RELIABILITY ASSESSMENT OF SABON-GARI DISTRIBUTION SUBSTATION BASED ON COMPONENTS PERFORMANCE

Hachimenum Nyebuchi Amadi, Senior Member IEEE
Department of Electrical and Electronics Engineering
Rivers State University, Port Harcourt, Nigeria
Email: {hachimenum.amadi@ust.edu.ng}

Abstract
This study deployed the analytical technique and assesses the reliability of the Nigerian electricity distribution system with the Sabon-Gari distribution substation in Kano State as a case study while considering the performance of each component of the substation. Data on daily outages on the feeders from January to December 2015 were collected from the substation logbooks and analysed to obtain the system reliability indices. The SAIDI, SAIFI, CAIDI and ASAI for the substation were 0.8905, 0.9823, 10.9008 and 0.9027 respectively. These values when compared with those of Denmark, the Netherlands and even Kenya were much higher (except for Kenya that reported a higher CAIDI) and therefore unacceptable. This paper recommends improvement in the substation reliability indices by adopting renewable energy technologies to reduce the present over-dependence on conventional energy resources, use of micro-grid in the remote/rural areas to lessen the stress on the national grid, automation of the entire network to facilitate the resolution of faults, implementation of smart distribution grid as well as timely/routine inspection and maintenance of distribution lines. The outcome of this study would be useful to system engineers tasked with substation design, operation and maintenance processes.

Keywords
Distribution feeder, Electricity distribution substation, Electricity outages, Reliability, Reliability indices

1. Introduction

Power systems have the primary purpose of meeting the energy needs of the modern man and by so doing yielding the much desirable high return on investment (ROI) to the Utility. However, experiences have demonstrated that this has not been the case because while the generation and transmission subsystems may not pose any problems, the distribution subsystem is oftentimes unreliable thereby resulting to poor power quality supply to the energy consumers and consequent depreciation of Utility ROI. Careful assessment of the status of the distribution network is necessary, therefore, to ensure uninterruptible supply of good quality power to the electricity users always.

Electricity Utilities are gradually getting fully deregulated and competitive such that the focus becomes the improvement of electrical power infrastructure reliability and how to guarantee the steady supply of electricity to customers within reasonable operational and maintenance costs. Currently, Utilities are under intense pressure from stakeholders to reinvent and re-strategize to ensure adequate reliability of electricity supply with reasonable cost implications [1]. This involves improvement in the reliability of electricity supply to meet customers’ expectations; meeting the demands by industry regulators who as part of deregulation are opting for improved performances by distribution companies based on the attainment of set targets and financial bonuses/penalties which unfortunately has a direct impact on companies’ bottom line and lastly ensuring that the shareholders/company owners get equitable returns on investment (ROI) [2][3].

With the ever-rising living standards in societies across the world and the consequent continuous demand for adequate and readily available electrical energy by the consumers, it has become necessary that distribution system networks are in good operational condition always especially for the reason that distribution systems supply electricity directly to the consumers. Reliability assessment is one of the techniques that confirm the capability of a distribution network to deliver uninterruptible electricity to the end-users at all times. This is especially expedient because the power system is complex being comprised of several equipment and components which are subject to failure while in use in the system thereby causing the country severe economic losses. Experts have attributed 80% of power outages to the frequent failures of distribution system equipment and components [4][5].

The power system is expected to provide uninterruptible electricity to consumers; and how reliable the system is, determines its capability to perform this function. System reliability involves momentary and sustained interruptions. Interruptions of duration equal to or longer than five minutes are classed as Sustained Interruption and constitute a reliability issue but those below five minutes are classified as Momentary; the effect on power quality being characterized by fluctuations in voltage, harmonic distortions and abnormal waveforms [6][7].

Power system reliability assessment task is to ascertain the extent to which the system is reliable, to predict which scheme is the most reliable and to determine which areas
require funding so to achieve improvement in the overall performance of the system [8]. Reliability assessments help power system customers, investors and stakeholders determine the condition of the utility system by determining the values of its indices the improvement of which enhances system planning, operation and performance.

Power system reliability is often explained in terms of adequacy and security. Adequacy describes the system capacity to meet the energy needs of the consumers while security describes the system capability to respond favourably in the event of fault-induced disturbances, etc. Distribution subsystems are rarely loaded to full limits, system adequacy is therefore not always a big challenge; the reliability focus most times is on system security [2]. Two techniques commonly used for the assessment of distribution system reliability [9] are:

- The Monte Carlo technique otherwise referred to as simulation method is cumbersome and time-consuming requiring much statistics and drawings for accurate results to be achieved.
- The Analytical method relies on solutions obtained from mathematical models being based on assumptions made about how the failure rate and repair times are distributed statistically.

System reliability assessment helps also to maintain a reasonable balance in generation, transmission and distribution [6][10].

Utilities use basic indices namely System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Customer Average Interruption Duration Index (CAIDI) and Average Service Availability Index (ASAI) to measure reliability levels of power distribution systems [7][11]. A considerable amount of literature has been published on the subject of reliability and the need for its sustenance and improvement in power systems. For example, Ref [12] evaluated the reliability of the Nigeria power distribution system by carrying out a monthly evaluation of the Ekpoma Network feeders in Edo State from January to December 2012 using feeder load data obtained from the Power Holding Company of Nigeria (PHCN). Their findings revealed that daily failures in the feeders were as a result of incessant electrical faults in the distribution system.

In their study, Ref [13] used the NEPLAN software to predict the reliability of the Port Harcourt distribution network based on data collected in respect of the Choba distribution network from the Power Holding Company of Nigeria (PHCN) and found that the use of NEPLAN revealed much about the performance of the network and made a prediction of potential outages in the system easier. The study further observed that there was great difficulty in accessing necessary data for researches into the network and recommended that Utility should ensure detailed documentation of all data (operational and maintenance) to enhance research works on the Port Harcourt electricity distribution network.

Ref [14] on the other hand assessed the reliability of the Ayede 330/132KV injection substation which feeds the Jericho, Ijebu ode, Ibadan North, Sagamu, Ayede and Iseyin substations putting into consideration the various subsystem components and found that the reliability of the substation can be boosted by reducing the failure rate of the components and by improving upon the mean time between failures (MTBF). Within that same period, Ref [15] applied the analytical method and the ETAP software in evaluating the reliability of the Omotsha distribution network during the period 2009 - 2011 before and after the deployment of some photovoltaic (PV) system at the injection substations and observed that the inclusion of the PV system resulted in a considerable improvement in both the substation performance and the revenue that accrued to the Utility. Similarly, Ref [11] investigated the reliability of the power distribution network in the Kano Metropolis of Nigeria based on some outage data sources from the Power Holding Company of Nigeria (PHCN) and concluded that a significant percentage of the outages that occur on power distribution lines are caused by environmental factors e.g. wind, storm, lightning, birds/animals and trees. A twelve-months study by Ref [16] on the daily power interruptions in the 33Kv and two 11Kv feeders domiciled in Ede town attempted to ascertain the reliability of distribution feeders in Osun State, Nigeria and observed that no one singular index can be completely relied upon to correctly describe the reliability of a power system; a combination of indices will always give a better assessment result. The study further noted that the SAIDI, SAIFI and ASAI values obtained in respect of the distribution feeders were far from the internationally statutory values of 2.5 hours, 0.01 and 99.8 respectively and concluded that the finding was the reason for the poor power quality often experienced in the Ede town and the entire Osun State.

Other studies include that of Ref [18] which used the analytical method and network reduction technique and estimated the reliability indices of each component in the Ayetoro 1 substation, Aguda Lagos state for twelve months based on data collected from the substation. The aim was to determine the contribution of these components to the overall reliability of the distribution substation and the impact on the efficient delivery of power to the consumers. The study found that transformer failure was responsible for most outages recorded in the area and recommended amongst others the regular inspection and prompt repair of damaged components to ensure improvement in the substation performance and the quality of power supply to the consumers. Ref [19] on the other hand, deployed the Electrical Transient Analyzer Program (ETAP) and
evaluated the outage and reliability levels in the Benin Electricity Distribution Network in 2013 using feeder outage data from the network and compared the results with those obtained after some distributed generators were added to the network. The study found that there existed a linear relationship between the system annual outage duration, the Expected Energy Not Supplied (EENS) and the Expected Cost of Interruption (ECOST). The findings revealed also that the incorporation of the distributed generators resulted in a 90.2% improvement in the EENS and a 90.5% reduction in the ECOST. Ref [20] investigated the power distribution networks in Rivers State using data accessed from the Port Harcourt Electricity Distribution Company (PHEDC) and found that the average system availability index (ASAI) of the networks fell short of the presumed value of 99.99%. The study, therefore, recommended an increase in power production funding and the complete automation of the networks to boost the reliability of the entire distribution sub-system.

A more recent study by Ref [21] used the analytical technique and evaluated the reliability of a power distribution network by subjecting the network to a series of interruptions and noting the failure rate on each component and the system reliability in terms of the System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI) and Average Service Availability Index (ASAI). The study concluded that the distribution system reliability can be improved upon, through the reconfiguration of feeders.

Distribution substations deliver power directly to electricity consumers and are expected to function optimally without interruptions. Most studies focus only on substation connectivity and neglect the effect of protective components malfunction to distribution system reliability. The present study deploys the analytical method in the reliability assessment of the Sabon-Gari power distribution substation in Kano State, northwestern Nigeria based on historical data accessed from the Sabon-Gari substation from January to December 2015. The findings show that the outage duration, frequency of outage and period of restoration of power supply represented by the reliability indices SAIDI, SAIFI and CAIDI in the distribution substation were higher when compared with select countries like Denmark, The Netherlands except for Kenya which had a higher SAIFI. The ASAI from the study also was found to be much lower than for these countries. The paper recommends improvement in the values of the SAIDI, SAIFI and CAIDI to boost the ASAI of the substation and the entire distribution network through the adoption of renewable energy technologies to reduce the present over-dependence on conventional energy resources, use of micro-grid in the remote/rural areas to lessen the stress on the national grid, automation of the entire network to facilitate the resolution of faults in and around substation feeders, implementation of smart distribution grid in addition to routine inspection and maintenance of distribution lines by regular trimming and cutting of nearby trees to prevent short-circuiting of the lines and consequent earth faults. It is expected that the study outcome will guide power engineers to improve on distribution substation design, planning and operations.

2. Materials and Method
The study evaluated the reliability of the Sabon-Gari distribution substation in the Kano electricity distribution network over the period January to December, 2015 using the analytical technique on data from the substation logbook obtained from the Power Holding Company of Nigeria (PHCN). The study chose to carry out the network simulation on the Electrical Transient and Analysis Program (ETAP) version 12.6 software owing to its unique features especially the capability to perform real-time operations fast. Figure 1 shows the screenshot of the single-line representation of the Sabon-Gari distribution substation; one of the substations in the Kano electricity distribution network.

3. Reliability Assessment Metrics and Indices
Several metrics and indices are deployed by Utilities while recording, organizing and reporting on reliability events; these help in enhancing the reliability assessment exercise. The followings are some of the metrics and indices used in this study.

Failure Rate, \( \lambda \)

\[
\lambda = \frac{\text{Number of Outages on Component in a given period}}{\text{Total Time Component is in operation}}
\]  

(1)

Average Failure Rate at Load Point \( i, j \), \( \lambda_{i,j} \) (E/yr)

\[
\lambda_{i,j} = \sum_{j \in \text{Component}} \lambda_{i,j}
\]  

(2)

Where:
\( \lambda_{e,j} \) = the average failure rate of element \( j \)

\( N_e \) = the total number of the elements whose faults will interrupt load point \( j \).

Annual Outage Duration at Load Point \( i \), \( U_i \) (hr/yr)

\[
U_i = \sum_{j \in N_e} \lambda_{e,j} r_{ij}
\]

Where:

\( r_{ij} \) = the failure duration at load point, \( i \) due to a failed element, \( j \)

Average Outage Duration at Load Point \( i \), \( r_i \) (hr)

\[
r_i = \frac{U_i}{\lambda_i}
\]

System Average Interruption Duration Index, SAIDI (hr/customer.yr)

\[
SAIDI = \frac{\text{Sum of Customer Interruption Durations}}{\text{Total number of Customer Interruptions}}
\]

\[
= \frac{\sum U_i N_i}{\sum N_i}
\]

System Average Interruption Frequency Index, SAIFI (f/customer.yr)

\[
SAIFI = \frac{\text{Total number of Customer Interruptions}}{\text{Total number of Customers Served}}
\]

\[
= \frac{\sum \lambda_i N_i}{\sum N_i}
\]

Average Service Availability Index, ASAI (pu)

\[
ASAI = \frac{\text{Customer Hours Available Service}}{\text{Customer Hours Demanded}}
\]

Where 8760 is the number of hours in a Calendar year.

Average Service Unavailability Index, ASUI (pu)

\[
ASUI = 1 - ASAI
\]

Mean Time Between Failures (MTBF)

\[
MTBF = \frac{\text{Total System Operating Hours}}{\text{Number of Failures}}
\]

Mean Time To Repair (MTTR)

\[
MTTR = \frac{\text{Total Duration of Outages}}{\text{Frequency of Outage}}
\]

Availability

\[
\text{Availability} = \frac{MTBF}{MTBF + MTTR}
\]

The algorithm describing the steps involved in the assessment process is shown in Figure 2.
4. Results and Discussion

Table 1 shows the basic reliability indices i.e. the failure rate per year, average outage time and annual outage time of the substation components which are graphically represented in Figures 3 and 4. These indices were evaluated using data obtained from the Power Holding Company of Nigeria in Kano State and then used to calculate the indices in Table 2 for the study period.

As can be seen in Table 1, the substation transformers recorded the highest average outage time of 27.08 hours followed by fuses (12.67 hours) and outgoing feeders (9 hours). What this means is that most of the outages that were experienced by electricity customers in the Sabon-Gari district during the period under study were as a result of transformer failure due to overload, followed by blown fuses resulting from faults or overload and partly because of issues arising from the outgoing feeders, or due to short-circuit, overload or broken conductor.

It could be stated therefore that the reliability challenges encountered in the Sabon-Gari electricity substation in 2015 were basically due to the aforementioned components of the substation. The busbar and circuit breakers, however, did not contribute much to the outages that occurred in the study area during the period in review as each recorded low average outage time values of 2.667 and 3.417 respectively.

The relays performed even better with average outage time of 0.5833 and 1.3333 respectively. It is interesting to note that among all the substation components, the surge arrester performed best with no outage time during the study period. This means that the substation was adequately secured against lightning-induced voltages and similar occurrences such as a fault or switching operations that would have adversely affected the reliability level of the substation during the period under review.

Table 2 shows the computed customer reliability indices and indicates that July had the highest SAIDI value of 0.0897 followed by April and October each having a value 0.0877. The month of March, however, recorded the least value 0.0607 followed by February with a value 0.0609. This means that the electricity supply interruptions were timeously attended to and the faults promptly cleared in the study area in March and February 2015.

Interestingly, the substation recorded a SAIFI of 0.8905 which ordinarily is acceptable as it signified that the rate of interruptions in electricity supply in the substation service area was generally low. But accurate system reliability determination requires the interpretation of two or more indices combined and not simply based on the information about a single index as doing so could be misleading. Analysed monthly, September and December topped the values with 0.0920 and 0.0867 respectively while March and May recorded the least values of 0.0700 and 0.0763 respectively.

The study also revealed that the substation had overall CAIDI value of 10.901 hours/customer indicating that the customer in the study area experienced average electricity outage of 10.901 hours daily throughout the study year.

Table 1: Reliability Indices on Substation Components in Sabon-Gari Substation in 2015

| Component          | Failure Rate (f/yr) | Average Outage Time (Hours) | Annual Outage Time/Unavailability (Hours) |
|--------------------|---------------------|-----------------------------|------------------------------------------|
| Transformer        | 0.0055              | 27.0833                     | 0.1490                                   |
| Supply Incomer     | 0.0071              | 3.8333                      | 0.0272                                   |
| Switchgear         | 0.0144              | 6.1667                      | 0.0888                                   |
| Busbar             | 0.0012              | 2.6667                      | 0.0032                                   |
| Circuit Breaker    | 0.0051              | 3.4167                      | 0.0174                                   |
| Fuses              | 0.0430              | 12.6683                     | 0.5447                                   |
| Switches           | 0.0045              | 4.25                        | 0.0191                                   |
| Overcurrent Relay  | 0.0029              | 1.3333                      | 0.0039                                   |
| Earth Fault Relay  | 0.0014              | 0.5833                      | 0.0008                                   |
| Surge Arrester     | 0                   | 0                           | 0                                        |
| Outgoing Feeder    | 0.0225              | 9                           | 0.2025                                   |

Table 2: Computed Customer Reliability Indices

- July: SAIDI = 0.0897, SAIFI = 0.8905
- April and October: SAIDI = 0.0877, SAIFI = 0.8905
- March: SAIDI = 0.0607, SAIFI = 0.8905
- February: SAIDI = 0.0609, SAIFI = 0.8905

The study also revealed that the substation had overall CAIDI value of 10.901 hours/customer indicating that the customer in the study area experienced average electricity outage of 10.901 hours daily throughout the study year.
In other words, it took Utility average of 10.901 hours to restore electricity to the customer each time an interruption in supply occurred.

July and October topped the list of monthly CAIDI with 1.1006 and 1.0761 respectively, meaning that in July, it took Utility 1.1006 hours to restore electricity to the customer while it took 1.0761 hours to do same in October. With low CAIDI of 0.7294 and 0.7472 recorded in September and February respectively, it is obvious that electricity restoration to consumers was quicker in these two months than in the rest of the months.

Table 2 also indicates that the substation recorded an ASAI of 90.27% which means that the substation was functional 90% approximately of the study period. This value is very poor because, by the Institution of Electrical and Electronics Engineers (IEEE) Standard, Utilities globally are expected to report ASAI value of at least 99.99% annually [18]. The substation recorded its highest value of ASAI (92.19%) in March and reported the lowest value (88.35%) in April. Figures 3 and 4 are the graphical representations of the failure rate and the outage duration of the substation components.

| Month      | No. of Customers | Duration of Interruptions | Total Expected Hours | Frequency of Interruption | SAIDI (Hrs/Cust.) | SAIFI (Int./Cust.) | CAIDI (Hrs/Cust.) | ASAI (%) |
|------------|------------------|---------------------------|----------------------|---------------------------|-------------------|-------------------|-------------------|----------|
| January    | 957              | 61.2                      | 744                  | 76                        | 0.0640            | 0.0794            | 0.8061            | 91.77    |
| February   | 957              | 58.3                      | 672                  | 78                        | 0.0609            | 0.0815            | 0.7472            | 91.32    |
| March      | 957              | 58.1                      | 744                  | 67                        | 0.0607            | 0.0700            | 0.8671            | 92.19    |
| April      | 957              | 83.9                      | 720                  | 82                        | 0.0877            | 0.0857            | 1.0233            | 88.35    |
| May        | 957              | 73.4                      | 744                  | 73                        | 0.0767            | 0.0763            | 1.0052            | 90.13    |
| June       | 957              | 73.4                      | 720                  | 79                        | 0.0767            | 0.0826            | 0.9286            | 89.81    |
| July       | 957              | 85.8                      | 744                  | 78                        | 0.0897            | 0.0815            | 1.1006            | 88.47    |
| August     | 957              | 68.2                      | 744                  | 82                        | 0.0713            | 0.0857            | 0.8320            | 90.83    |
| September  | 957              | 64.2                      | 720                  | 88                        | 0.0671            | 0.0920            | 0.7294            | 91.08    |
| October    | 957              | 83.9                      | 744                  | 78                        | 0.0877            | 0.0815            | 1.0761            | 88.72    |
| November   | 957              | 70.53                     | 720                  | 76                        | 0.0737            | 0.0794            | 0.9282            | 90.21    |
| December   | 957              | 71.09                     | 744                  | 83                        | 0.0743            | 0.0867            | 0.8570            | 90.45    |
| **Total**  | **957**          | **852.02**                | **8760**             | **940**                   | **0.8905**        | **0.9823**        | **10.9008**       | **90.27** |
Fig. 3: The failure rate of each component

Fig. 4: Outage duration of each Component
Fig. 5: Monthly SAIDI for the Sabon-Gari Substation

Fig. 6: Monthly SAIFI for the Sabon-Gari Substation

Fig. 7: Monthly CAIDI for the Sabon-Gari Substation
Fig. 8: Monthly ASAI for the Sabon-Gari Substation

Fig. 9: Combined SAIDI, SAIFI, CAIDI and ASAI for the Substation Components
Table 3. Outages profiles and computed reliability indices for Sabon-Gari Distribution Substation from January to December 2015 contd.

| Component Description | No. of Failures | Outage Duration (Hours) | Total Service Hours Expected (Hours) | Failure Rate (f/yr) | MTBF | MTTR | Availability (%) |
|-----------------------|----------------|-------------------------|--------------------------------------|---------------------|------|------|------------------|
| Transformer           | 48             | 325                     | 8760                                 | 0.0055              | 182.5| 6.7708 | 96.42            |
| Supply Incomer        | 62             | 46                      | 8760                                 | 0.0071              | 141.29| 0.7419 | 99.48            |
| Switchgear            | 126            | 74                      | 8760                                 | 0.0144              | 69.52 | 0.5873 | 99.16            |
| Busbar                | 10             | 32                      | 8760                                 | 0.0012              | 876   | 3.2   | 99.64            |
| Circuit Breaker       | 45             | 41                      | 8760                                 | 0.0051              | 194.67| 0.9111 | 99.54            |
| Fuses                 | 376            | 152.02                  | 8760                                 | 0.0430              | 23.30 | 0.4043 | 98.30            |
| Switches              | 39             | 51                      | 8760                                 | 0.0045              | 224.62| 1.3077 | 99.42            |
| Overcurrent Relay     | 25             | 16                      | 8760                                 | 0.0029              | 350.4 | 0.64  | 99.82            |
| Earth Fault Relay     | 12             | 7                       | 8760                                 | 0.0014              | 730   | 0.5833 | 99.92            |
| Surge Arrester        | 0              | 0                       | 8760                                 | 0                   |       |       |                  |
| Outgoing Feeder       | 197            | 108                     | 8760                                 | 0.0225              | 44.4670| 0.5482 | 98.78            |
|                       | **940**        | **852.02**              | **8760**                             |                     | **9.3192**| **0.9064** | **91.14**        |

Fig. 10 Monthly MTBR for Components in the Sabon-Gari Substation
Fig. 11 Monthly MTTR for Components in the Sabon-Gari Substation

Table 4. Benchmarks for reliability indices comparison adapted from Refs [18][22]

| Country | SAIDI (Minutes/Year) | SAIFI (Interruptions/Customer) | CAIDI (Minutes/Outage) | ASAI (%) |
|---------|-----------------------|--------------------------------|------------------------|-----------|
| The Netherlands | 33                    | 0.3                            | 75                     | 99.97     |
| Denmark | 24                    | 0.5                            | 70                     | 99.98     |
| Kenya   | 11.7                  | 5.6                            | 2.1                    | 99.54     |
| Nigeria (Sabon-Gari, Kano State) | 53.43                | 0.9823                         | 654.05                | 90.27     |
Figures 5 to 8 show the graphical representation of the monthly system reliability indices for the substation for the period covered in the study. In Figure 5 which represents the SAIDI, the interruption duration peaked in July and was minimum in March.

The SAIFI graph in Figure 6 indicates that the interruption rate was highest in September but least in March.

Figure 7 represents the CAIFI and displays the trend in customer interruptions frequency, that is, the customers that experienced the most interruptions during the period under study. The ASAI is as shown in Figure 8 while Figure 9 shows the combined reliability indices for the substation components accordingly.

The substation also recorded Mean Time Between Failures (MTBF) of 9.3192 and Mean Time To Repair (MTTR) of 0.9064. This is graphically represented in Figures 10 and 11.

Distribution substation reliability is often assessed by comparing same to some reliability benchmarks. This study adopted as benchmarks (Table 4), computed values for power distribution reliability in three countries namely Denmark, The Netherlands and Kenya based on the IEEE Guide.

As shown in Table 4 and represented graphically in Figure 12, the Sabon-Gari substation has a SAIDI of 53.43 minutes/year, SAIFI of 0.9823, CAIDI of approximately 654 minutes/outage and an ASAI of 90.27%.

The results show that the outage duration, frequency of outage and period of restoration of power supply represented by the reliability indices SAIDI, SAIFI and CAIDI in the distribution substation were comparatively higher than those for Denmark, The Netherlands except for Kenya which had a higher SAIFI indicating that Kenya electricity consumers experience a higher number of interruptions in supply annually than their counterparts in Denmark, The Netherlands and Nigeria. Correspondingly, the ASAI from the study was much lower than for these select countries. This paper thus recommends improvement in the values of these indices to boost the ASAI of the substation and indeed the entire distribution network through the following measures:

The adoption of renewable energy technologies to reduce the present over-dependence on conventional energy resources, use of micro-grid in the remote/rural areas to lessen the stress on the national grid, automation of the entire network to facilitate the resolution of faults in and around substation feeders, implementation of smart distribution grid in addition to routine inspection and maintenance of distribution lines by regular trimming and cutting of nearby trees to prevent short-circuiting of the lines and consequent earth faults. The foregoing suggestions would enhance electricity supply reliability to consumers in Sabon-Gari and the entire Kano State.

5. Conclusion

The study evaluated the reliability of the Sabon-Gari distribution substation in the Kano electricity distribution network in Nigeria for the period January to December 2015 using the analytical technique on data accessed from the substation logbook. The results show that the SAIDI, SAIFI and CAIDI in the distribution substation were comparatively higher than those for Denmark, The Netherlands except for Kenya which had a higher SAIFI indicating that Kenya electricity consumers experience a higher number of interruptions in supply annually than their counterparts in Denmark, The Netherlands and Nigeria. Correspondingly, the ASAI from the study was much lower than for these select countries. This paper thus recommends improvement in the values of these indices to boost the ASAI of the substation and indeed the entire distribution network through the following measures:

The adoption of renewable energy technologies to reduce the present over-dependence on conventional energy resources, use of micro-grid in the remote/rural areas to lessen the stress on the national grid, automation of the entire network to facilitate the resolution of faults in and around substation feeders, implementation of smart distribution grid in addition to routine inspection and maintenance of distribution lines by regular trimming and cutting of nearby trees to prevent short-circuiting of the lines and consequent earth faults. The foregoing suggestions would enhance electricity supply reliability to consumers in Sabon-Gari and the entire Kano State.

References
[1] Allan, R and R. Billinton, Probabilistic Assessment of Power systems, Proceedings of the IEEE, 88(2), February 2000.
[2] Dorji, T. Reliability Assessment of Distribution Systems - Including a case study on Wangdue Distribution System in Bhutan. Master of Science Dissertation in Electric Power Engineering, Norwegian University of Science and Technology, Department of Electrical Power Engineering, May 2009.
[3] Taylor, T.; Markshall, M and Neumann, E. Developing a Reliability Improvement Strategy for Utility Distribution Systems, IEEE, 444-449.
[4] Li, D. and Wang, Y. Evaluation of Distribution Network Reliability Based on Network Equivalent. In: Lee J. (eds) Advanced Electrical and Electronics Engineering. Lecture Notes in Electrical Engineering, 87, (2011) Springer, Berlin, Heidelberg.
[5] Yang, S. (1986). Basic and application of reliability analysis in the power system. Hydraulic and Electric Power Press, Beijing.
[6] Paci, A.; Čelo, M. and R. Bualoti. Distribution System Reliability Indices. Case Study Albanian Distribution System. Journal of Multidisciplinary Engineering Science and Technology (JMEST),5(12), December – 2018.
[7] IEEE Guide for Electric Power Distribution Reliability Indices, IEEE Standard 1366, 2003 Edition.

[8] Brown, R.E.; Gupta, S.; Christie, R.D.; Venkata, S.S. and R. Fletcher, Distribution System Reliability Assessment Using Hierarchical Markov Modeling, IEEE Transactions on Power Delivery, 11(4), October 1996.

[9] Kjolle, G. and K. Sand, RELRAD-An analytical approach for Distribution System Reliability Assessment, IEEE Transactions on Power Delivery, 7 (2), April 1991.

[10] Allan, R.N. and M.G. DaSilva, “Evaluation of Reliability Indices and Outage costs in distribution system,” IEEE Trans. Power Systems, 10 (1), 413-419, Feb. 1995.

[11] Okorie, P. and A.I.Abdu, Reliability Evaluation of Power Distribution Network System in Kano Metropolis of Nigeria. International Journal of Electrical and Electronic Science, (2015): 2(1),1-5.

[12] Onime, F. and G.A. Adegojiwa. Reliability Analysis of Power Distribution System in Nigeria: A Case Study of Ekpoma Network, Edo State. International Journal of Electronics and Electrical Engineering. (2014):2(3).

[13] Uhumwenguho, R and E. Omorogiuwa (2014). Reliability Prediction of Port Harcourt Electricity Distribution Network using NEPLAN, The International Journal of Engineering and Sciences (IJES), 3(12): 68-79.

[14] Adefarati, T., Babarinde, A.K., Oluwole, A.S., and K. Olusuyi. Reliability Evaluation of Ayede 330/132KV Substation. International Journal of Engineering and Innovative Technology (IJEIT), (2014):4 (4).

[15] Izuegbunam, F.I., Uba, I.S., Akwukwaegbu, I.O. and D. O. Dike. Reliability Evaluation of Onitsha Power Distribution Network via Analytical Technique and the Impact of PV System. IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), 9 (3), Ver. II (May – Jun. 2014), 15-22.

[16] Johnson, D.O. Assessment of Electric Power Distribution Feeders Reliability: A Case Study of Feeders that Supply Ede Town. International Conference on Electric Power Engineering (Icepeng 2015), October 14-16, 2015.

[17] Folarin, D.A., Sakala, J.D., Matlotse, E and M. A. Gasenmelwe-Jeffrey. Appraisal of Electric Power Distribution Feeders Reliability in the Region Unit in Nigeria. International Journal of Engineering Research & Technology (IJERT), (2017):6 (04).

[18] Akintola, A. A. (2017). Reliability Evaluation of Secondary Distribution System in Nigeria: A Case Study of Ayetoro l Substation, Aguda, Lagos State. A Master of Engineering (M.Eng.) Degree Thesis in Electrical and Electronics Engineering, College of Engineering, Covenant University, Ota, Ogun State, Nigeria.

[19] Uzoechi, L.O. and E. Udo. Development of Outage Evaluation and Reliability Model for Benin City Power Distribution Network. American Journal of Engineering Research (AJER), (2017):6(3), 168-175.

[20] Atimati, E.E., Ezema, L.S., Iwuchukwu, U.C., Paulinus-Nwammu, C.F. and E.O. Ezugwu. Reliability Indices Evaluation of Distribution Networks for Automation. International Journal of Power Systems. (2019):4.

[21] Kirubarani, K. and A.P. Fathima. Distribution System Reliability Assessment for Improved Feeder Configurations. International Journal of Engineering and Advanced Technology (IJEAT), (2019):8(6).

[22] Kenya Power (2019). Nairobi county Reliability Indices for the period Jan to December 2019. Available at https://www.kplc.co.ke/content/item/795/system-average-interruption-frequency-index-saifi.