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Research Article

Reliability Study of Electrical Distribution Network in Kampala East

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Abstract

This research focuses on the reliability study of the electrical distribution network in Kampala East, which is connected to Lugogo, Nakawa, Kireka and Ntinda substations. The network is unable to supply its customers with reliable power at all times. Methods used in this research involve data identification, collection, cleaning, analyzing and interpretation. Also conducted are determination of reliability indices, identification of causes of supply interruptions and improvement of reliability. Depending on the reliability study outcome, the electrical distribution network in Kampala East has customer hours lost (System Average Interruption Duration Index) of 8.34 per month per customer, number of outages per month per customer (System Average Interruption Frequency Index) is 5.65 hours, Energy not served to customers of 2.14 GWh per month and Faults resolution time (Customer Average Interruption Duration Index) of 1.58 hours. The major cause of interruptions are system faults and emergency shutdowns. In this study, Reconfiguring network through use of appropriate combinations of opening of sectionalizing (normally Closed) switches and closing of tie-line (normally- Open) switches on feeders, the reliability is improved to 4.18 customers hours lost per month per customer and the number of outages per month per customer is 5.35, the energy not served of 0.18 GWh and faults resolution time of 0.84 Hours. This gives percentage improvements of 49.88%, 5.31%, 54.2%, and 88.61% in SAIDI, SAIFI, ENS and CAIDI respectively. The current level of reliability of electrical distribution network in Kampala East exceeds the target set by the regulator for 2022.

Nomenclature and units

GWh	Gigawatt hour
kV	Kilovolt
A	Ampere
GW	Gigawatts
kW	Kilowatts
kWh	Kilowatt hour

1.0 Introduction

The electrical grid is a network interconnected for delivery of electricity to consumers from producers. Electrical grids are composed of varied sizes spanning whole continents or nations. A power grid system is divided into three separate components as the power generation, responsible for production of electrical power from various resources. The power transmission, a component that enables safe delivery of electrical power from generation centers to the distribution locations. The power distribution; this component is responsible for channeling of power from the transmission Substations to the distribution substations and finally availing this power to the final consumers at a suitable voltage (Ali A. Chowddhury, 2009), (Alhelou et al., 2019).

Power generation has been standardized at 11kV, 25kV up to 33kV. Transmission voltages of 66kV, 132kV, 220kV, 400kV, 735kV, 800kV up to 1000kV are being utilized all over the world. But the range 66kV to 132kV is referred to as sub-transmission voltages, with 220kV and above being categorized as primary transmission voltages. Medium voltages of 33kV and 11kV, Lower voltages of 415V and 240V are classified as Electrical distribution network. In operation of a power system, a generation voltage like 11kV for instance is stepped up to 220kV /400kV for primary transmission over long distances to the load centers. At the load centers, 220kV/400kV is stepped down to 132kV or 66kV for sub-transmission. Then the 132kV/66kV is stepped down for 33kV/11kV for distribution purposes and actual consumption by customers (Hussen & Ibrahim, 2020).

Furthermore, typical power system will be subjected to various interruptions ranging from planned maintenance; emergency shutdowns, and system faults, reliability of power supply becomes an issue of great concern. Preferably, the reliability of an electrical power system from the lookout of users/consumers is the non-interrupted supply of electricity coming from the generating plants, the transmission system and the distribution network. In genuineness, the key pointers of the reliability of electrical power for customers are the duration and frequency of disruptions at their point of use (Ali A. Chowddhury, 2009).

Literatures show that over 80% of interruptions to customers are attributed to loopholes in the Electrical distribution network. The Electrical distribution section is the feeblest link amongst the supply source of supply of electrical power to the load points of consumers. Today, in various electrical power companies, adequate levels of continuity of service is evaluated through comparisons of real interruption occurrences and interval performance guides with the desired targets (Ali A. Chowddhury, 2009). So, this study singles out the electrical distribution network as far as reliability is concerned.

A historic calculation method to estimation of reliability of networks of distributing electrical power is generally applied. Historical calculation comprises of the gathering and examination of the outage of the distribution and user's interruption data. It is vital for power utilities to quantify the actual reliability performance points and describe indicators of performance in evaluating the elementary purpose to provide a profitable and dependable supply of electrical power to every user. Historic calculation usually is designated as computing the previous performance of a power system by constantly sorting the duration, frequency, and system causes of component failures and interruptions to customers (Ali A. Chowddhury, 2009).

Umeme Limited in Uganda distributes electricity as the main company. The company operates the distribution grid on a period of 20-years as a concession which started on first, in the month of March, in the year 2005, from the Uganda government. Umeme has grappled over the years with the issue of providing adequate reliability of power supply to its customers (Umeme, n.d.). It is therefore against such a back ground that this research compliance report of Reliability study of Electrical Distribution Network in Kampala East comes into the spotlight to study further on this subject and try to close the prevalent gaps.

Therefore, in this paper, reliability indices of Kampala East electrical distribution network are determined. Causes of interruptions in the network are analyzed and the reliability of the area is improved through a method of network reconfiguration by placement of sectionalizing (normally closed) and tie-line (normally open) switches on feeder/lines.

2.0 Materials and Methods

In this section, the materials and methods for this research are presented.

Figure 1 below summarizes the methods used for this research study.

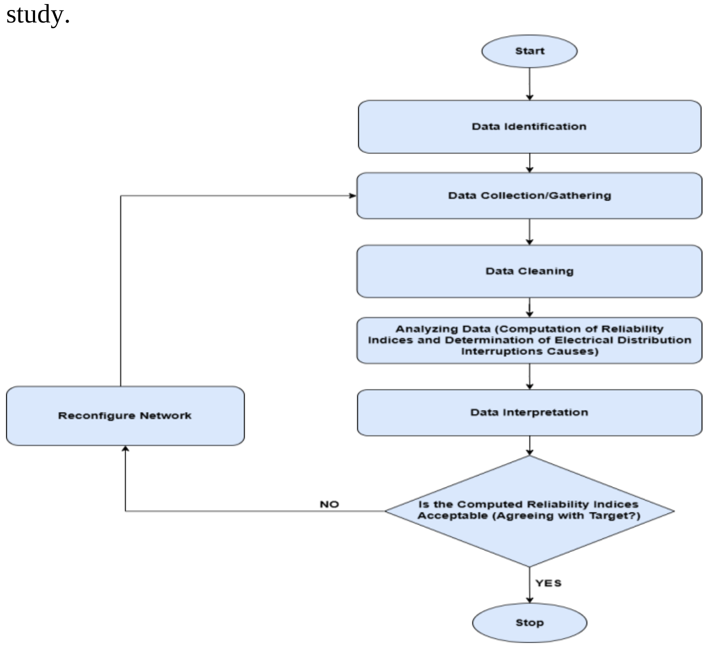

Figure 1: The methodology of the research study

2.1 Current Level of Reliability of the Electrical Distribution Network in Kampala East

The following steps were undertaken, Identification, Collection, Cleaning, Analysis and Interpretation of Data.

2.1.1 Identification of the Type of the Data collected.

The type of data identified and collected included: Names of Distribution Substations, Substation Power Transformers and their ratings, Distribution Feeder Names, Distribution Voltage Levels (11kV or 33kV), Load in Amps, Outage Categories (Planned Shutdowns, Faults, Emergency Shutdowns and Network Constraints), Planned Maintenance Detailed Work Description, Fault Causes of service interruptions to customers, Momentary Fault Interruptions, Sustained Fault Interruptions, Power System faults, Location of Fault, Interruptions due to Planned Shutdowns, Emergency Shutdowns, and Network Constraints, Partial Outage details, Protection Relay Faults Information (Over- currents, Earth Faults, Sensitive Earth Faults (SEF) Open Circuits etc.), For Distance Relays, the distance of fault, Interruption Times, Restoration Times, Interruptions Durations, Interruption Frequency, and Network Re-configurations for network optimization information.

2.1.2 Data Collection:

This was achieved through the following means: Supervisory Control and Data Acquisition (SCADA), Discussions with field technical personnel, Site visits to substations, feeder service areas, Outage department Planned/Emergency shutdown schedules from company booklets/Journals and Email and Questionnaires to help get answers from industrial experts.

2.1.3 Data Cleaning

This is a process of data cleansing made up of data extraction (retrieving system data from the SCADA servers for processing) and editing. Editing is undertaken in order to correct wrong or erroneous, misplaced, and crucial information repeated in system data. It aids to present a studied and critically examined data to stake holders in form of publications. Erroneous Information which generally is rechecked include; load (A), voltage (kV), Feeder names, Plant (Substation) names, frequency of interruption and duration of interruptions. To check out the job types created and eradicate the jobs cancelled, incorrect alarm jobs, and jobs of capacitor banks to guarantee that only the following jobs types- unplanned shutdowns, planned shutdowns, Emergency shutdowns, load shedding and faults prevails.

2.1.4 Analyzing the Data

Here data was analyzed using the pivot tables software in excel through a Compilation Process, to undertake the following: To perform checks on the number of times a particular feeder opened (interruption frequency), tally elapse time (interruption duration), and to compile the indices of reliability in a considered period.
A historical method of assessment is utilized to determine the reliability indicators/indices of SAIFI, SAIDI, CAIDI and ENS.

- **System Average Interruption Frequency Index (SAIFI)**

The average amount of interruptions for every utility customer through the examination period. This is basically the overall number of interruptions for customers upon the total number of customers served on the system (Hussen & Ibrahim, 2020), (Teshome & Mabrahtu, 2020).

$$\text{SAIFI} = \frac{\text{Number of Affected Custmers} \times \text{Interruption Frequency}}{\text{Total Number of Customers Served}} \quad (1)$$

System Average Interruption Duration Index (SAIDI)

It is normally known as customer hours of interruption or customer minutes, and is intended to give evidence about the average period the customers are being interrupted (Teshome & Mabrahtu, 2020), (Teixeira & Grid, 2019).

$$\text{SAIDI} = \frac{\text{Numbers of Customers affected} \times \text{Interruption Duration}}{\text{Total Number of customers Served}} \quad (2)$$

- **Customer Average Interruption Duration Index (CAIDI)**

The average period in hours required to reinstate service to the average customer for every sustained interruption. It is the summation of customer interruption durations upon the total number of times of customer interruptions (Hussen & Ibrahim, 2020), (Teshome & Mabrahtu, 2020).

$$\text{CAIDI} = \frac{SAIDI}{SAIFI} \quad (3)$$

- **Energy Not Supplied Index (ENS)**

This index represents the total energy not supplied by the system. The energy amount un-served to customers because of interruptions.

$$\text{ENS (GWh)} = \frac{\text{MW} \times \text{Interruption Duration}}{1{,}000} \quad (4)$$

The lower the values of the indices of SAIFI, SAIDI, CAIDI and ENS, the higher the level of reliability of an electrical distribution network.

2.2 Analysis of the Causes of Interruptions in Electrical Distribution Network in Kampala East

This was conducted through systematic study of the processed data to identify the causes of interruptions embedded in feeders and interconnectors with reliability indices which don’t match with the desired values. The greatest significant causes of interruptions were revealed by fault drivers and a compilation of a fault drivers report was undertaken.

2.3 Strategy of Reliability Improvement of Network using Reconfiguration

The use of sectionalizing switches and tie-lines were made, and a reliability index known as Contingency-Load- Loss Index (CLLI) was formulated (Gangly, 2021).

The CLLI is applied in the placement of tie-lines and sectionalizing switches into planning. This index is intended to evaluate the reliability of an electrical distribution feeder.

$$\text{CLLI} = \frac{\text{NDL}_{\text{Avg}}}{\text{I}_{\text{Total}}} \quad (5)$$

where;

NDL_{Avg}= Average Non- Delivered Load

I_{Total}= Total Load Demand

The range of CLLI is (0 – 1). Zero signifies the best electrical distribution reliable network. Whereas one means the worst reliable network.

Minimization of CLLI maximizes the reliability of an electrical distribution network.

Consider an example of two electrical distribution networks composed of 7 nodes of equal power demand (for instance, 100kVA). The substation is located at node 1. This is shown in the figure 2 below (Gangly, 2021);

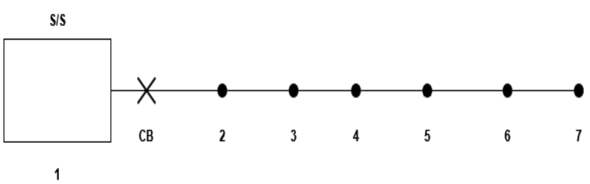

Figure 2 (a): A single feeder distribution network without a sectionalizing switch

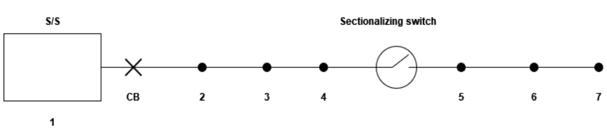

Figure 2 (b): A single feeder distribution network with a sectionalizing switch

From Figure 2 (a) above, there are 7 nodes, the circuit breaker locations for the feeders are in the substation, each of the nodes have a demand at peak of 100kVA. Assumptions taken are that no simultaneous failure of branches or lines and each of the failure branch/line event is independent. Also, the number of branches/lines is equal to (7-1) which is 6, in the event of a fault in any one branch or line, the circuit breaker trips and hence rendering all the branches /lines off supply, a total load of (100×6) = 600kVA is lost. From Equation (3.6);

$$\text{CLLI of network A} = \frac{(600\times6)/6}{600} = 1 \quad (6)$$

This is the worst-case scenario of CLLI

From Figure 2 (b) above; similar to figure (a), there are also 7 nodes. The difference between figure (a) and (b) is the presence of a normally closed sectionalizing switch just like an isolator but never a circuit breaker. These sectionalizing switches are operated on no-load since they lack current interrupters. The sectionalizing switch sectionalizes feeder 1 electrical distribution network into sections 1 and 2. Section 1 is the up-stream of feeder network and section 2 is the down-stream of feeder network. For any fault in the downstream, we can open the sectionalizing switch and isolate the faulty part. This will preserve supply to the branches/lines in the upstream network with improved reliability. For a fault in any of the branches of the downstream network, there will be loss of load of (100×3) = 300kVA. Total Non-Delivered Load (NDL) of all the three branches will be (300×3) kVA. For a fault in any section of the upstream network, the circuit breaker will trip rendering a total loss of load of (100×6) = 600kVA. Total Non-Delivered Load (NDL) of all the three branches will be (600×3) kVA. Total Non-Delivered Load (NDL) for all the 6 branches equals (300×3) kVA+(600×3) kVA. Average Non-Delivered Load (NDL_{Avg}) is obtained by dividing by 6 number of branches. From Equation (3.6);

$$\text{CLLI of network B} = \frac{(600 \times 3 + 300 \times 3)/6}{600} = 0.75 \quad (7)$$

This value of CLLI of 0.75 shows that the reliability of feeder network 2 is better than that of network 1

Hence, it is justified to use a network reconfiguration method by operation of sectionalizing switches and tie-lines as the overall reliability of the electrical distribution network is improved.

2.4 Steps for Network Reconfiguration

The following steps were followed to reconfigure network (Ali A. Chowddhury, 2009)(Gangly, 2021);

Step 1; Identification of the Primary distribution network topology

Step 2; Identification of all normally closed (sectionalizing switches) and normally open-points (tie switches) between feeders on the network under study.

Step 3; Load analysis to estimate loads to be transferred and or isolated (MW or MVA) without violating systems constraints of power, load current, system voltage and radiality.

The power constraints;

Determination of power Transformer ratings in terms of MVA plus overload capabilities (Supply, 2021).

$$P_L \leq P_{Lmax} \quad (8)$$

where;

P_L = Actual Power Loading

P_{Lmax} = Maximum Power Loading

The loading (current) constraint(Supply, 2021).

Determination of power Transformer Current Loadings, protection settings in terms of current of circuit breakers controlling Power Transformers and distribution feeders under study.

$$I_i \leq I_{i\,max} \quad (9)$$

where;

I_i= Actual Current Loading

I_{imax} = Maximum Current Loading

The Voltage Constraint(Supply, 2021)**,** (Dulău & Bică, 2020)**.**

A voltage variation of±10% in High voltage range (33/11kV) and ±6% in the Low voltage range (415/240V) are allowed in compliance with the inequality;

$$V_{min} \leq V_i \leq V_{max} \quad (10)$$

where;

V_{min} = Minimum System Voltage

Vi = Actual System Voltage

V_{max} = Maximum System Voltage

Table 1: Voltage limits.

Voltage	Range	Lower Limit	Upper Limit
33kV	±10%	29.7kV	36.3kV
11kV	±10%	9.9kV	12.1kV
415V	±6%	390.1V	439.9V
240	±6%	225.6V	254.4V

Actions taken when the voltage in the electrical distribution network of Kampala East is outside the statutory levels are (Han et al., 2022): Establish the cause of under or overvoltage, Establish the condition of the tap changer AVR at individual power transformers at Substations, Lower or raise the taps of transformers whose tap changers are not in AVR mode, Switch out or in capacitor banks where applicable. Liaise with big customers who have capacitor banks and advise them accordingly, and if all the above measures fail then load shed or energize feeders.

The radiality of the feeder maintained (Supply, 2021)**.**

The electrical distribution network of the feeder has to be maintained radial at all times. This will be ensured by opening a section of the feeder using a sectionalizing switch before load is transferred to a nearby appropriate feeder.

Step 4; Choosing a combination of switching devices (sectionalizing and tie-line) switches to be used to achieve a desired load transfer.

Step 5; Actual execution of the load transfers through operating the switching devices.

Step 6; Monitoring the Performance of the Reconfigured Network to satisfy system constraints of power, current loading, system voltage and radiality.

Step 7; Keeping a record of old/new status of open-points together with statuses of other sections/branches of the network opened/closed.

Step 8; Reversing of the reconfigured network when normal conditions return.

The flow chart to be followed in reconfiguration of the electrical distribution network in Kampala East

The above steps are summarized in a flow-chart of figure 3 below.

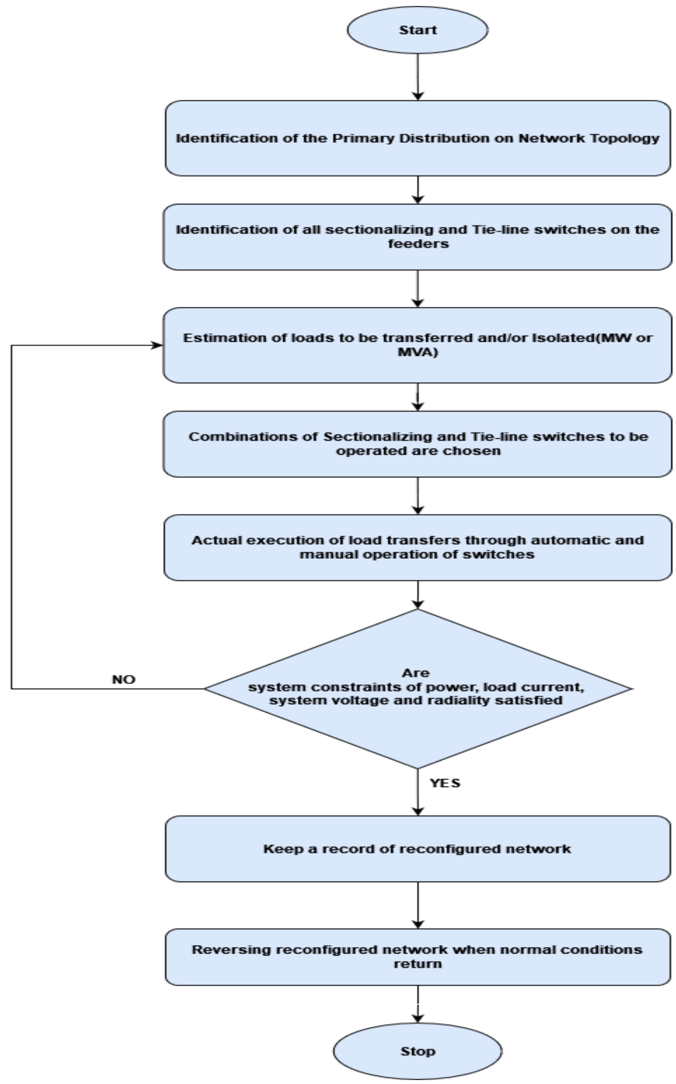

Figure 3: Flow-Chart for Network Reconfiguration in Kampala East(Gangly, 2021).

2.5 Materials Used

The following materials were utilized; SCADA 33/11kV Network Diagrams of Lugogo, Ntinda, Nakawa and Kireka Substations, SCADA Software Called Power Advantage of GE Energy for Power and smart Grids, System Operation Manuals of the Electrical Distribution Network of Umeme, SCADA Databases (Servers), Large Display Screens for Network Monitoring, Desktop Computers for Electrical Distribution Network Operations, Laptop computers for Data Processing, Pivot Tables Software for Analyzing Data, Computer Microsoft packages of Word, Excel and Power Point, and Vehicles/transport for site visits.

3.0 Results and Discussion

3.1 Reliability of the Network between January and June 2022.

Customer Hours Lost (SAIDI) of 8.34 hours per month per customer. This means that every Customer was off supply for 8.34 hours per month. Number of outages per month per customer (SAIFI) is 5.65. This means that every customer experienced 5.65 times of power outage per month. Fault Resolution Time (CAIDI) of 1.58 hours. This means that each time power went off, it took 1.58 hours to restore supply. Energy Not Served (ENS) of 2.14 GWh. This means that the energy which was not delivered to customers amounted to 2.14 GWh.

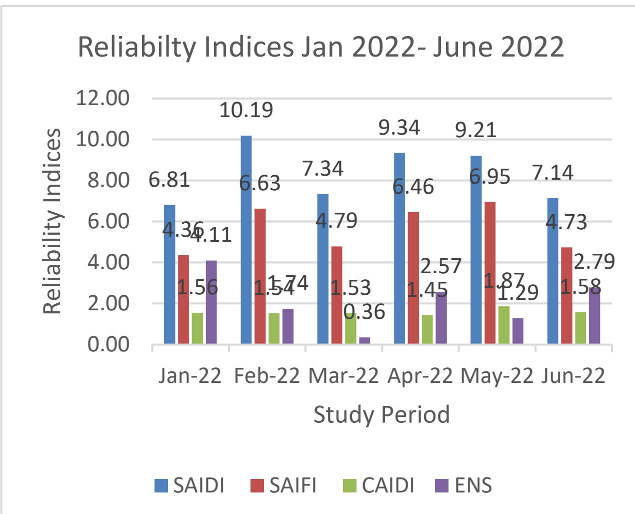

Figure 4: Reliability Indices between Jan 2022 and June 2022

3.2 Causes of Interruptions of the Electrical Distribution Network in Kampala East

Transients at 35%. This percentage represents faults of a temporary nature not more than five minutes caused by operation of auto-reclose facility in protection relays. Jumpers at 25%. This percentage represents break in Jumper conductors causing short circuits, Earth faults and open circuits. Conductors 9%. This percentage represents breakage of conductors, entangled Conductors, causing open circuits, short circuits and earth faults. Cable Faults, Storms and Others at 4% each. This percentage represents Short Circuits/Open Circuits/Earth faults in Underground cables, stormy weather and others like Under/Overvoltage conditions. Poles and Vegetations at 3% each. This percentage represents broken or badly leaning poles and vegetation growth near power networks. Unidentified Faults, Through Faults, MU, Overloads, Fire and Vandalism at 1% each. Unidentified faults are very difficult to unearth but become visible with time. The best example is a tree branch which sometimes is blown by wind to short conductors of power lines. Metering Units (MU) short circuits and cause power failure. Too much load current passing through circuits causes breaker tripping. Fire outbreak causes burning of power components and hence power failures. Vandalized components will always fail and hence cut off the power supply.

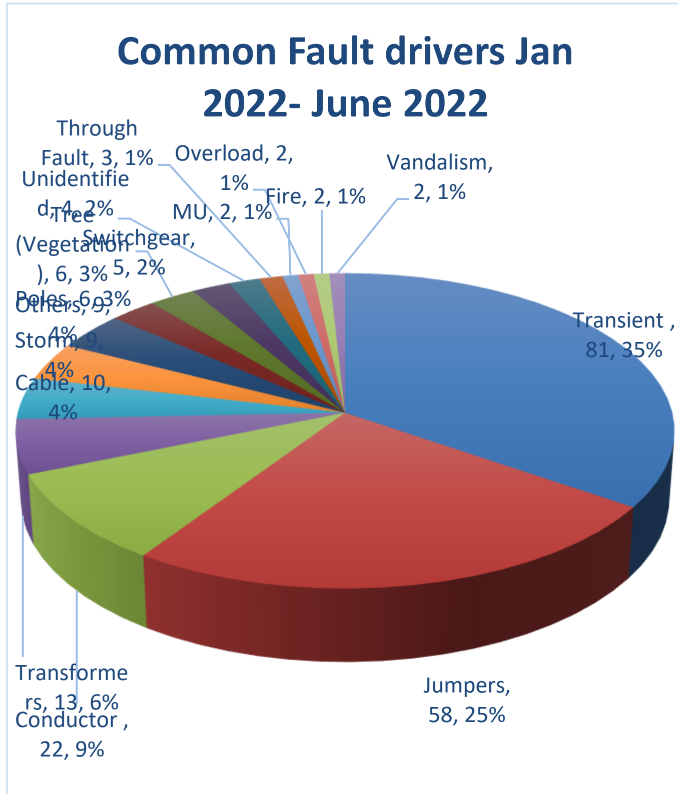

Figure 5: Pie- Chart of Common Fault Drivers in Kampala East.

3.3 Reliability Indices Trend in Kampala East between July 2022 and December 2022

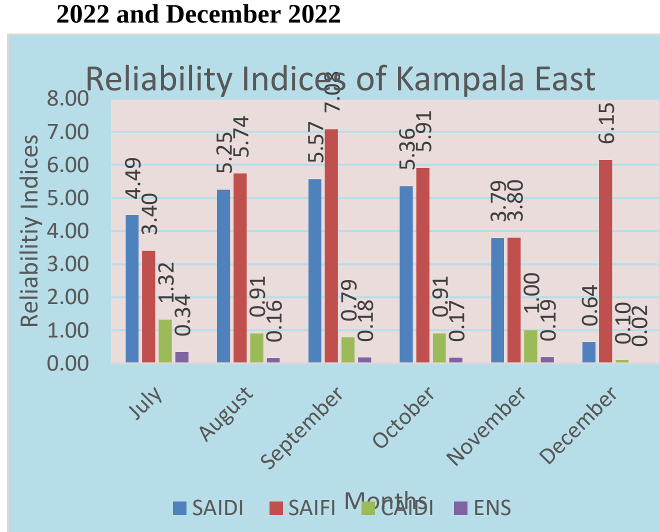

Figure 6: Reliability Indices in Kampala East between July 2022 and December 2022

Customer Hours Lost (SAIDI) of 4.18 hours per month per customer. This means that every Customer was off supply for 4.18 hours per month. Number of outages per month per customer (SAIFI) is 5.35. This means that every customer experienced 5.35 times of power outage per month. Fault Resolution Time (CAIDI) of 0.84 hours. This means that each time power went off, it took 0.84 hours to restore supply. Energy Not Served (ENS) of 0.18 GWh. This means that the energy which was not delivered to customers amounted to 0.18 GWh

Hence, the reliability is improved to 4.18 customers hours lost per month per customer. The number of outages per month per customer is 5.35. Faults resolution time of 0.84 Hours. The energy not served of 0.18 GWh. This gives percentage improvements of 49.88%, 5.31%, 54.2%, and 88.61% in SAIDI, SAIFI, ENS and CAIDI respectively.

Compared with the targeted values for 2022 set by the regulator of Customer hours lost (SAIDI) of 6.25 hours per month per customer, Outages per month per customer (SAIFI) of 5.41, Fault Resolution Time (CAIDI) of 1.15 hours, and Energy Not Served (ENS) of 0.42 GWh per month, the electrical distribution Network in Kampala East is performing at a level that is slightly better than the desired or set target.

4.0 Conclusion

The current level of reliability of the electrical distribution network in Kampala East was determined. In order to register improvement in the reliability of power supply to customers, this research had to look at cost-effective means of doing so, and among the techniques employed is the reconfiguration of the electrical distribution network in Kampala East through Opening of sectionalizing (normally-Closed) switches and closing of Tie-Line (normally-open) switches. The reconfigured network was able to reduce on interruption durations and interruption frequency of either a complete or a bigger part of the feeders affected with interruptions which would have been left totally off. This action improves the Contingency-load-Loss Index (CLLI) and hence improvement of reliability of the electrical distribution network in Kampala East due to improved SAIDI, SAIFI, CAIDI and ENS.

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Declaration of Conflict of Interest

The authors of this paper declare no conflict of interest.

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