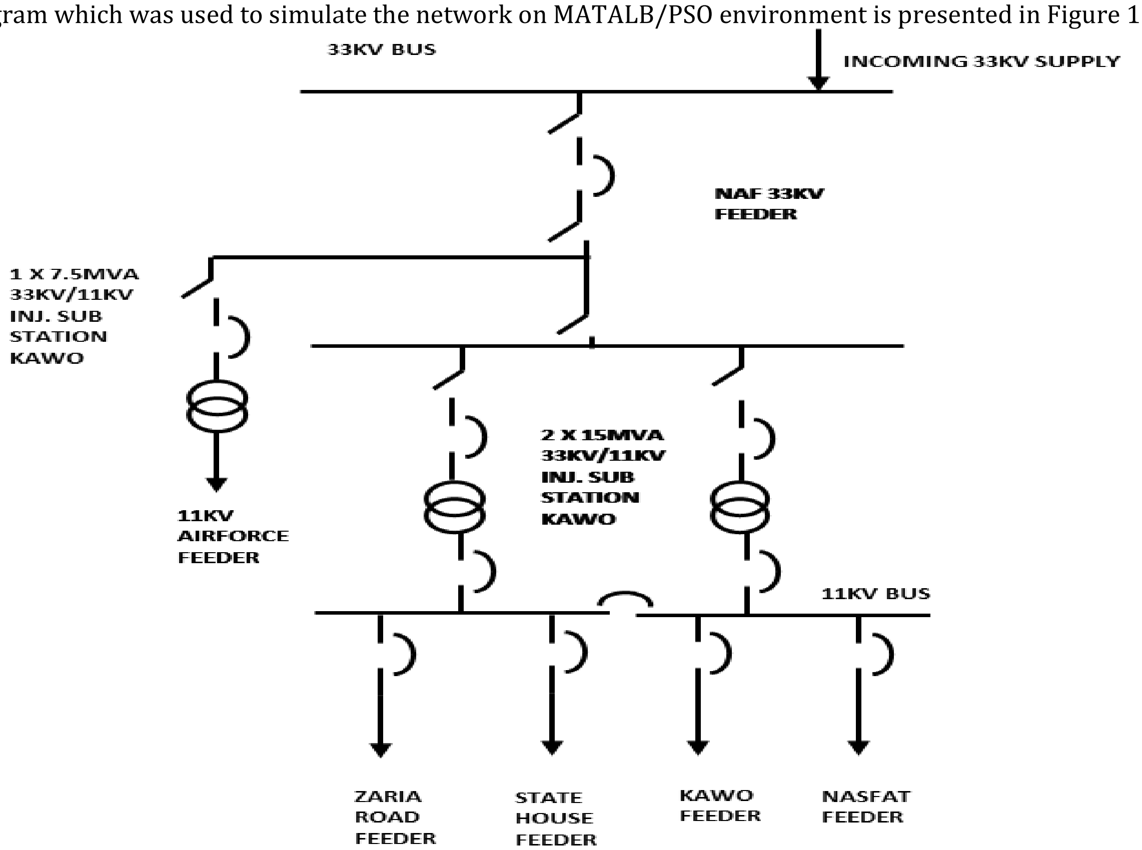

Figure 1. NAF base 33/11kv network single line diagram

Reliability indices

Reliability is a probability expression that needs to be quantified to make it suitable for scientific analysis. This quantification was carried out by introducing performance parameters which indicate the degree of reliability and are called reliability indices as presented in (Equations 1 – 13) [23-24]

FAILURE RATE (f/yr): $\lambda = \frac{\sum_{i=1}^{n} NO}{\sum OT}$ (1)

MTTR (HRS): $\frac{\sum_{i=1}^{n} NO}{FO}$; (2)

UNAVAILABILITY: $\frac{\lambda \times \left[\frac{\sum_{i=1}^{n} NO}{FO}\right]}{TP}$; (3)

SAIFI (FAILURE/CUSTOMER): $\frac{OF}{\sum NC_S}$; (4)

CAIDI: $\frac{\sum_{i=1}^{n} OD}{OF}$; (5)

ASUI: $\frac{OD}{\sum hd}$; (6)

AENS (KWh/CUST.yr): $\frac{ENS}{Nt}$ (7)

MTBF (HRS): $\frac{\sum_{i=1}^{n} OHi}{NF}$; (8)

AVAILABILITY: $\frac{\left[\frac{\sum_{i=1}^{n} OHi}{NF}\right] - \left[\frac{\sum_{i=1}^{n} NO}{FO}\right]}{\left[\frac{\sum_{i=1}^{n} OHi}{NF}\right]}$; (9)

RELIABILITY: (R) $= e^{-\lambda t}$; (10)

SAIDI (HRS/CUST-YR): $\frac{\sum_{i=1}^{n} OD}{\sum NC_s}$; (11)

ASAI: $\frac{\left[8760 - \frac{\sum_{i=1}^{n} OD}{OF}\right]}{8760}$; (12)

ENS (KWh/yr): ENS **=** $\sum_{i=1}^{n} (KW)i \times U$ (KWh/yr); (13)

3.1 Fault Tree Analysis: Risk is a systematic deductive technique, which allows the development of the causal relations leading to a given undesired event [25-26]. FTA is the most commonly used technique for causal analysis in risk and reliability studies [27]. FTA is a failure analysis in which an undesired state of a system is analyzed using Boolean logic to combine a series of lower-level events [28]. In (Equation 14-15), the approach to the calculation leading to the determination of undesirable events on the feeder are shown while Figure 1 represents the process followed.

Identified failure = $\sum_{i=1}^{n} UE_{i_{s1}} = UE_{k_{s2}}$ (14)

$\prod_{k=1}^{n} UE_{i_{s1}}$ (15)

$UE = Undesired\ Events, S1 = stage\ one, S2 = stage\ two$

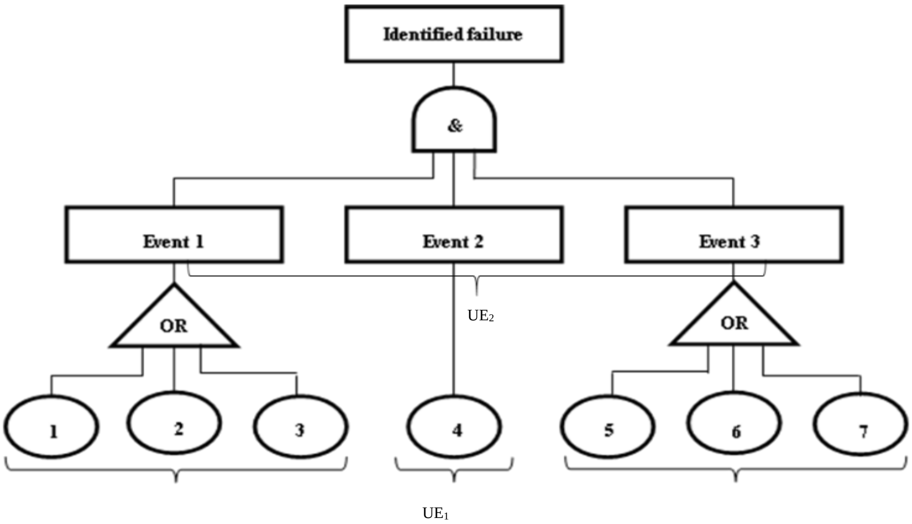

Figure 2. The FTA Approach

Particle Swarm Optimization (PSO): The PSO was used to optimize the reliability of the network through minimizing the transmission line losses. This involves adopting a PSO based algorithm for the network reconfiguration in order to optimally locate the positions of the tie and sectionalizing switches to minimize loss and improve reliability in a radial distribution network.

Real power loss reduction: The power loss reduction is potentially able to subsidize the operating cost of the Utility service providers and increase the loading capacity of the network. The total power loss of the M-th radial configuration is determined by the summation of losses in all line sections according to the following [29, 30] as shown in (Equation 17- 24)

$$P_{loss} = \sum_{j=1}^{Nb_{naf}} R_j \times \left(\frac{P_j^2 + Q_j^2}{V_j^2}\right) M_j \quad (17)$$

where,

M_j is the switch state of *j-th* branch, with 0 indicating switch open and 1 indicating switch closed.

Nbnaf is the number of the buses, R_j is the resistance of the *j*-th branch, P_j is the active power flowing through the terminal of *j*-th branch, Q_j is the reactive power flowing through the terminal of *j*-th branch, V_j is the terminal node voltage of the *j*-th branch

Sum of Weighted Cost Function: The most straightforward approach to multi objective optimization is the weight cost function approach. This will be applied to set a trade-off on objective functions according to the weight assigned to them as shown in (Equation 19)

$$cost = \sum_{m=1}^{NL} W_m f_x \qquad x = 1,2, \quad (18)$$

where, f_x is the objective function and W_m the weighting factor.

Aggregate Objective Function: An Aggregate Objective Function (AOF), is a function that combines the objectives into a scalar function. The AOF basically contains parameters to be selected. These parameters reflect the relative importance of each objective. An objective with higher importance will be given priority during the optimization process. The AOF is simply a weighted linear combination of all the objective functions.

The Aggregate Objective Function proposed for this work can be described in equation (xvii).

$$fi = (w_1 f_1 + w_2 f_2) \times K_a \quad (19)$$

$$Cost = \min\left(\sum_{x=1}^{Nbnaf} f_x\right) \quad (20)$$

where, f_1 is given as equation (xiv) and f_2 is assigned to any other equation as may be considered in the objective function. As for the case under consideration, the active power loss is our focus.
w_1 is the weight assigned to f_1 and w_2 is the weight assigned to f_2
These objective functions are subjected to constraint, which must be satisfied.
Node voltage constraint

$$V_{minimum}(a) \leq V(a) \leq V_{maximum}(a) \tag{21}$$

Branch Power constraint

$$P_a \leq P_{a\ maximum} \tag{22}$$

$$Q_a \leq Q_{a\ maximum} \tag{23}$$

Radial Network constraint

$$\sum_{i=1}^{nnaf} \sum_{j=1}^{nbus} aij = 1 \text{ or -1} \tag{24}$$

$nbus$ is the number of total buses, $nnaf$ is the number of branches, aij is the elements of the incidence matrix A which has dimension of $nl \times nbus$.

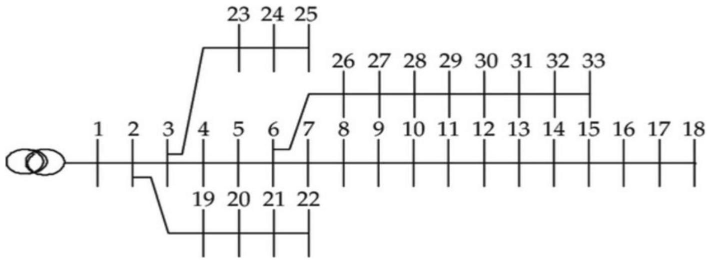

Figure 3: The single line diagram of the IEEE 33 Bus

No islanding in the distribution network Model of Network Reconfiguration: The formula given by Equation (17) was used to describe the real power loss. This formula is for the power loss with weight assigned. Weights of w = 1 was assigned to the power loss. The choice of this values is to give more priority to the power loss. Backward-Forward Sweep (BFS) Technique for Power Flow Analysis:.

Table 1. Faults during the period under consideration

Fault type	**Counts**
Isolation due to fault	48
Animal encroachment (birds, lizards)	7 (5,2)
Trimming of trees	40
J&P fuse	33
Ring main unit (RMU) fault	15
Wire cut	10
Broken cross arm	7
Pull out conductor	14
Conductor resting stay on wire HT pole (loose contact)	8
Wire twist	6
Jumper cut	30
Maintenance (relay calibration, on tag, fuse fault)	4, 6, 2
Broken pole	4
Broken pole due to accident	1
Transient fault	110
Wire bridging due to object	1
Wind	15
Rain	83
No physical fault seen/perceived fault	64
On emergency from HT(33kv supply) / fault tracing	26
Upriser (cable fault)	6
Lightening	1
Network component failure	4
Birds / bats (animal encroachment)	5
Network repairs	8

The backward sweep is basically a current or power flow solution with possible voltage updates. It starts from the branches in the last layer and move towards the branches connected to the root node. The updated effective power flowing in each branch are obtained in the backward propagation computation by considering the node voltages of previous iteration. The forward sweep is basically a voltage drop calculation with possible current or power flow updates. Nodal voltages are updated in a forward sweep starting from branches in the first layer toward those in the last. Particle swarm optimization (PSO) is a meta-heuristic global optimization method developed from the dynamics and social psychological principles of swarm behaviour observed in nature. It can be seen in the social behaviour and swarm intelligence of bird, swarm of bees and fish flock movement. The PSO process was eventually achieved through the writing of codes on the Matrix Laboratory MATLAB. Both the FTA and PSO processes were first tested on the IEEE 33 bus test bed after which it was implemented on the NAF Base Feeder. In Figures 3 and 4, the Single Line Diagrams of the both networks are presented while Table 1 show the data and the basis on which the FTA was done.

4. Results

In Table 2, the results showing the reliability indices is presented. Further, Tables 3 and 4 show the average values of SAIFI and SAIDI respectively and this was interpreted graphically on the excel spreadsheet as shown in Figures 5 & 6. In Tables 5 and 6, the summary or results of network performance is presented for the cases of IEEE 33-Bus and NAF Base network. Table 7 show the results from the FTA which has been categorized to three different groups namely, Transformer, Network and Transmission Line failures and eventually Figure 7 show the reconfigured network for the new pathway.

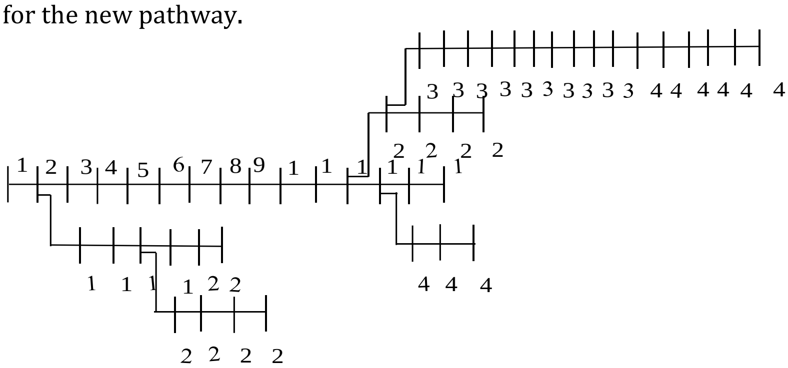

Figure 4. The single line diagram NAF Feeder

Table 2. Reliability Indices Results

RS	FEEDERS	FAILURE RATE (f/yr)	MTBF (hrs)	MTTR (hrs)	AVAILABILITY (pu)	UNAVAILABILITY (pu)	RELIABILITY (pu)	SAIFI (f/cust-yr)	SAIDI (hrs/cust-yr)	CAIDI (hrs)	ASAI (pu)	ASUI (pu)	ENS (KWh/yr)
2017	KAWO	0.0014	730.0000	5.3558	0.9927	0.0073	0.9674	0.0076	0.0141	5.3558	1.0000	0.007	7.8835
	NAF BASE	0.0011	876.0000	3.9530	0.9955	0.0045	0.9729	0.0389	0.1538	3.9530	1.0000	0.0045	1.1808
	NASFAT	0.0013	796.3636	7.1191	0.9911	0.0089	0.9702	0.0032	0.0230	7.1191	1.0000	0.0089	3.9189
	ZARIA	0.0025	398.1818	5.7823	0.9855	0.0143	0.9410	0.0033	0.0190	5.7823	1.0000	0.0145	37.0905
2018	KAWO	0.0005	2.1900 (1.0e+003 *)	5.1325	0.9977	0.0023	0.9891	0.0009	0.0045	5.1325	1.0000	0.0023	0.1043
	NAF BASE	0.0010	0.9733 (1.0e+003 *)	1.1744	0.9988	0.0012	0.9756	0.0350	0.0411	1.1744	1.0000	0.0012	0.1918
	NASFAT	0.0014	0.7300 (1.0e+003 *)	3.5133	0.9952	0.0048	0.9676	0.0035	0.0124	3.5133	1.0000	0.0048	1.2858
	ZARIA	0.0007	1.4600 (1.0e+003 *)	3.7417	0.9974	0.0026	0.9836	0.0009	0.0034	3.7417	1.0000	0.0026	0.5913
2019	KAWO	0.0039	257.6471	6.3859	0.9752	0.0242	0.9101	0.0075	0.0476	6.3859	1.0000	0.0248	111.5718
	NAF BASE	0.0031	324.4444	1.7181	0.9947	0.0053	0.9281	0.1051	0.1805	1.7181	1.0000	0.0053	16.0739

	NASFAT	0.0067	151.0345	4.1379	0.9726	0.0267	0.8507	0.0171	0.0706	4.1379	1.0000	0.0274	339.3310
	STATE HOUSE	0.0023	438.0000	5.3630	0.9878	0.0121	0.9464	0.0038	0.0204	5.3630	1.0000	0.0122	16.9660
	ZARIA	0.0048	213.6585	7.3302	0.9657	0.0332	0.8916	0.0061	0.0449	7.3302	1.0000	0.0343	360.8698
2020	KAWO	0.0028	365.0000	4.8550	0.9867	0.0131	0.9359	0.0038	0.0256	4.8550	1.0000	0.0133	0.0274
	NAF BASE	0.0014	730.0000	3.2858	0.9955	0.0045	0.9676	0.0467	0.1534	3.2858	1.0000	0.0045	0.0014
	NASFAT	0.0056	182.5000	3.1371	0.9828	0.0169	0.8751	0.0141	0.0443	3.1371	1.0000	0.0172	0.1492
	STATE HOUSE	0.0044	230.5263	3.2945	0.9857	0.0141	0.8997	0.0072	0.0238	3.2945	1.0000	0.0143	0.0995
	ZARIA	0.0100	104.2857	4.1687	0.9600	0.0384	0.7863	0.0125	0.0523	4.1687	1.0000	0.0400	1.8154

Table 3. Average SAIFI Results

Feeders	Average (INT/CUST-YR)
Kawo	0.0041
Naf base	0.0564
Nasfat	0.0095
State house	0.0055
Zaria	0.0057

Table 4. Average SAIDI Results

Feeders	Average (HRS/CUST-YR)	Yearly duration (HRS)
Kawo	0.0229	103.2037
Nafbase	0.1322	787.6277
Nasfat	0.0376	184.2499
State house	0.0221	193.5960
Zaria	0.0299	169.5170

Table 5. Summary Results for Performance IEEE Bus

Description of parameters	Before reconfiguration	After reconfiguration
Total active loss	221.7199 KW	191.1977 KW
Percentage reduction in active loss	--	220.8576 %
Minimum voltage (p.u)	0.94171	0.95589
Maximum voltage (p.u)	0.99414	0.99578
SAIFI	2.9989	1.7028
Percentage improvement in reliability	--	2.4311 %
Tie switches	(4 18) (26 27)	

Table 6. Summary Results for Perfomance Kawo Feeder

Description of parameters	Before reconfiguration	After reconfiguration
Total active loss	63.4004kW	20.3689kW
Percentage reduction in active loss	--	63.0791%
Minimum voltage (p.u)	0.96815 @ Bu 36	0.99047 @ Bus 36
Maximum voltage (p.u)	0.99494 @ Bus 2	1.0054 @ Bus 21
SAIFI	2.404	1.4628
Percentage improvement in reliability	--	1.7955%
Tie switches	(17 20) (11 31)	

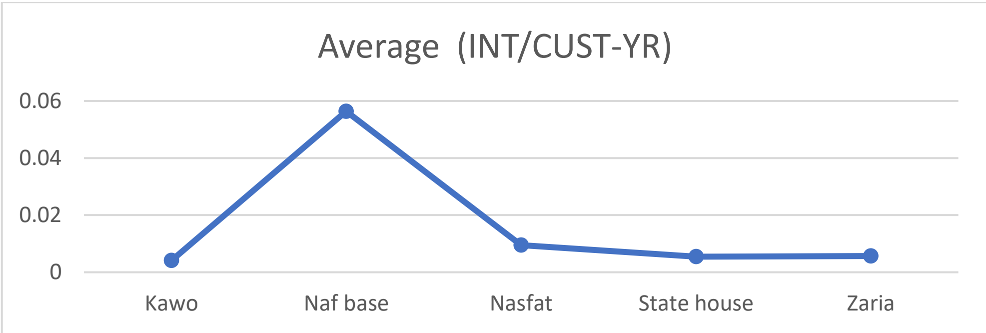

Figure 5. Graph of SAIFI

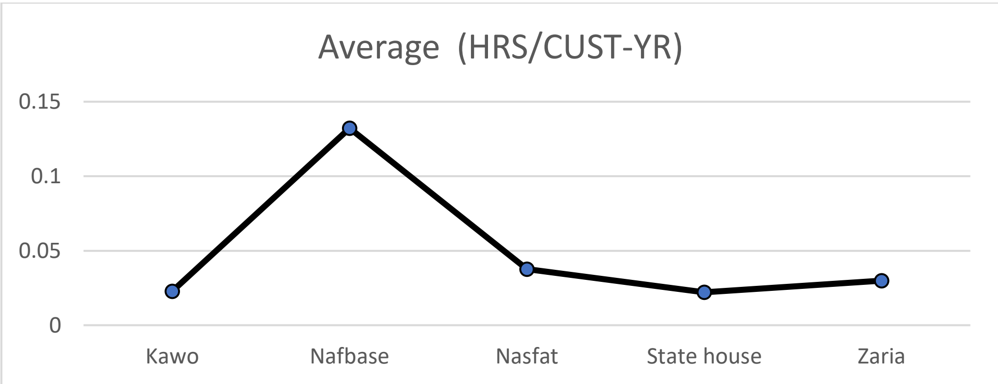

Figure 6. Graph of SAIDI

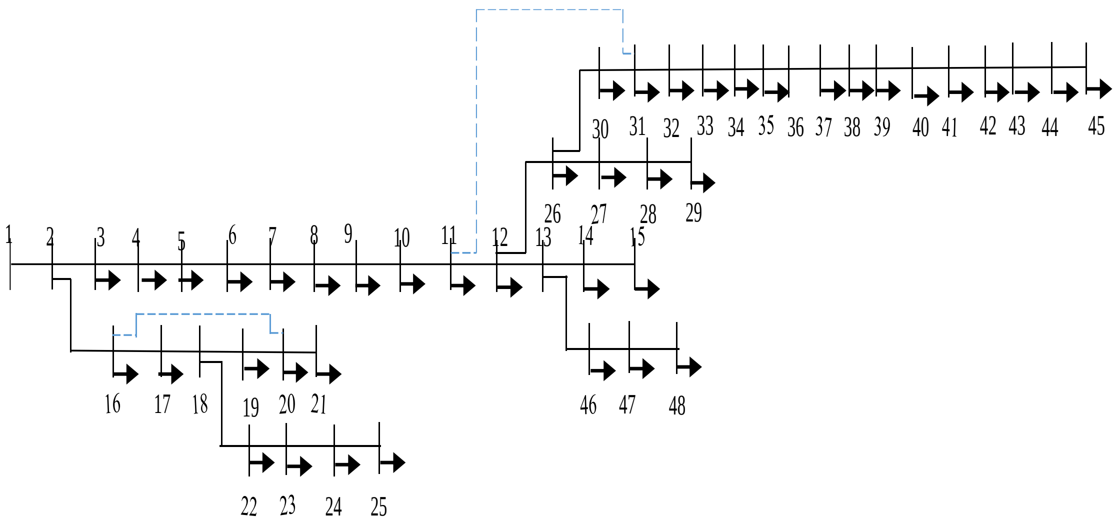

Figure 7. Diagram of the reconfigured network showing the current new pathway

5. Discussion

From the results above, on the average, NAF BASE feeder is said to be the least reliable with a SAIFI value of 0.0041int/cust-yr when compared to Kawo Feeder which has a comparative better reliability with a SAIFI value of 0.0564 int/cust-yr. The SAIDI value of 103.2037 hrs for the O feeder and a value of 787.6277 hrs for the NAF BASE feeder. Using the reliability indices formulae with the aid of MATLAB, the reliability and availability was evaluated and analyzed. Generally, comparing it with the international IEEE standard std 1366-2020 of 2.13hrs for SAIDI, it can be said that the network is less reliable and it's below standard. FTA was used to identify and establish the events leading to failures on the network and a value of 7.094558e-06 f/yr was achieved. The BFS algorithm was used to determine the power loss while SAIFI was used to evaluate the reliability. The PSO based reconfiguration algorithm was used to optimally place the tie and sectionalizing switches while the AOF is basically a weighted linear combination of the objective functions power loss and SAIFI which was used to formulate the cost function for the reconfiguration. The proposed method was applied on IEEE 33 test bus system and the following results were obtained are: percentage reduction of active loss 220.8576 % and percentage improvement in reliability 2.4311 %. The proposed method was also applied to KAWO network system of the 33KV NAF feeder network system. The results obtained were percentage reduction of active loss obtained 63.0791 %, and percentage improvement in reliability 1.7955 %. A reliability of 1.4628 int/cost-yr was established and comparing with the IEEE standard benchmark value of 0.9900, it was discovered that the network was below standard. Although the KAWO feeder performed better when generally compared to others in the network however with respect to results validation with the IEEE test bus system, the KAWO network system needs continual maintenance actions to reduce probability of failures along the network.

6. Conclusion

The overall reliability of the distribution network system has been determined with respect to the standard benchmark. In general terms, it was discovered that the reliability as well as the availability of the network is below the standard obtainable internationally. Hence, the network is less reliable. The failure causing events of this network has been identified and established. The reliability of the network system has been optimized and reconfigured for better performance in terms of loss minimization consequently improving the quality of power. Based on proposed method applied on IEEE 33 test bus system with the following results obtained: percentage reduction of active loss 220.8576 % and percentage improvement in reliability 2.4311 %. Also, applied to KAWO network system of the 33/11KV NAF feeder network system with the following results obtained: percentage reduction of active loss 63.0791 % and percentage improvement in reliability 1.7955 %. This further shows that based on validation with the IEEE test bus system, the reliability level of the KAWO network system is below standard.

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Author contributions:

Idris A Araga: Conceptualization, Methodology, **Abel E Airoboman:** Data collection, Writing-Original draft preparation, Software, Validation, **Mohammad A Jibrin:** Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

References

1. Akintola, A. A. (2017)," Reliability Evaluation of Secondary Distribution System in Nigeria": A case study of Ayetoro 1 substation, Aguda, Lagos state; Master of Engineering, a dissertation, Department of Electrical and Information Engineering, college of engineering, covenant university, Ota, Ogun state, Nigeria.
2. Kantoğlu, B and İ. Duzdar Argun, "Evaulation of renewable energy source alternatives prioritization", TUJE, vol. 7, no. 1, pp. 1–8, 2023, doi: 10.31127/tuje.1001488.
3. Anthony R. (2014), "Reliability Analysis of Distribution Network", Master of Science Thesis, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia.

4. A. E. Airoboman, A. Olalekan Salau and M. Chhabra, "Review of the Performance of the Power Sector in Some Selected African Countries," *2022 IEEE Nigeria 4th International Conference on Disruptive Technologies for Sustainable Development (NIGERCON)*, Abuja, Nigeria, 2022, pp. 1-5, doi: 10.1109/NIGERCON54645.2022.9803097..
5. A. E. Airoboman and M. Tyo, "Modelling of a Maintenance Information Monitoring System for Distribution Network Feeders within Kaduna Using Matlab Simulink," *2023 IEEE PES/IAS PowerAfrica*, Marrakech, Morocco, 2023, pp. 1-5, doi: 10.1109/PowerAfrica57932.2023.10363231.
6. Airoboman AE, Shaibu, A and Aku, D. (2023) "Evaluating the impact of injecting the 3050MW Mambilla power plant into the Nigerian grid network" *Journal of Advances in Science and Engineering*. Vol. 8 pp. 27-48.
7. R. Temiz and M. R. Tür, "Investment technique for ensuring energy supply continuity in ring grids", TUJE, vol. 8, no. 2, pp. 186–195, 2024, doi: 10.31127/tuje.1357643
8. Airoboman AE (2022) "Reliability Assessment of Power System Network: A Detailed Review" International Journal of Engineering Technologies Vol.7, No.4, pp. 90-103
9. S.L. Braide, D.C. Idoniboyeobu and G. Gomene, "Evaluation of Transmission Distribution Power Outages in Nigeria." Global Scientific, vol. 9, no. 8, pp. 850-861, 2021.
10. Billinton, R. and Jonnavithula, S, (1996). "A Test System for Teaching Overall Power System Reliability Assessment". IEEE Transactions on Power Systems, Vol. 11, No. 4, 1670-1676.
11. M. A. Aderibigbe, A. U. Adoghe, F. Agbetuyi and A. E. Airoboman, "A Review on Optimal Placement of Distributed Generators for Reliability Improvement on Distribution Network," *2021 IEEE PES/IAS PowerAfrica*, Nairobi, Kenya, 2021, pp. 1-5, doi: 10.1109/PowerAfrica52236.2021.9543266.
12. Akintola A. A. and Awosope C. O. A, (2017), "Reliability Analysis of Secondary Distribution System in Nigeria: A Case Study of Ayetoro 1 Substation, Lagos State," The International Journal of Engineering and Science (IJES), Vol. 6, Issue 7, PP 13- 21, 2017, ISSN (e): 2319 – 1813 ISSN (p): 2319 – 1805.
13. Airoboman AE and Idiagi NS (2020) "Reliability Prediction in the Nigerian Power Industry using Neural Network" *Journal of Electrical and Electronics Engineering (JEEE).* Vol. 13, No.2, pp. 17-22. Publisher: *Editura Universitatii din Oradea Romania*.
14. Abdul-Wahhab, T. M. and Ahmed, R. A. (2018) "Reliability Evaluation of Al_Mansour 11kV Distribution Network in Baghdad City," Engineering and Technology Journal, Vol. 36, Part A, No. 3, pp. 304-314.
15. Anteneh, D and Khan, B., (2019), "Reliability Enhancement of Distribution Substation by Using Network Reconfiguration a Case Study at Debre Berhan Distribution Substation". International Journal of Economy, Energy and Environment. Vol. 4, No. 2, 2019, pp. 33-40.
16. Oreke, F. C. and Idoniboyeobu, D. C. (2017), "Reliability Assessment of Electrical Energy Distribution System – A Case Study of Port Harcourt Distribution Network", International Journal for Research in Applied Science & Engineering Technology (IJRASET), Volume 5 Issue VI, June 2017, IC Value: 45.98 ISSN: 2321-9653.
17. Ololade, O. S., Junjie T. and Sinneh, I. S. (2020) "Reliability and Fault Analysis of Electrical Distribution System: A Case Study of Kafanchan Distribution Substation in Kaduna State, Nigeria.". *American Journal of Engineering Research (AJER),* vol. 9(01), 2020, pp 180-188.
18. Idoniboyeobu, D. C, Braide, S. L. and Songo, Y. (2020)" Investigating Reliability of Power Distribution System using Fault Tree Analysis (FTA)" GSJ: Volume 8, Issue 3, March 2020, ISSN 2320-9186
19. Javadi, M. S., Nobakht, A., Meskarbashee, A. (2011), "Fault Tree Analysis Approach in Reliability Assessment of Power System", International journal of Multidisciplinary Sciences and Engineering, vol. 2, no. 6, September 2011, [ISSN: 2045-7057]
20. Jaleel, A, M; Kdair Abd, M. (2021) "Reliability Evaluation of Electric Distribution Network with Distributed Generation Integrated" *International Journal of Intelligent Engineering and Systems, Vol.14, No.5, 2021*
21. Alberah J. (2018). "Development of distribution network reconfiguration scheme for loss minimization and reliability improvement based on particle swarm optimization technique: A case study of ungwan boro injection sub-station" A dissertation submitted to the school of postgraduate studies, Ahmadu Bello University, Zaria.
22. Airoboman, A.E, Ogujor E. A. and Okakwu, I.K., (2017); "Reliability Analysis of Power System Network: A case study of Transmission Company of Nigeria, Benin city"; 2017 IEEE PES-IAS Power Africa.
23. Airoboman, A.E (2020) "Reliability Assessment on Power Network in Benin Metropolis". *Academy Journal of Science and Engineering AJSE.* Vol. 13, No. 1, pp. 15-27
24. Amuta, EO. Ongbali, SO. Hope, O. Airoboman, AE, Sobola, G. and Dike, HN (2024) "Identifying Key Reliability Factors in Micro-Grid Systems using Principal Component Analysis" *Journal Européen des Systèmes Automatisés*, Vol. 57, No. 1, pp. 303-309.
25. F. Erdem, "Risk assessment with the fuzzy logic method for Ankara OIZ environmental waste water treatment plant", TUJE, vol. 6, no. 4, pp. 268–275, 2022, doi: 10.31127/tuje.975623.

26. S. Çeliker, E. Saraç Eşsiz, and M. Oturakcı, "Integrated AHP-FMEA risk assessment method to stainless tank production process", TUJE, vol. 5, no. 3, pp. 118–122, 2021, doi: 10.31127/tuje.702369.
27. R.U. Nighot, (2003), "Incorporation substation and switching station related outages in composite system reliability evaluation", MSc. Thesis, College of Graduate Studies and Research, University of Saskatchewan, Canada.
28. C.C. Fong, C.H. Grigg, (1994) "Bulk power system reliability performance assessment, Reliability Engineering System" Saf. 46 page 25–31.
29. Alhaddad, F. M., & El-Hawary, M. (2014). "Optimal Filter Placement and Sizing Using Ant Colony Optimization in Electrical Distribution System". Paper presented at the Electrical Power and Energy Conference (EPEC), 2014 IEEE, 128-133.
30. A.E. Airoboman,, H. Ahmed and I. Shefiu, (2019)"Losses Optimization of Induction Motor Using Particle Swam Optimization Technique" *Advances in Electrical and Telecommunication Engineering.* Vol. 2, No. 2, pp. 55-62