# Distribution Injection Substation using Faults-Tree Techniques in a Developing Economy

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## ABSTRACT

Electricity supply involves complex and highly integrated system (generation, transmission and distribution etc). Failure in any part can cause interruptions (black out) which ranges from inconveniencing large number of local residents which may leads to total outage as a concern for poor power supply. Essentially, electricity power reliability and supply has been an important and most driving issue for consumer economic activities as a requirement from electricity supply utilities, this will necessitate and enhance reliable and efficient electric power supply for daily operations. This research work present a reliability assessment techniques (means time before failure/MTBF, meantime to repair (MTTR), system average interruption frequency index (SAIFI), system average interruptions duration index (SAIDI) etc). In order to assess the activities of four (4) outgoing distribution feeders of 11k- station-road,11kv Amadi –North feeder, 11kv - Flour-mill and 11kv Borokiri distribution feeder using the application of electricity transient analyzer tool Etap version 12.6 for modeling, simulation (specialized software). The analysis was carried out using 2019 and 2020 historical data set the zone under investigation in the study. The study considered load point 1-4 respectively for the four (4) outgoing feeder. Load point analysis shows the results of MTBF and MTTR as 11.07hrs, 55.5hrs for station-road feeder, similarly flour-mill feeder captured 14.3hrs, 10.29hrs for MTBF and MTTR respectively, while Borokiri 11kv feeder shows MTBF and MTTR with 10.71hrs, 5.47hrs. In the same manner the Amadi-North shows 19.91hrs and 10.29hrs in the year under this research study. The maintenance metrics which measures the average time for non-repairable asses before system failing to engage in productive services in a year before repair in other words the average life span of the load-point feeder before failure and repair are systematic ranked as load point 2 (Amadi-north which about twenty hours engagement, followed by load pon3 (flour-mill feeder), load-point 1 (Station-roadfeeder) and load point 4 (Borikiri feeder). Consequently, the mean time to repair (MTTR), is the average time to repair and restore a failed system for the loads points 1-4 which are: MTTR (5.58hrs, 10.27hrs, 10.29hrs and 5.47hrs respectively. This indicate that load point – 4 (Borokiri feeders) which shows less average time to repair and restore the failed systems followed by load point-1(station road), load-point 2 (Amadi north) and load-points 3 (Borokiri) in that manner. This also considered the fault-tree analysis (Boolean algebra) for system component analysis and reliability. Having considered the activities of the four(4) – outgoing feeder from marine-base injection substations taking electric power supply from Nzimiro (Transmission substation, Ts) which operations are configured radically and aimed at minimizing the cost of active and reactive power losses on the view to improve system security for power quality and voltage profile to the zone under study. Evidently, this research work has proposed an automatic sectionalizing devices (line reclosers, interrupters, fuses controllers etc) in order to reduce the losses to the affected customers load points, thereby enhancing efficient power supply and reliability to consumers in order to make a savings.

**Keywords:** Transmission Substation, Distribution, Fault-Tree Techniques, Electric power, Feeder

## 1. Introduction

Electric power system is fundamentally set up to supply electricity with little or no interruptions to its end-users. The amount of power outages that occur while the system performs its intended function is part of what determines the overall reliability of the system another factor that determines its reliability is the quality and sufficiency of electricity delivered. In furtherance, the capacity of a power system to continuously and reliably deliver steady and quality electricity means that the customers are satisfied and the electricity suppliers are obtaining returns on their investments as they continue their business of supplying power.

In Nigeria today, the unreliable and poor nature of the power supply has imposed significant cost on the economy. According to Braide & Kenneth (2018), small-scales operators are more affected by the power outage as they are unable to finance the cost of backup power necessary to mitigate the impact of frequent power shortages. Power interruption or shortages have deeply affected the drive for economic growth and technological development of Nigerian society. Therefore it is very important to take seriously the issue of reliability of the power distribution system.

Generation, transmission and distribution are the three subsystems of an electric power system. At the generating station, electricity is generated and transmitted through the high voltage transmission lines to the distribution substations. The distribution substation system considered covers the electrical system between the substation fed by the sub-transmission system and the supply line to the consumers' meters i.e. 11kv to 0.415kv transformation (Braide et al., 2018). The distribution substations are usually sited relatively close to the customers for effective delivery and monitoring. Reliable and safe transfer of electricity to the customer should be ensured by a reliable and performing distribution network but not by the redundant type and that is the main subject studied in this dissertation.

Actually in Nigeria today, the power industry lacks automation and power outage which has become endemic. The ills of the nation's power sector are many despite heavy investments from the Federal Government in the sector. The existing distribution networks are constraints to the core power system reliability such as poor reliability, high line losses, low voltage profiles, overloading of transformers, poor maintenance, haphazard layouts, and whimsical load connections. According to Braide et al. (2019), there is no load distribution networks that are being exposed to several distortions. According to NEPA report in 2015, the present structure of the distribution networks in Nigeria does not support quick fault detection, isolation of faulty components and quick restoration of service to the end-users. Hence at this junction, due to lack of efficiency, reliability and availability in the power sector, the Nigerian Electrically Supply Industry (NEST) was unbundled into eighteen companies comprising of six Generating Companies (GENCOs), one transmission Company (TRANSCO) and eleven Distribution Companies (DISCOs), According to Idoniboyeobu, (2021), the intention of this metamorphosis was to ensure improved system reliability. But his is very difficult to achieve because of the poor system maintainability long time. The issues of maintenance of electric power equipment is of paramount national interest (Braide et al., 2018; Braide, et al., 2020).

The electric power distribution substations are the most critical part of a power system because the power equipment in the distribution substation that connect to the consumers to the power grid. With reference to Braide & Kenneth (2018), reports, a substation reliability assessment evaluates the effect of these aspects on the service continuity of the main power system connected to the substation.

With the increasing demand of electricity supply the distribution companies have to achieve an acceptable level of reliability quality flexibility and safety at an economic price in order to ensure improved electricity delivery and maintain consumers' loyalty and expectations.

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 (Braide et al., 2018).In effect, the purpose of establishing generating stations and the hurdles overcome to transmit 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 highly important. The distribution systems account for about 90 percentage of all customer reliability problems, improving distribution reliability which is key to improving customer reliability (Oke et al., 2019).

## 2. Materials And Methods

### 2.1 Materials

Single line diagram character: using power supply system Nzimiro are modeled in Electrical Transient Analyzer Tool (Etap 12.6)**.**

The distribution injection substation in this study case are fed from the Port Harcourt town 132/33kV injection transmission substation located at Nzimiro Street by Port Harcourt – Aba Express Road, which takes it power study from Afam power station located at Oyibo Local Government Area.

The outgoing feeder Nzimiro transmission substation from 132/33KV to the state government secretariat supplies at 2×15mVA 33/11KV injection substation which is commonly referred to as secretariat supply station. Station-road, Amadi-north Flour mill and Borikiri 11KV outgoing feeders.

### 2.2 Method Used

The method adopted the reliability index technique in conjunction with fault-tree analysis which is based on logical evaluation of power system components on the expected failure rate (y), the average outage time (r), annual outages time/unavailability (U). The implementation of the fault-tree-analysis (FTA) is geared towards network modeling of the distribution system with the view to consider system configuration connected together either in series, parallel meshed or a combination of the system components.

The structure relationship between a system and its component are strongly considered for the study under investigation.

The following steps were taken in analyzing the method used was considered.

The system reliability indices for the distribution system under study were identified
The contributions to each of the system reliability indices under study were computed.

$$SAIFI^C = \frac{\lambda_i I_i}{n_i} \qquad (1)$$

$$SAIDI^C = \frac{\lambda_i\left(\sum_{I=1}^{I_i} d_{ij}\right)}{n_i} = \frac{\lambda_i D_i}{n_i} \qquad (2)$$

$$CAIDI^C = \lambda\left(\frac{D_i}{I_i}\right) \qquad (3)$$

Where
$SAIFI^C$ = Contribution to SAIFI from the feeders
$SAIDI^C$ = Contribution to SAIDI from the feeders
$CAIDI^C$ = Contribution to CAIDI from the feeders
$\lambda_i$ = Failure rates of feeders i.
$li =$ Number of customers experiencing sustained interruptions, due to aa failure of feeder i
$d_{ij}$ =Interruption duration for customer j due to a failure of feeder i.
$n_i$ = Total number of customers on a feeder i.
$D_i$ = Sum of customers interruption duration due to a failure of feeder i.

i. Compute Mean sum of reliability indices.
ii. Plot a graph of Mean sum of reliability indices Versus Distribution feeder
iii. Obtain a generalized model using curve fitting approach

### 2.3 Fault Tree and Reliability Block Diagram

The reliability block diagram is a success-oriented network describing the function of the system. It shows the logical connections of functioning components needed to fulfil a specified system function. The fault tree can be converted to a reliability block diagram, and vice versa. In the fault tree, a basic event is the occurrence of a particular component's failure mode, while in reliability block diagram, a block means the particular component is functioning or the specified, failure mode doesn't happen.

The figure shows a series structure is equivalent to a fault tree where all the basic events are connected through OR-gate. The TOP event occurs if either component fails. In the same way, a parallel structure may represent as a fault tree where the basic events are connected through an AND-gate. The TOP event occurs if the entire component fails.

## 2.4 Probability for Analytical Consideration

System behaviour is stochastic in nature and therefore, it is logical to expect that the assessment of a system's performance should be determined using methods based on probabilistic techniques. Probabilistic evaluation of a power system recognizes not only the severity of a state or event, and its impact on system behaviour and operation, but also the likelihood or probability of the state or event occurring.

Probability theory is basic to fault tree analysis because it provides an analytical treatment of events, and events are the fundamental components of fault tree.

Let *n* denote the number of different basic events in the fault tree, the fault tree is said to be of order *n*. the *n* basic events are numbered, and the following state variables are introduced;

$$Y_i = \begin{cases} 1 & \textit{if basic event i occurs at time t} \\ 2 & \textit{Otherwise i = 1,2,...n} \end{cases} \quad (4)$$

Let $Y(n) = [\, Y_1(t), Y_2(t), \dots . Y_n(t)]$ (5)

Denote the state vector for structure at time t. the purpose of a quantitative analysis of a fault tree is to determine the probability of the TOP event (system failure). The state of the TOP event at time t can be described by the binary variables $\Psi Y(t)$.

$$\Psi Y_i(t) = \begin{cases} 1 & if\ TOP\ event\ occurs\ at\ time\ t \\ 0 & otherwise \end{cases} \quad (6)$$

From equation above, it can be assumed that the states of n basic events can determine the state of the TOP event. This function is called the structure function of a fault tree.

$$\Psi Y(t) = \Psi Y_1(t), Y_2(t), \dots . Yn\ (t) \quad (7)$$

Let $qi(t)$ denote the probability that basic event occurs at time t, for i = 1,2, …, n.

$$q_i(t) = \Pr(Y)_i(t) = 1 = EY_i(t) fori = 1,2, \dots, \mathrm{n} \quad (8)$$

If the basic event means that component in the system is a failed state for $i = 1,2 \dots \mathrm{n}$. letp $(i)$ denote the probability that component is in a functioning state at time t; q i (t) is called the unreliability of component *i* at time t.

$$\Pr(Y_i(t) = 1) = q_i(t) = 1 - \mathrm{P_i}(t) fori = 1,2, \dots, \mathrm{n} \quad (9)$$

Let $Q_0(t)$ denote the probability that the TOP event (system failure) occurs at time t.

$$Q_0(t) = \Pr\big(\Psi\big(Y(t)\big) = 1\big) = E(\Psi\big(Y(t)\big)) \quad (10)$$

A few applications of the above statements on Probability theorem to the Fault Tree Diagram are presented as;

**Fault Tree with a single AND-Gate Structure**

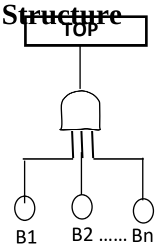


**Figure 3.2: Fault with single AND Gate**

In this fault tree, the TOP event occurs if and only if all the basic events B1, B2, …., Bn occur simultaneously. The strucuture function of this fault tree is given as;

$$\Psi Y(t) Y_1(t), Y_2(t) \dots . . Y_n(t) = \prod_{i=1}^{n} Y_i(t) \quad (11)$$

The basic events are assumed to be independent, then

$$Q_0 = E(\Psi(Y(t)) = EY_1(t), Y_2(t) \ldots . Y_n(t)$$
(12)

$$= E(Y_1(t)), E(Y_2(t)) \ldots . E(Y_n(t))$$

$$= q_1(t), q_2(t) \ldots . qY_n(t) = \prod_{i=1}^{n} q_i(t)$$
(13)

The unavailable of the TOP event, $Q\ 0(t)$, can also be determined by the algebraic operation. Let $B_i(t)$ denote that basic event $B_i$ occurs at time t; *i*=1, 2, …n.

$$Q_0 = \Pr(B_1\ (t) \cap B_2(t) \cap \ldots . \cap B_n(t)$$

$$= E(Y_1(t)), E(Y_2(t)) \ldots . E(Y_n(t))$$
(14)

$$= q_1(t), q_2(t) \ldots . q(t) = \prod_{i=1}^{n} q_i(t)$$
(15)

### Fault Tree with a Single OR-Gate Structure

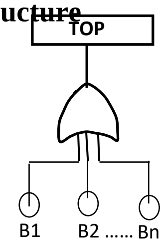


**Figure 3.3: Fault Tree with a single OR-Gate**

Consider the fault tree in Figure 3.1 and 3.2 respectively, the TOP event occurs if at least one of the basic events B2… Bn occurs. The structure function of this fault tree is

$$\Psi Y(t) = 1 - (1 - Y_1(t))(1 - Y_2(t) \ldots . . (1 - Y_n(t))$$

$$= 1 - \prod_{i-1}^{n}(1 - Y_i(t))$$
(16)

The basic events are assumed to be independent, then

$$Q_0(t) = E(\Psi(Y(t)) = 1 - E(1 - Y_i(t))$$

$$\prod_{i-1}^{n} = (1 - \prod_{i-1}^{n} \left(1 - E(Y_i(t))\right) = 1 - \prod_{i-1}^{n}(1 - q_i(t))$$
(17)

Let ( ) i B t denotes that the basic event occurs at time t and * ( ) i B t denotes that the basic event does not occur at time t. these above equations can be expressed in Boolean algebra.

$$\Pr(B_1 * (t)) = 1 - \Pr(B_1(t)) =$$

$$1 - q_1(t) \text{ for} i = 1,2, \ldots . n$$
(18)

and

$$Q_0(t) = \Pr(B_1(t) \cup \ldots . \cup B_n(t))$$

$$= 1 - \Pr({B^*}_1(t) \cap {B^*}_2(t) \cap \ldots . \cap B_n^*(t))$$
(19)

$$= 1 - \Pr({B^*}_1(t)) . \Pr({B^*}_2(t)) \ldots . . \Pr B_n^*(t))$$
(20)

$$= 1 - \prod_{i-1}^{n}(1 - q_1(t))$$
(21)

This chapter deals with the reliability assessment and unavailability evaluation of a distribution system using the 33/11 KV distribution substation of the case study.

The method of analysis adopted here was Fault Tree Analysis (FTA) approach. It is a deductive and an analytical approach that will involve qualitative and quantitative analysis of the distribution network.

This method is different from other methods used by other researchers on the tonic as shown in the literature review, Most of the researchers adopted manual calculations of the reliability metrics or indices to carry out the reliability assessment of a particular power component in the substation instead of the entire distribution. As a result, no specific root- cause of the system failure was uncovered by their methods. In the conclusion of their work,, only suggested causes of the problem were made.

However, in my work, the Fault Tree Analysis was applied to the entire distribution system and its component In order to concisely ascertain the system failure. In the process, the following were displayed.

(i) Line diagram of the distribution network, whether in series or parallel, of tlu:
(ii) substation under study.
(iii) Logical arrangement of the power equipment on the diagram.
(iv) Translation of the physical line diagram into the reliability block diagram (RBD) using the Boolean

symbols And-Gate and OR - Gate for the implementation of FTA in the qualitative analysis to determine the failure path in the system.

(v) Calculations of the reliability indices such as MTBF, MDT or MTTR, MTT'F and unavailability of all the major power components of the substation for the quantitative analysis in order to assess the reliability capacity of the system and determine which power component was responsible for the system failure or unavailability.

## 2.5 Implementation of Fault Tree

The implementation of FTA is often cantered on statistical distributions of the rate of component failure and time taken to restore component back to service. It's the method must used in evaluating reliability indices based on the expected Failure rate (y), the average outage time (r), and the expected annual outage time/unavailability (u) which means suitable to the analysis of a simple radial system. Distribution systems contain grids which are either radial or meshed.

The implementation of FTA in the analysis is all about the Network modeling of the distribution system, which is viewed as a network of components connected together either in series, parallel meshed or a combination of these. The structural relationships between a system and is components are considered in this technique. By carrying out the reliability analysis on each component that makes up the system, the FTA technique presents all the imminent failure modes and then pin-points their resulting affects on the system. The FTA method help determine at least those components within the system which failures result in an interruption of the* network services.

## 2.6 Display of FTA with Series System

A radial system of electrical distribution system consists of set of series components such as breakers, lines, switches, transformers and at the end "Customers" (Anthony, 2014). From reliability view point, all the components in series must be working together to ensure system success or the failure of either with lead to the entire system failure. This implies that a series system is a non- redundant system.

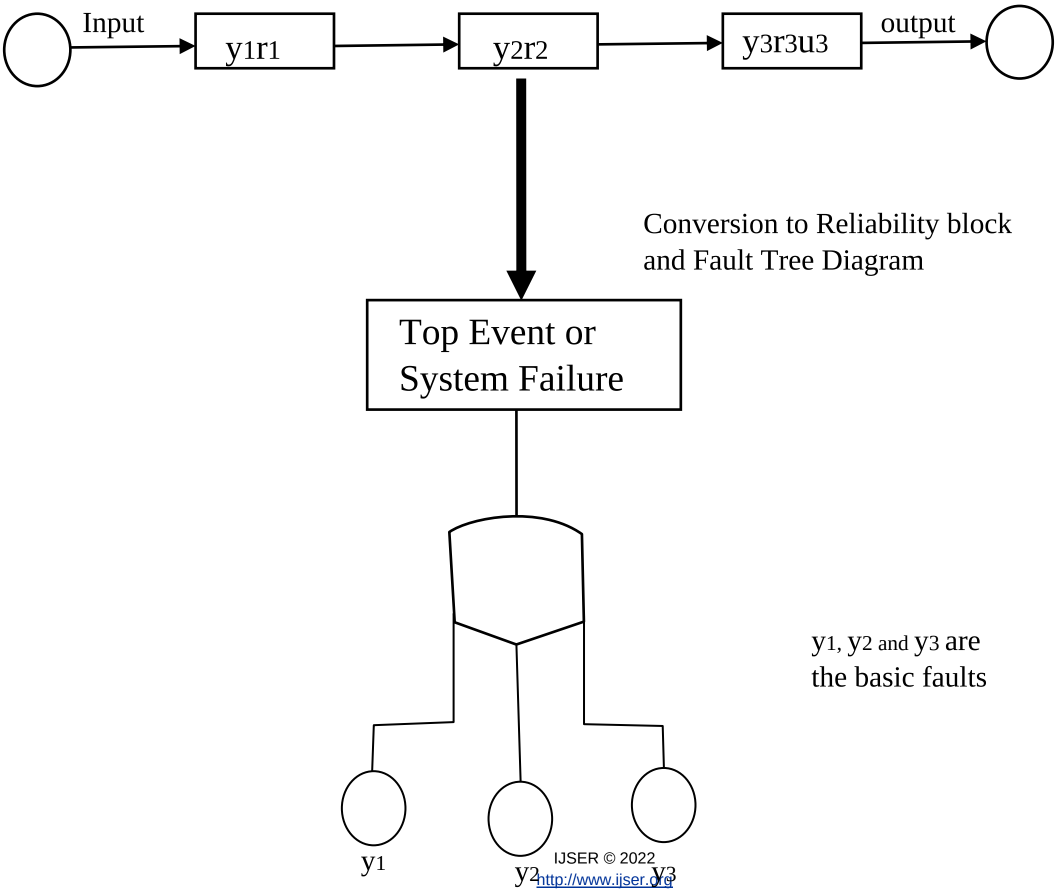


**Figure 3.4: Typical Diagram of a Series System**

As displayed in the diagram above, the series block diagram is being converted to the FT A diagram where the basic fault (y1, y2, y3) events were connected through the OR - GATE. This implies that the Top event (System failure) occurs if either of the components fails.

Mathematically, Dorji (2007) provided the formula used in the calculations involve in the series system with the given equations below.

Where Y = Expected failure rate
U = Annual outage time
R = Average outage time.

$$Ys = y1 + y2 + y3 = \sum yi \quad (22)$$

$$Rs = \frac{Us}{Ys} \quad (23)$$

2.7 Data Collection

The data sourced out from the substation was of the year 2015. The data was as a result of the records from the substation's logbook which contains the durations and frequency of outages. RSU's substation, just like every other distribution substation in Nigeria, does have a robust, network structure for quick fault detection and isolation and quick restoration of service in terms of breakdown. In the course of research work, it is records of power shortages or interruption? during the year 2015 that taken into consideration. Power interruptions due to load shedding were not taken into account because these were forced power shortages. In power system, load shedding is a scheduled outage. It is intentional and purposeful. It is not attributable to the distribution system failure or any power equipment failure in the substation. Through the reliability analysis of the distribution substation research work seeks to uncover the major component failure that causes power failure in the system in a situation where there's available power for distribution.

2.7.1 Reliability Parameters

Mean Time Between Failures (MTBF)

Mean time between failures is one of the basic ways of measuring the reliability of repairable components in a power system. MTBF is also the time that before a component, assembly, or system fouls, under the condition of a constant failure rate. It describes the total time the component is in operation. (Gonen, 2014).

Mean Down Time (MDT) Or Mean Time to Repair (MTTR)

It is the average time it takes to identify the location of a failure and to repair that failure thereby restoring the component into normal operation. It describes the average time for which a component is out of service due to fault before it is restored to normal operation.

Availability:

It is the measure of the duration for which the component is in operation at any time. It deals with the duration for which the system is fully operational for its specific operation.

2.7.2 Reliability Parameters in Fault Tree Analysis

Reliability expressions are used in fault tree analysis to determine the failure rate probability of the basic and overall top events. The expressions include:

$$\text{Failure rate, } \lambda = \frac{\text{Number of outages on component in given period}}{\text{Total time a component is in operation}}$$

$$R(t) = e-\lambda T \quad (24)$$

$$R(t) + Q(t) = 1 \quad (25)$$

$$Q(t) = l-R(t) = I-e-\lambda T \quad (26)$$

$$Q(r) = \lambda T = \frac{T}{MTBF} \quad (27)$$

$$MTBF = \frac{Total\ system\ operating\ hours}{Number\ of\ failure} \quad (28)$$

$$MTTR = \frac{Total\ duration\ of\ outages}{Frequency\ of\ outage} \quad (29)$$

Failure frequency, f $= \dfrac{1}{MTBF + MTTR}$ (30)

Availability, A $= \dfrac{MTBF}{MTBF + MTTR}$ (31)

Unavailability, U = $\dfrac{MTTR}{MTBF + MTTR} = \dfrac{F \times MTTR}{8760}$ (32)

Where, R (t) = Reliability
Q(t) = Failure probability
λ = Failure rate
T = Average down time per failure
MTBF = Mean Time Between failure
MTTR = Mean Time To Repair
8760 = Total Hour for a year

### 2.7.3 Qualitative Assessment of the substation Power equipment

The purpose of performing the qualitative fault tree analysis on the components is to determine the minimal cut sets that could basically lead to overall system failure or unavailability of power in the 33kv/11kv distribution substation. The analysis was performed on the substation network, to display the potential components' failures:

Let:
Fa = 33kv wining failure or line failure.
Fb = Battery bank failure
Fc = Auxiliary transformer failure
Fd = 33kv circuit breaker failure
Fe = current transformer failure
F∂ = Disc insulator failure
Fg = Power transformer T, Failure
Fn = Power transformer T2 failure
Fi = Station road 11KV
Fj = Amadi north 11KV
Fk = Flour Mail 11KV
F1 = Borikiri 11KV

The diagram above shows the logical arrangement of the power equipment in the substation, It was obtained from the substation control unit. This is a single feed structure of the distribution system of the substation.

Boolean algebra expression/fault tree representation:

$F_a$:transformer

$F_b$: Indoor breaker

$F_c$:outdoor breaker

$F_d$:transformer gang isolator

$F_e$:line isolator

$F_f$:potential transformer

$F_g$:current transformer

$F_h$:transformer control

$F_i$: DC rectifier

$F_j$:lightning arrestor

$F_k$:auxiliary transformer

$F_l$: HT pole

$F_m$:upriser

$F_n$:batteries

$F_o$:bushing

$F_p$: Relays

$F_q$: Armoured Cable

$F_r$:bus sectionalizer

$F_s$:silical gel

$F_t$:incoming tracker

$F_u$:raking pin

$F_v$:pin oil circuit breaker

$F_w$: Disc Insulator

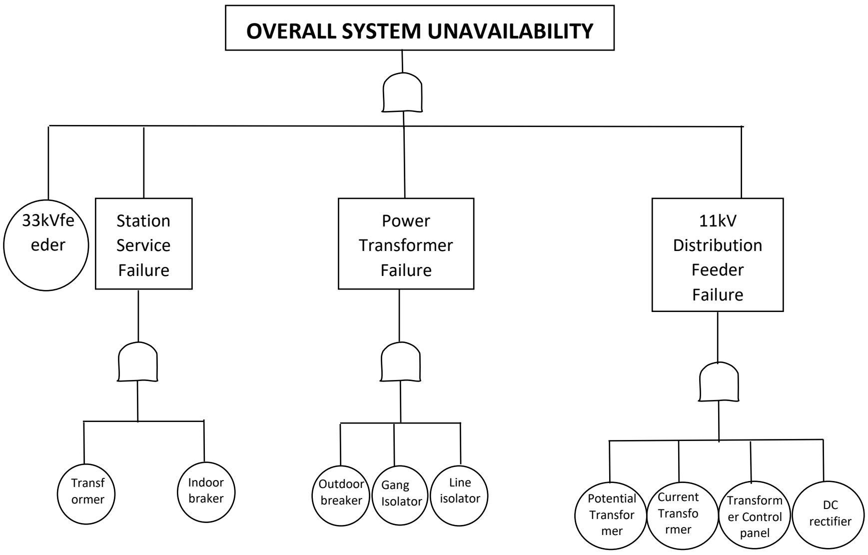
$F_x$: Pin Insulator

$F_y$: Incoming breaker

$F_z$:outgoing breaker

$F_{z_a}$:supply cable to auxiliary transformer

Case 1



Case 1: Failure output for station service

$F_a$ n $F_b$ (33)

Failure output for power transformer

$F_c$ n $F_d$ n $F_e$ (34)

Failure output for 11kv Distribution Feeder

$F_f$ n $F_g$ n $F_h$ n $F_i$ (35)

**Table 1: Multiplication operation on truth table (1)**

| **Input** | | **Output** | |
|---|---|---|---|
| A | B | X = A.B | Remarks: Availability/Unavailability |
| 0 | 0 | 0 | Unavailability |
| 0 | 1 | 0 | Unavailability |
| 0 | 1 | 0 | Unavailability |
| 1 | 0 | 0 | Unavailability |

**Table 2: Multiplication operation on truth table (2)**

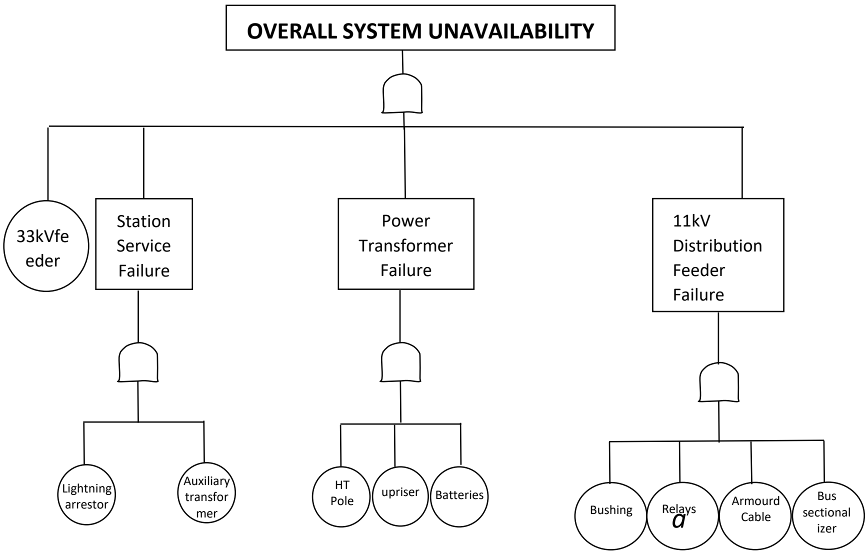
| **Input** | | | **Output** | |
|---|---|---|---|---|
| A | B | C | X = A.B.C | Remarks: Availability/Unavailability |
| 0 | 0 | 0 | 0 | Unavailability |
| 0 | 0 | 1 | 0 | Unavailability |
| 0 | 1 | 1 | 0 | Unavailability |

| | | | | |
|---|---|---|---|---|
| 1 | 1 | 1 | 1 | Availability |
| 1 | 0 | 1 | 0 | Unavailability |
| 1 | 0 | 0 | 0 | Unavailability |
| 1 | 1 | 0 | 0 | Unavailability |

**Table 3: Multiplication operation on truth table (3)**

| Input | | | | Output | |
|---|---|---|---|---|---|
| A | B | C | D | X = A.B.C.D | Remarks: Availability/Unavailability |
| 0 | 0 | 0 | 0 | 0 | Unavailability |
| 1 | 1 | 1 | 1 | 1 | Availability |
| 1 | 0 | 1 | 1 | 0 | Unavailability |
| 1 | 0 | 0 | 1 | 0 | Availability |
| 1 | 0 | 0 | 0 | 0 | Unavailability |
| 0 | 0 | 0 | 1 | 0 | Unavailability |
| 0 | 0 | 1 | 1 | 0 | Unavailability |
| 0 | 1 | 1 | 1 | 0 | Unavailability |

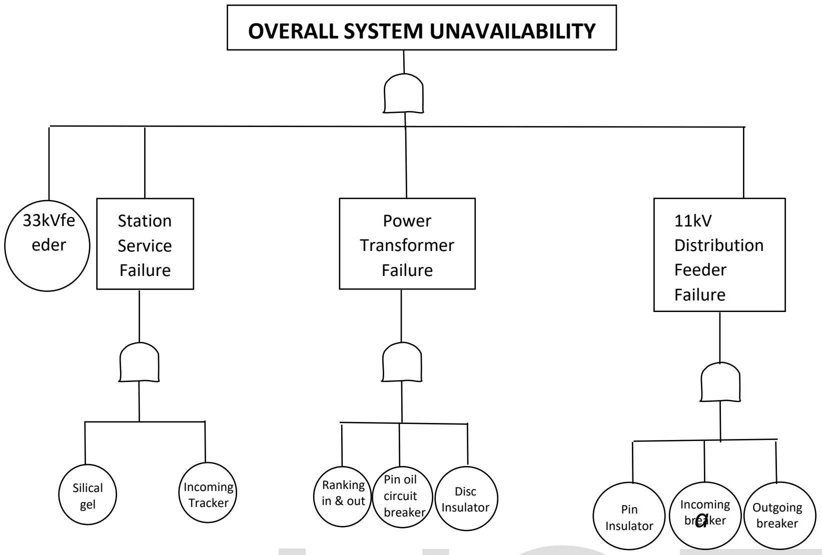
Case 2



Case 2: Failure output for station service
$F_j$n $F_k$ (3.36)
Failure output for power transformer
$F_l$n $F_m$ n $F_n$ (3.37)

Failure output for 11kv Distribution Feeder
$F_o$n $F_p$n $F_q$n $F_r$ (3.38)

## Case 3



Case 3: Failure output for station service

$F_s$n $F_t$ (39)

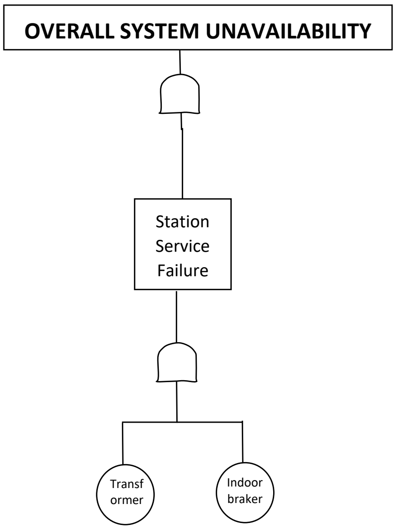
Failure output for power transformer

$F_u$n $F_v$ n $F_w$ (40)

Failure output for 11kv Distribution Feeder

$F_x$n $F_y$n $F_z$ (41)

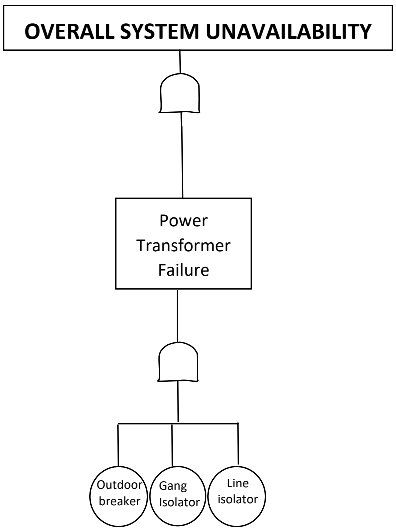
Case 4



Case 4: Failure output for station service

$F_b$n $F_b$ (42)

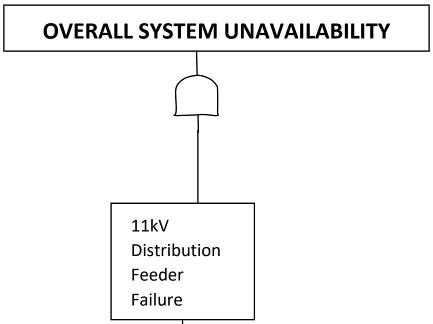
Case 5



Case 5 Failure output for power transformer

$F_c$n $F_d$ n $F_e$ (43)

Case 6



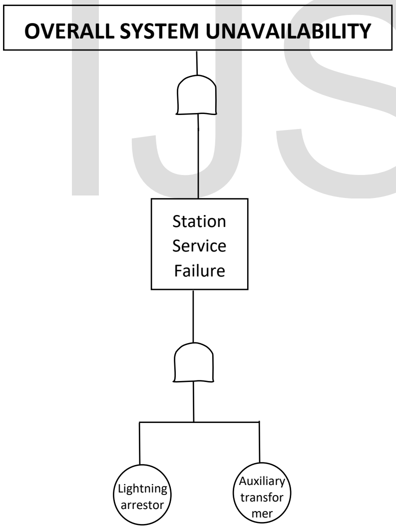
Case 6: Failure output for 11kv Distribution Feeder

$F_f$ n $F_g$ n $F_h$ n $F_i$ (3.44)

**Table 3.4: Multiplication operation on truth table (4)**

| **Input** | | | | **Output** | |
|---|---|---|---|---|---|
| A | B | C | D | X = A.B.C.D | Remarks: Availability/Unavailability |
| 0 | 0 | 1 | 0 | 0 | Unavailability |
| 1 | 0 | 0 | 0 | 0 | Unavailability |
| 1 | 1 | 1 | 1 | 1 | Availability of power supply |
| 1 | 0 | 1 | 1 | 0 | |

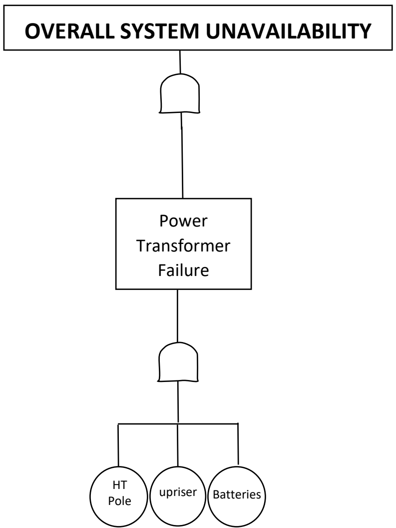
Case 7



Case 7: Failure output for station service

$F_j$ n $F_k$ (45)

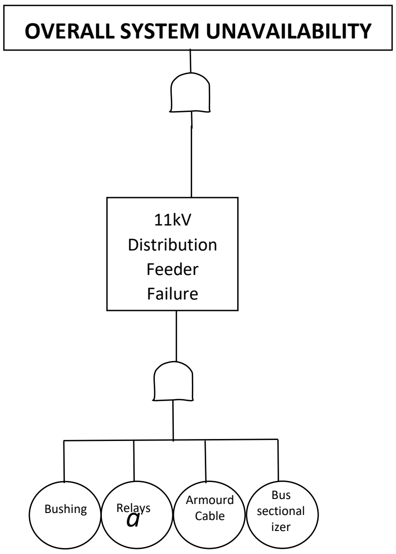
Case 8



Case 8: Failure output for power transformer

$F_l$ n $F_m$ n $F_n$ (46)

**Case9**



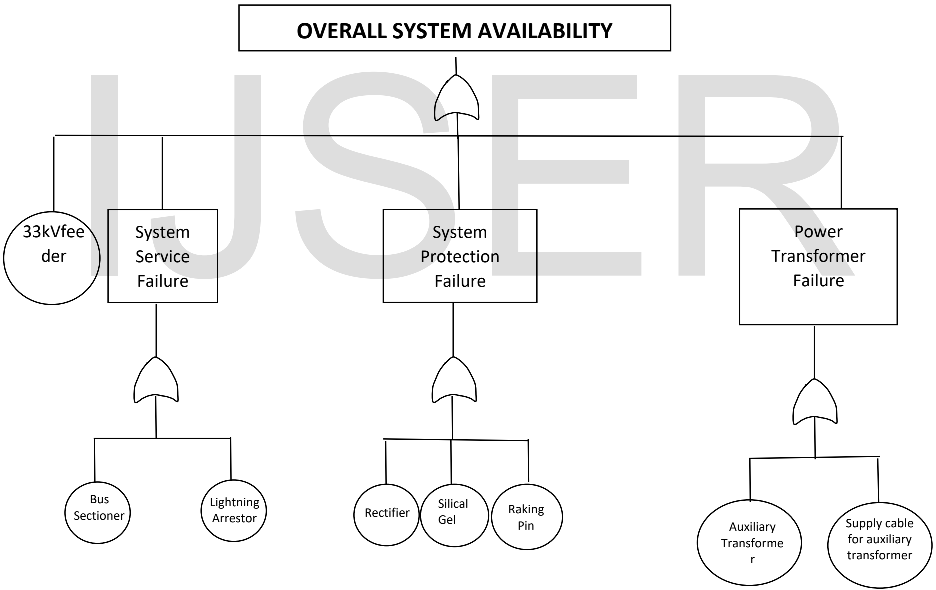
Failure output for 11kv Distribution Feeder

$F_o$ n $F_p$ n $F_q$ n $F_r$ (47)

**Table 5: Multiplication Operation on Truth Table (5)**

| **Input** | | | **Output** |
|---|---|---|---|
| A | B | C | X = A + B + C |
| 0 | 0 | 0 | 1 |
| 0 | 1 | 1 | 1 |
| 0 | 0 | 1 | 1 |
| 1 | 0 | 0 | 1 |
| 0 | 0 | 1 | 1 |
| 1 | 1 | 0 | 1 |
| 1 | 0 | 1 | 1 |

Case 10



Fault outputs on system service representation

$F_r$ u $F_j$ (48)

**Table 6: Addition operation on truth table**

| **Inputs** | | **Outputs** | **Remarks:** |
|---|---|---|---|
| A | B | X = A + B | Availability/Unavailability |
| 0 | 1 | 1 | Availability |
| 1 | 0 | 1 | Availability |
| 1 | 1 | 1 | Availability |

Fault outputs on system protection failure representation

$F_i$ u $F_s$ u $F_u$ (49)

**Table 7: Addition operation on truth table**

| **Inputs** | | | **Outputs** | **Remarks:** |
|---|---|---|---|---|
| A | B | C | X = A + B + C | Availability/Unavailability |
| 0 | 0 | 0 | 0 | Unavailability |
| 0 | 0 | 1 | 1 | Availability |
| 0 | 1 | 1 | 1 | Availability |

| | | | | |
|---|---|---|---|---|
| 1 | 1 | 1 | 1 | Availability |
| 1 | 0 | 1 | 1 | Availability |
| 1 | 1 | 0 | 1 | Availability |

Fault outputs on power transformer failure representation

$$F_k \text{u}\, F_{z_a} \quad (50)$$

**Table 8: Addition operation on truth table**

| Inputs | | Outputs | Remarks: |
|---|---|---|---|
| A | B | X = A + B | Availability/Unavailability |
| 0 | 0 | 0 | Unavailability |
| 1 | 1 | 1 | Availability |
| 0 | 1 | 1 | Availability |
| 1 | 0 | 1 | Availability |

### 3.7.4 Minimal cut set of the System Failure Path.

This shows the potential equipments or components failures that led to the overall system/failure causing breakdown or unavailability of power supply to customers. From the Fault Tree diagram of the 33kv/11kv substation, the following failures can be determined as:

Station service failure = ($F_n$ti$F_c$) (51)

System protection failure = ($F_d$U$F_e$U$F_r$) (52)

Power transformer failure = ($F_g$nFb) (53)

11kV distribution feeder failure = ($F_i$n$F_j$n$F_k$nFi) (54)

Overall system unavailability = FaU(FbnFc)U(FaUFeUFf)U(FgnFb)U(FinFjnFknFl) = $F_g$+($F_b$$F_c$) + ($F_d$+$F_c$+$F_r$)+($F_g$$F_h$)+($F_i$$F_j$$F_k$$F_i$) (55)

The minimal cut sets are $F_a$, ($F_b$$F_c$), $F_d$, $F_e$, $F_b$ ($F_g$$F_h$) and ($F_j$$F_j$$F_k$$F_i$). The list of the minimal cut sets can be seen in Table 3.9.

**Table 9: List of minimal cut sets and their corresponding power equipment.**

| S/No | Cut sets | Power Equipment |
|---|---|---|
| 1 | $F_a$ | 33kV wiring failure |
| 2 | $F_bF_c$ | Battery bank failure and Auxiliary transformer failure |
| 3 | $F_d$ | 33kV circuit breaker failure |
| 4 | $F_e$ | Current transformer failure |
| 5 | $F_r$ | D is insulator failure |
| 6 | $F_gF_b$ | Power transformer T1 failure and Power transformer T2 failure |
| 7 | $F_jF_jF_kF_i$ | 11kVdistribution feeders |

### 2.7.5 Quantitative Fault Tree Assessment of the substation Power Equipments.

The data received were analyzed based on the power equipment of the substation. Parameters such as durations of failure of each power equipment were extracted. Similarly, frequency of the failure of each power equipment were also extracted. All these data were extracted for a period of one year. It was a time when the substation system was redundant repeatedly from January 2016 to December 2016. The number of failure frequencies (F) and duration of failures (T) were also ext mean Time to Repair (MTBF), Mean Time to Repair (MTTR) and unavailability of power equipment were calculated too.

**Table 10: Power system equipment failures in State government Distribution injection station.**

| Power system equipment | Frequency (F) | Duration (Hrs) |
|---|---|---|
| 1 - 33kv line | 29 | 70 |
| 2 - Auxiliary Transformer | 22 | 45 |
| 3 - 110V DC. Battery Bank | 5 | 36 |
| 4 - 33kv circuit breaker | 2 | 2 |
| 5 - Current transformer | 1 | 1 |
| 6 - Disc Insulators | 10 | 12 |
| 7 - Power transformer | 11 | 40 |
| 8 - Power Transformer T2 | 3 | 12 |
| 9 - Station road 11KV | 86 | 264 |
| 10 - Amadi north 11KV | 40 | 84 |
| 11 - Flour Mail 11KV | 48 | 117 |
| 12 - Borikiri 11KV | 53 | 94 |
| Total | 310 | 777 |

## 2.8 Determination of the numerical values of the reliability parameters.

Here, mathematical calculations were done in order to determine of the reliability indices such as MTBF, MTTR, and unavailability for each component based on the frequency and duration of the failure (see appendix P).

**Table 11: Summary of the quantitative values of power equipment failures in government secretariat distribution injection station (33/11kV) for the year 2020**

| S/No | Power System equipment | Frequency (F) | Duration (Hrs) | MTBF (Hrs) | MTTR (Hrs) | Unavailability $10^{-4}$ |
|---|---|---|---|---|---|---|
| 1 | 33kV Line | 29 | 10 | 26.793 | 2.4137 | $7.990\times10^{-4}$ |
| 2 | Auxiliary Transta | 22 | 45 | 53.31818 | 51.37 | $51.37\times10^{-4}$ |
| 3 | 110 V DC Battery Bank | 5 | 36 | 155.4 | 7.2 | $41.095\times10^{-4}$ |
| 4 | 33 kV Circuit Breier | 2 | 2 | 388.5 | 1.0 | $2.283\times10^{-4}$ |
| 5 | CurrentTransfortner | 1 | 1 | 777 | 1.0 | $1.1415\times10^{-4}$ |
| 6 | Disc Insulators | 10 | 12 | 70.636 | 3.636 | $4.56647\times10^{-4}$ |
| 7 | Power TransibnnerTl | 11 | 40 | 259.66 | 3.666 | $12.5568\times10^{-4}$ |
| 8 | PowTran$fonnerT2 | 3 | 11 | 77.7 | 1.200 | $10.698\times10^{-4}$ |
| 9 | Station road 11KV | 86 | 264 | 9.34 | 3.06976 | $13.698\times10^{-4}$ |
| 10 | Amadi north 11KV | 40 | 84 | 19.425 | 2.100 | $95.89\times10^{-4}$ |
| 11 | Flour Mail 11KV | 48 | 117 | 16.1875 | 16.1875 | $133.5\times10^{-4}$ |
| 12 | Borikiri 11KV | 53 | 94 | 14.6605 | 1.7735 | $10730\times10^{-4}$ |

**Source:** Research desk

## 2.9 Calculation of Reliability Indices

The reliability indices for the sample system (load point, system and cost worth indices).

**Table 12: Historical Data of the Sample System**

| Load points | Failure frequency | Annual downtime (hrs) | Annual Uptime (hrs) | No. of Customer | Customer Types | Average Load (mw) |
|---|---|---|---|---|---|---|
| Station road 11KV | 791 | 3.890 | 4.413 | 2,120 | Residential | 3.9 |
| Amadi north 11KV | 440 | 4,530 | 4,230 | 1,308 | Res/Ind. | 4.2 |
| Flour Mail 11KV | 620 | 3,881 | 4,879 | 920 | Comm.. Res. | 3.4 |
| Borikiri 11KV | 890 | 5,475 | 3,285 | 2,770 | Residential | 4.3 |

**Load Point Indices**

**Case A: Station Road;**

Failure frequency, F =791

Total Annual Downtime, $\Sigma T_{dx}$= 4,413

Operating Time, T= 365×24hrs=8,760

Applying equation for load point failure rate

**Load Point Failure Rate,**

$$\lambda p = \frac{\Sigma F}{T} = \frac{791}{8,760} = 0.0902\, f\,/\,yr$$

**Annual outage duration**

$$\mu p = \frac{\Sigma Tdx}{T} = \frac{4,413}{8,760} = 0.504 hrs\,/\,yr$$

Average Outage Duration,

$$\gamma p = \frac{\mu p}{\lambda p} = \frac{0,.504}{0.0902} = 5.59 hrs$$

**Mean Time Before Failure,**

$$\text{MTBF} = \frac{T}{\Sigma F} = \frac{8,760}{791} = 11.07 hrs$$

**Mean Time To Repair,**

$$\text{MTTR} = \Sigma\frac{Tdx}{F} = \frac{4,413}{791} = 5.58 hrs$$

Applying the same equations and procedures the rest of the three load point of the samples system yields thus;

**Case B: Amadi North;**

$\lambda_p$ = 0.0502f/yr

$\mu_p$ = 0.517hrs/yr

$r_p$ = 10.30hrs

MTBF = 19.91hrs

MTTR = 10.29hrs

**Case C: Floor Mill;**

$\lambda_p$ = 0.0708f/yr

$\mu_p$ = 0.4430hrs/yr

$r_p$ = 6.28hrs

MTBF = 14.13hrs

MTTR = 10.29hrs

**Case B: Borokiri;**

$\lambda_p$ = 0.0934f/yr

$\mu_p$ = 0.511hrs/yr

$r_p$ = 5.47hrs

MTBF = 10.71hrs

MTTR = 5.47hrs

**Table 13: Load point indices of the study case under investigation system**

| **Load points** | **$\gamma_r$ (f/hr)** | **$r_t$ (hours)** | **$\mu_T$ (hr/yr)** |
|---|---|---|---|
| Station Rd – Lp1 | 0.0902 | 5.59 | 0.504 |
| Amadi north – Lp2 | 0.0502 | 10.30 | 0.517 |
| Flour Mill – Lp3 | 0.0708 | 6.28 | 0.4430 |
| Borikiri 11KV – Lp4 | 0.0934 | 5.47 | 0.511 |

**System Indices**

The system indices of the study case under investigation system are calculated

Applying these equations yields:

**System Average Interruption frequency Index**

$$SAIFI = \frac{\Sigma\lambda p.Np}{\Sigma} =$$

$$\frac{((0.0902 \times 2120) + (0.0502 \times 1{,}308) + (0.0708 \times 920) + (0.0934 \times 2{,}770))}{(2120 + 1308 + 920 + 2770)}$$

$$SAIFI == \frac{191.224 + 65.6616 + 65.136 + 258.718}{7118}$$

$$SAIFI == \frac{580.7396}{7118}$$

**SAIFI = 322.058F/cust.yr.**

**System Average Interruption Duration Index,**

$$SAIDI = \frac{\Sigma\mu p.Np}{\Sigma Np} =$$

$$\frac{((0.0504 \times 2120) + (0.517 \times 1308) + (0.4430 \times 920) + (0.511 \times 2770))}{(2120 + 1308 + 920 + 2770)}$$

$$SAIDI == \frac{1068.48 + 676.236 + 407.56 + 1415.47}{7118}$$

$$SAIDI == \frac{3567.746}{7118}$$

**SAIDI = 2152.47hrs/cust.yr.**

**Customer Average Interruption Index, CAIDI**

$$CAIDI = \frac{\Sigma\mu p.Np}{\Sigma} =$$

$$\frac{((0.0504 \times 2120) + (0.517 \times 1{,}308) + (0.4430 \times 920) + (0.511 \times 2{,}770))}{((0.0902 \times 2120) + (0.0502 \times 1308) + (0.0708 \times 920) + (0.0934 \times 2770))}$$

$$CAIDI == \frac{106848 + 676.236 + 407.56 + 1415.47}{191.224 + 65.66 + 65.136 + 258.7187}$$

$$CAIDI == \frac{3567.746}{580.738}$$

**CAIDI = 6.1434hrs/cust.Int.**

**Average Service Availability Index**

$$ASAI = \frac{\Sigma Np - 8760 - \Sigma\mu p.Np}{\Sigma Np.8{,}760}$$

$$ASAI =$$

$$\frac{(7118 \times 8760) - (0.504 \times 2120) + (0.517 \times 1308) + (0.4430 \times 920) + (0.511 \times 2770)}{7118 \times 8760}$$

$$ASAI = 62353680 - 1068.48 + 676.236 + 1415.4762353680 - (3160.186)$$

**ASAI = 62,350519.814**

**Table 14: System Indices for the Sample System**

| Index | Values | Units |
|---|---|---|
| SAIFI | 322.058 | Int./yr |
| SAIDI | 2152.47 | Hrs./yr |
| CAIDI | 6.1434 | Hrs./Cust-Int |
| ASAI | 62,350519.8 | % |

## 3 RESULTS AND DISCUSSION

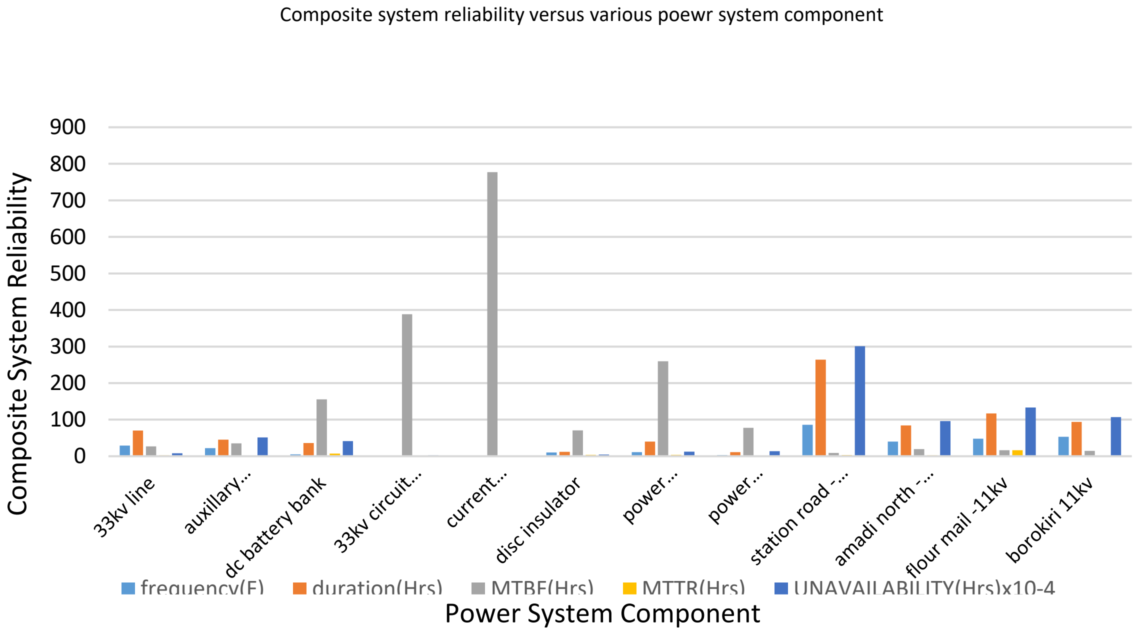


**Figure 4.1: Graph Representation of system component and composite system reliability**

Figure 4.1a shows the representation of components system reliability with respect to power system component under investigation. The graph shows the distribution of frequency (*f*) durations (D), mean time before failure (MTBF), meantime to repair (MTTR) in hours and unavailability (UN). This shows that the 33KV circuit breaker is more reliable because it has lets failure rate as compared to the Station road 11KV distribution feeder line which is more of frequency of occurrence followed by Borokiri 11KV feeder respectively which needed urgent attention for system reliability and perform.

**Table 4.1: Power System Components Versus System Reliability Parameters**

| Power system Equipment | Frequency(F) | Duration(Hrs) | MTBF(Hrs) | MTTR(Hrs) | Unavailability (Hrs)x10-4 |
|---|---|---|---|---|---|
| 33kv line | 29 | 70 | 26.793 | 2.4137 | 7.99 |
| Auxillary transformer | 22 | 45 | 35.31818 | 2.045 | 51.3 |
| DC battery bank | 5 | 36 | 155.4 | 7.2 | 41.09 |
| 33kv circuit breaker | 2 | 2 | 388.5 | 1 | 2.28 |
| Current transformer | 1 | 1 | 777 | 1 | 1.14 |
| Disc insulator | 10 | 12 | 70.636 | 3.636 | 4.566 |
| Power transformer T1 | 11 | 40 | 259.66 | 3.666 | 12.5568 |
| Power transformer T2 | 3 | 11 | 77.7 | 1.2 | 13.69 |
| Station road -11kv feeder | 86 | 264 | 9.034 | 3.06976 | 301 |
| Amadi north -11kv feeder | 40 | 84 | 19.425 | 2.1 | 95.89 |

| | | | | | |
|---|---|---|---|---|---|
| Flour mail -11kv feeder | 48 | 117 | 16.1875 | 16.1875 | 133 |
| Borokiri 11kv feeder | 53 | 94 | 14.6609 | 1.7735 | 107 |

The composite graphical representation of the reliability indices: MTBF, MTTR, Unavailability, frequencies of power system component are determined to access the activities of power system components. Particularly the occurrence of faults in station road feeder is more followed by Borokiri, flour mail and Amadi north. Evidently, the component 33kV feeder also experienced outages as presented in figure 4.1a.

**Table 4.2: Shows the distribution of power component**

| Power system Equipment | Frequency(F) | Duration(Hrs) | MTBF(Hrs) | MTTR(Hrs) | Unavailability (Hrs)x10-4 |
|---|---|---|---|---|---|
| 33kv line | 29 | 70 | 26.793 | 2.4137 | 7.99 |
| Auxillary transformer | 22 | 45 | 35.31818 | 2.045 | 51.3 |
| DC battery bank | 5 | 36 | 155.4 | 7.2 | 41.09 |
| 33kv circuit breaker | 2 | 2 | 388.5 | 1 | 2.28 |
| Current transformer | 1 | 1 | 777 | 1 | 1.14 |
| Disc insulator | 10 | 12 | 70.636 | 3.636 | 4.566 |
| Power transformer T1 | 11 | 40 | 259.66 | 3.666 | 12.5568 |
| Power transformer T2 | 3 | 11 | 77.7 | 1.2 | 13.69 |
| Station road -11kv | 86 | 264 | 9.034 | 3.06976 | 301 |
| Amadi north -11kv | 40 | 84 | 19.425 | 2.1 | 95.89 |
| Flour mail -11kv | 48 | 117 | 16.1875 | 16.1875 | 133 |
| Borokiri 11kv | 53 | 94 | 14.6609 | 1.7735 | 107 |

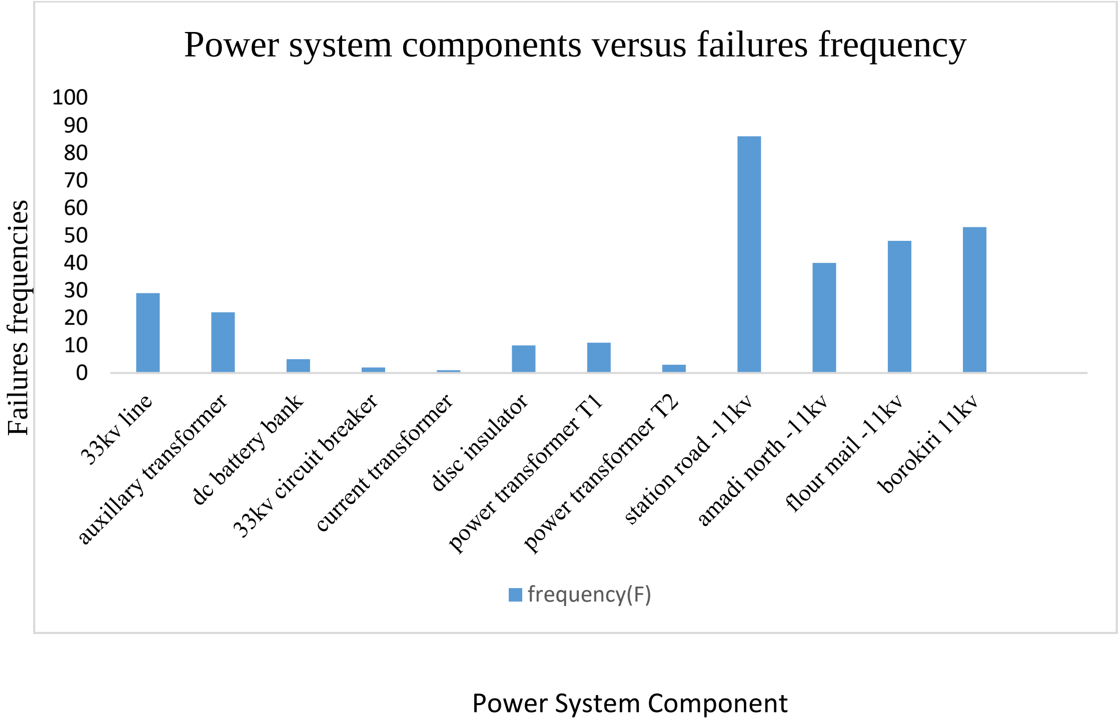


**Figure 4.2: Graphical representation showing system failures and power system components**

Figure 4.2 shows that distribution of failures frequency and system component under investigation. Twelve respective components are examined with respects to frequency of occurrence. It was observed that the current transformer components has the least failure of occurrences in terms of duration (hrs), followed by 33KV circuit breaker, DC circuit breaker respectively, this necessitate serious attension on the view to reduce failure rate for system reliably and performance. Figure 4.2 vividly shows the graphical representation power system frequencies of failures distribution in the year 2019/2020. Its captured 11kV station feeder had the highest number of occurrence of outages due to network failures, followed by Borokiri, flour-mail and Amadi-north feeder with qualitative values of 86, 53, 48 and 40.

**Table 4.3: Power System Components and Frequency**

| Power system Equipment | frequency(F) |
|---|---|
| 33kv line | 29 |
| Auxillary transformer | 22 |
| DC battery bank | 5 |
| 33kv circuit breaker | 2 |
| Current transformer | 1 |
| Disc insulator | 10 |
| Power transformer T1 | 11 |
| Power transformer T2 | 3 |
| Station road -11kv | 86 |
| Amadi north -11kv | 40 |
| Flour mail -11kv | 48 |
| Borokiri 11kv | 53 |

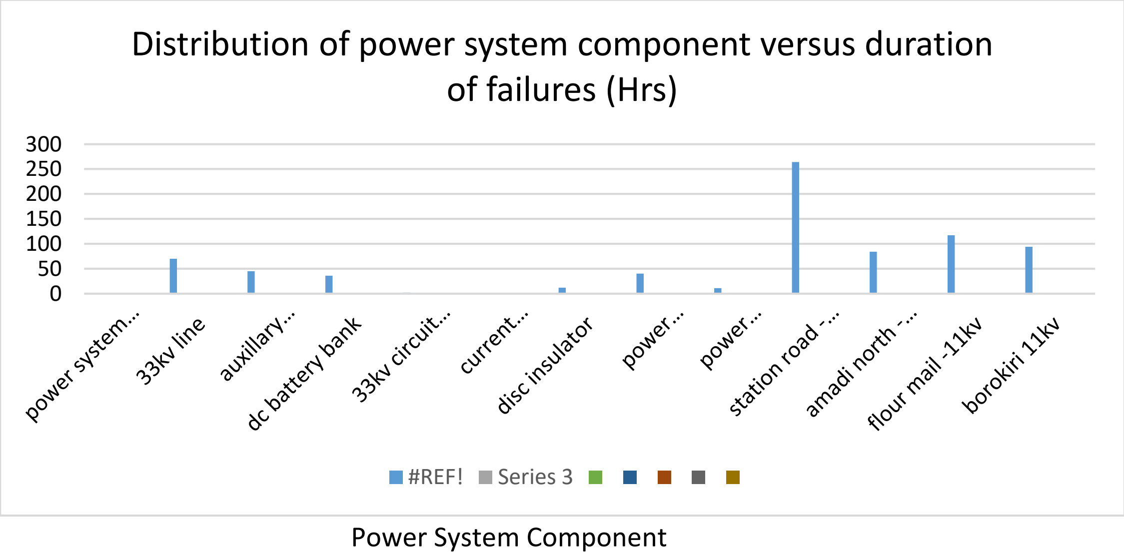


**Figure 4.3: Graphical representation of power components and failures of duration of system**

Figure 4.3 shows that distribution of system components and duration of system failures under investigation. Its show that the duration in hours of failure is least in current transformer and highest in station road 11KV distribution networks followed by flour mail-11KV distribution feeder, Borokiri 11KV distribution Amadi, north 11KV distribution feeder respectively. This means that there showed by system upgraded and improvement in order to enhance the existing reliability of the system under review.

**Table 4.4: Power System Components and Duration (hrs)**

| Power system equipment | Duration(Hrs) |
|---|---|
| 33kv line | 70 |
| Auxillary transformer | 45 |
| DC battery bank | 36 |
| 33kv circuit breaker | 2 |
| Current transformer | 1 |
| Disc insulator | 12 |
| Power transformer T1 | 40 |
| Power transformer T2 | 11 |
| Station road -11kv | 264 |
| Amadi north -11kv | 84 |
| Flour mail -11kv | 117 |
| Borokiri 11kv | 94 |

**Table 4.5: Power System Equipment Versus MTBF (Hrs)**

| **Power System Equipment** | **MTBF(Hrs)** |
|---|---|
| 33kv line | 26.793 |
| Auxillary transformer | 35.31818 |
| DC battery bank | 155.4 |
| 33kv circuit breaker | 388.5 |
| Current transformer | 777 |
| Disc insulator | 70.636 |
| Power transformer T1 | 259.66 |
| Power transformer T2 | 77.7 |
| Station road -11kv | 9.034 |
| Amadi north -11kv | 19.425 |
| Flour mail -11kv | 16.1875 |
| Borokiri 11kv | 14.6609 |

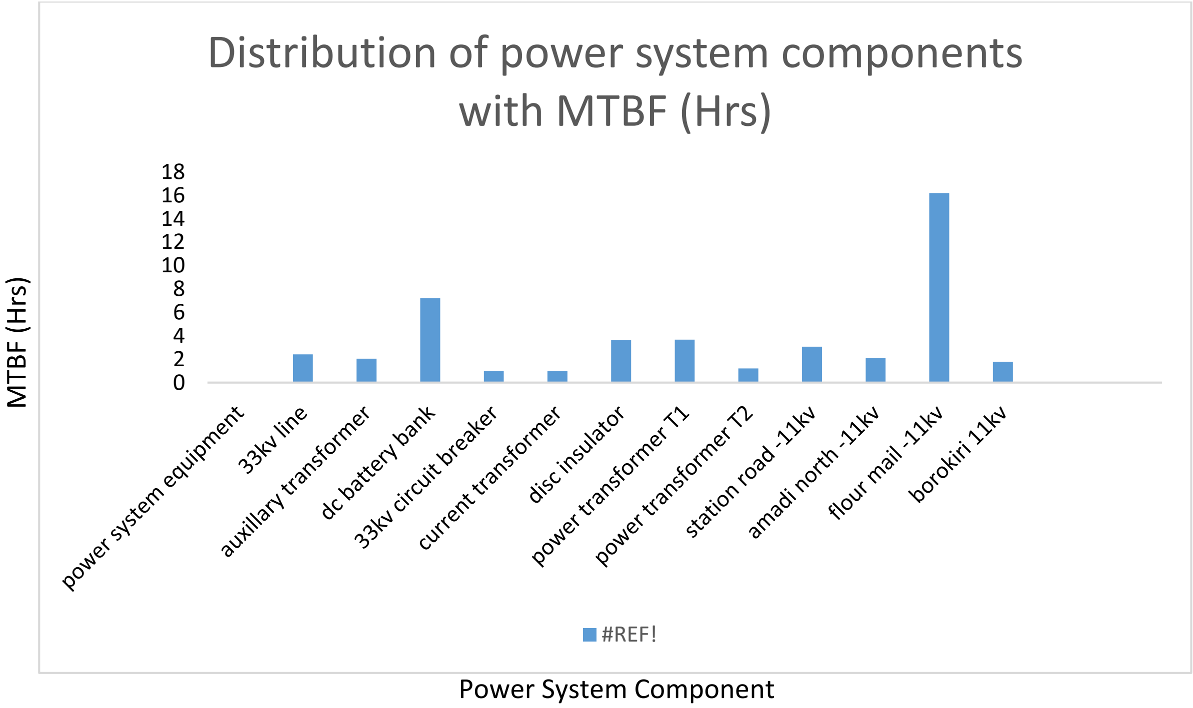


**Figure 4.4: Graphical distribution of system components with mean to repair (MTTR)**

Figure 4.4 shows the graphical representation of the distribution of power system components with mean time between failure, MTBF (hrs). The results show that the current transformer, power transformer-1, Disc insulator indicates meantime to failure before breakdown or go out of the unreliability that may leads to the total system outages/breakout. The distribution of system components while DC battery bank and, 33kV circuit breaker had the highest means to repair within the period review within the set replacement in order to improve power quality. That is the component has not been repaired or fixed for a long period of hours (1hour).

**Table 4.6: Power System Equipment Versus MTTR (Hrs)**

| **Power system equipment** | **MTTR(Hrs)** |
|---|---|
| 33kv line | 2.4137 |
| Auxillary transformer | 2.045 |
| DC battery bank | 7.2 |
| 33kv circuit breaker | 1 |
| Current transformer | 1 |
| Disc insulator | 3.636 |
| Power transformer T1 | 3.666 |
| Power transformer T2 | 1.2 |
| Station road -11kv | 3.06976 |
| Amadi north -11kv | 2.1 |
| Flour mail -11kv | 16.1875 |
| Borokiri 11kv | 1.7735 |

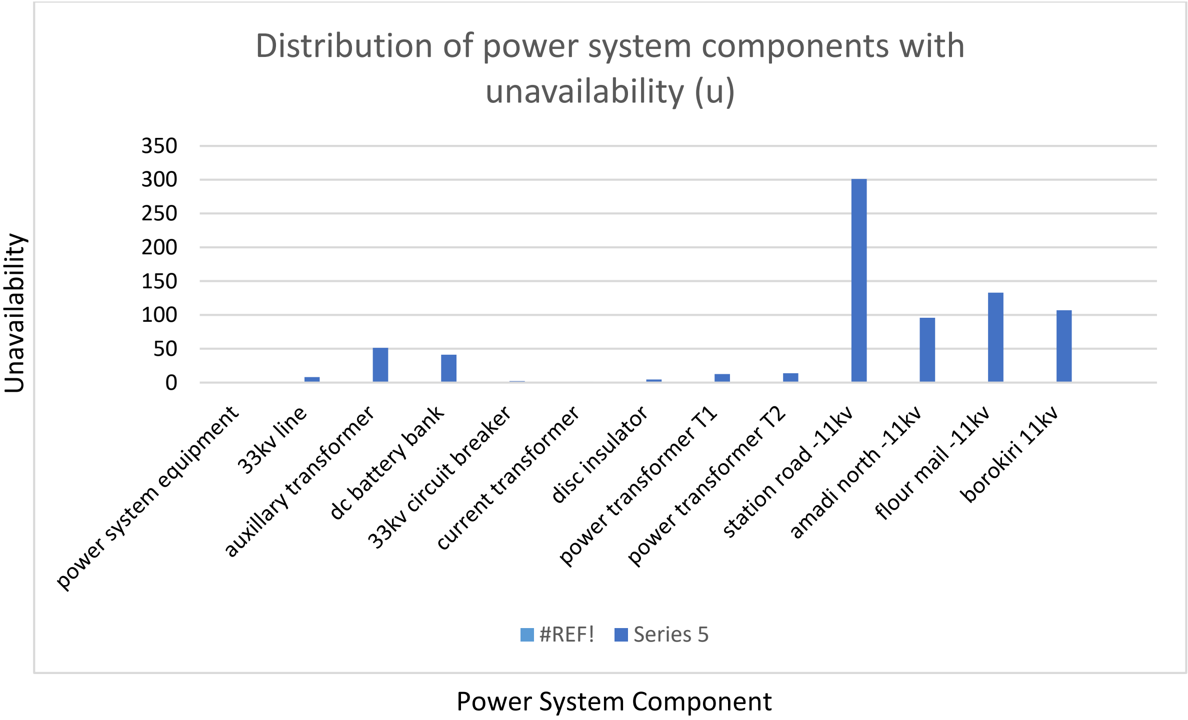


**Figure 4.5: Distribution of graphical showing the system components with unavailability (U)**

Figure 4.5 shows the graphical distribution of power system components with unavailability. The results shows that failures of some of the system components (current transformers and disc insulator etc.) results into unavailability this will lends to making the system to express power outage/breakout e distribution systems under investigation. Evidently, the current transform had the least probability of system unavailability; this has led to the system reliability failure.

that can affect the economic activities in the study zone. It shows the distribution of power system component. The component station road feeder had the highest probability of unavailability among other power equipment used in th

**Table 4.7: Power System Equipment Versus unavailability (Hrs)**

| **Power system equipment** | **Unavailability (Hrs)x10-4** |
|---|---|
| 33kv line | 7.99 |
| Auxillary transformer | 51.3 |
| DC battery bank | 41.09 |
| 33kv circuit breaker | 2.28 |
| Current transformer | 1.14 |
| Disc insulator | 4.566 |
| Power transformer T1 | 12.5568 |
| Power transformer T2 | 13.69 |
| Station road -11kv | 301 |
| Amadi north -11kv | 95.89 |
| Flour mail -11kv | 133 |
| Borokiri 11kv | 107 |

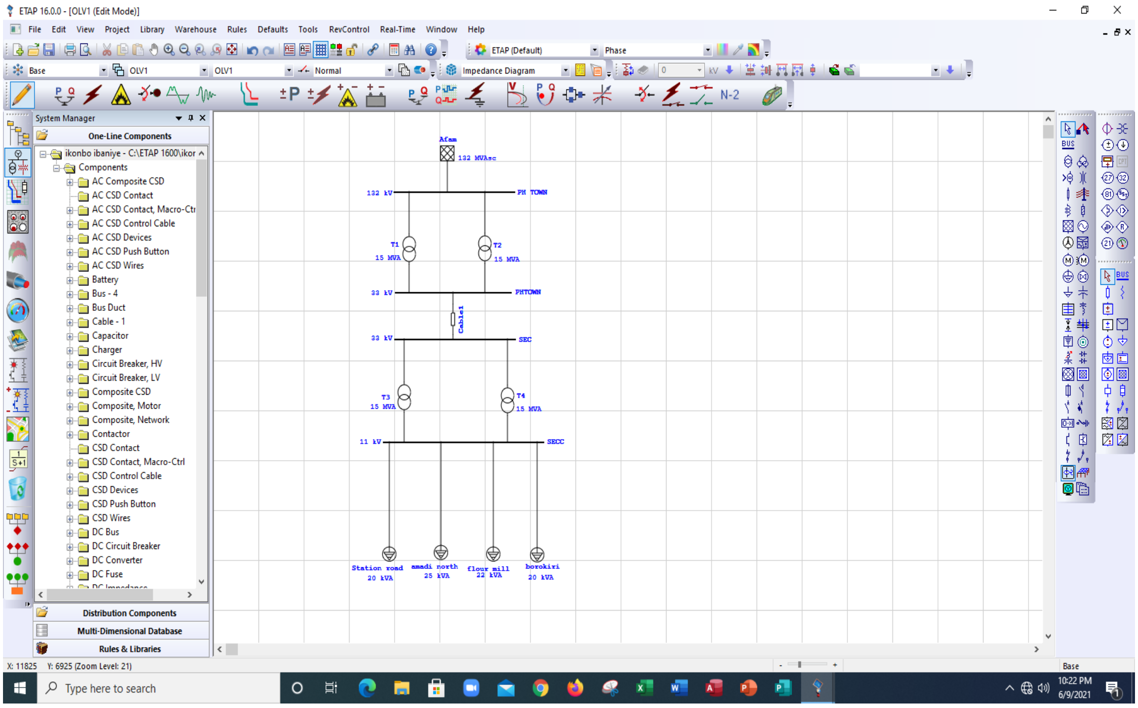


Figure 4.6: Existing network understudy load flow (without simulation)

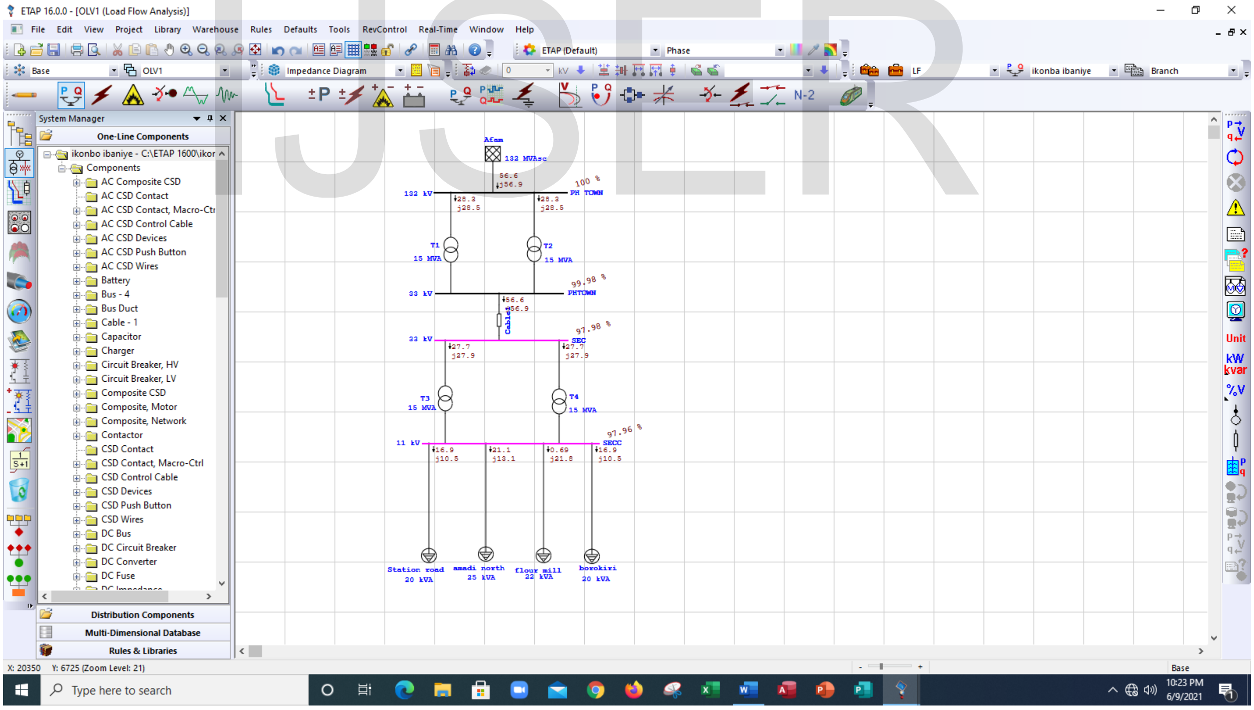


Figure 4.7: Existing network understudy with simulation and violations of buses load flow study

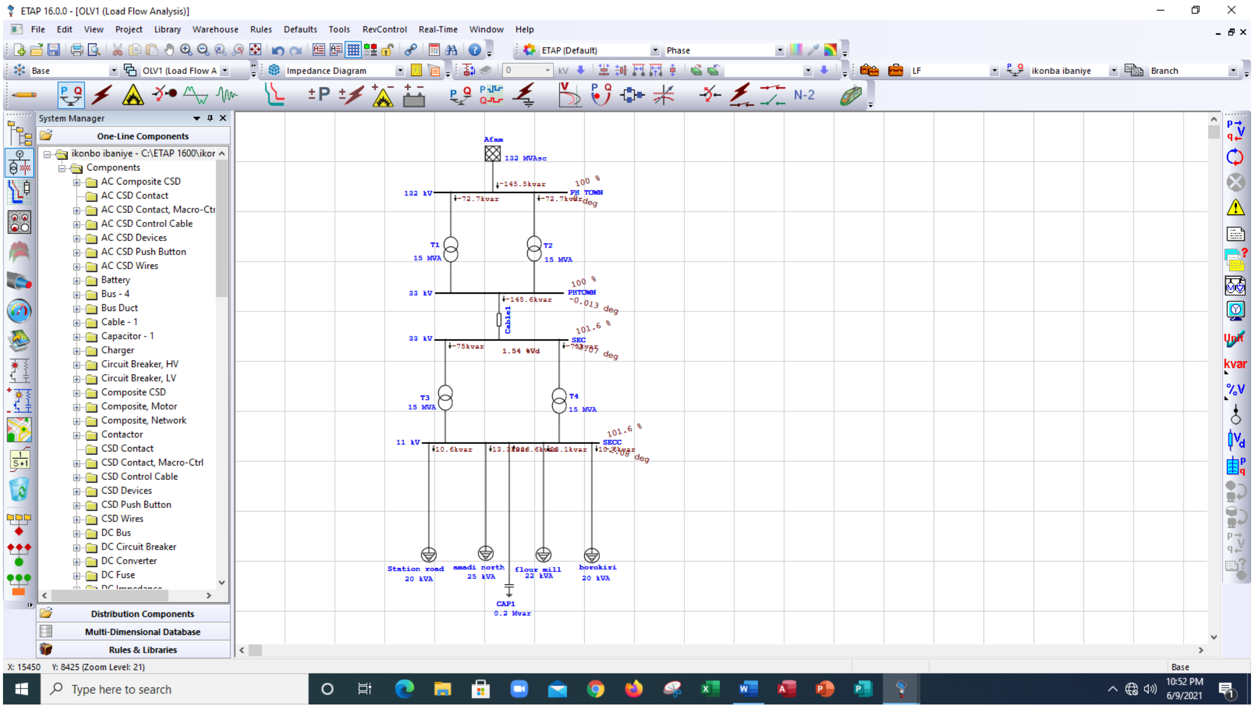


Figure 4.8: Existing network compensation with capacitor bank (0.2mVar) load flow

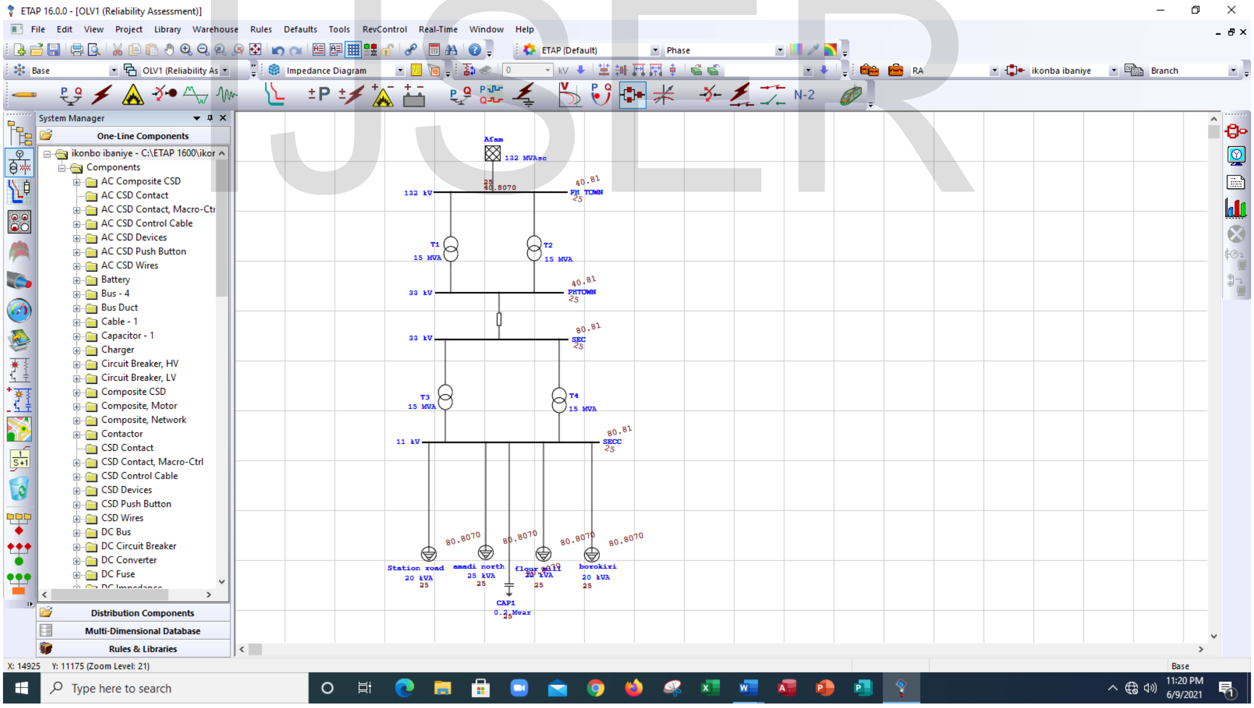


Figure 4.9: Reliability index assessment for system component.

## 4. CONCLUSION AND RECOMMENDATION

### 4.1 Conclusion

The operation and planning of the distribution system consists of the assessment of the customers power supply reliability which is an important characteristics of the system under investigation. In this study, reliability analysis of state – secretariat -11kV feeder, floor mill -11kV feeder, Borokiri -11kV feeder, and Amadi-north -11kV feeder electricity supply system was carried out on the view to identify the existing outages issues recorded and probably provide reliablity analysis indices of the power system components in order to enhance and promote reliable power quality.

The performance – indices was computed with respect to mean time between failure (MTBF), meantime to repair (MTTR), availability (A), unavailability (UA) which presented a more suitable and computational results that can be put on records as a follow-up for subsquent analysis in the study case that is it will be a good working and referees guide for power systems engineers and planner. This research actually utilize the reliability – indices and fault –tree analysis technique for the reliability assessment of 33/11kV distribution station with a clear representation of single line diagram (SLD) of the study taking supply from Afam – power generation station via zone – 4 (transmission substation) Nzimiro.

the fault –tree engagement showed the logical arrangement of the power equipment and their contribution towards overall system unavailability. The fault tree technique considered a qualitative minimal cut sets that easily lead to the overlal system unavailability. therfore power system contribution majorly to system unavailability should be upgraded to obtain better reliability of the system.

## 4.3 Recommendations

Following to the findings and analysis of this researcc work these recommendation are considered:

(i) The reliability-indices parameters failure-rate average outages duration, MTBF, MTTR etc are regularly checked and monitored for determining the state of the system components under investigation.

(ii) prompt response of experience personnel team for immediate fault recitification as soon as possible as to reduce interruption duration.

(iii) Expansion and upgrade of the existing power system need to be given strong attension.

(iv) Provision of PV installation systems as a form of back-up power supply are recommended strongly to avoid economic activities and administrative work in the study area due to interruption of efficient power supply.

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