# Reliability Indices Evaluation of Distribution Networks for Automation

Ehinomen E. Atimati, Longinus S. Ezema, Uchechi. C. Iwuchukwu,
Chiedozie F. Paulinus-Nwammuo, Ernest O. Ezugwu
Department of Electrical and Electronic Engineering
Federal University of Technology
Owerri, Imo State, NIGERIA
ezemms@yahoo.com

*Abstract: -* The world electric power systems are fast becoming smart, with the grid possessing capabilities that enable it self-heal in the case of device failures. If the Nigerian distribution networks are automated, it would go a long way in sustaining the ailing power grid. For automation to be carried out in the network, certain features would be enhanced through integration of high-speed, reliable and secure data communication networks to manage the complex power systems effectively and intelligently. This work presents the reliability evaluation of power distribution networks in Rivers State, Nigeria. Certain reliability indices were calculated using data obtained from Port Harcourt Electricity Distribution Company (PHEDC), Ahoada Business unit and Agogo Services, Egi Power Distribution network. The Performance, reliability and quality of service of the networks were investigated. The investigation revealed the system had an average availability of 64.44% for Ahoada and 74.10% for Egi as against the ASAI goal of 99.99%, this values were obtained for Egi Network despite the fact it was supplied by a private turbine signaling that to enhance distribution network reliability, increased investment in power production was required and as such an indigenous automated distribution system that can remedy the unreliable local distribution system was suggested.

*Key words: -* Automation, Distribution Network, Performance Indices, Power Distribution, Power Quality, Reliability.

## 1 Introduction

Electric power distribution system functions mainly to receive electric power at one or more supply points and deliver it to individual loads. Since they play a major part in the electricity value chain and the part closest to the customers care has to be taken to ensure that its management is of the best standards. The Institute of Electrical and Electronic Engineers (IEEE) has defined Automation Distribution System (ADS) as a system that enables an electric utility to monitor, coordinate, and operate distribution components in real-time and possibly from remote locations [1]. This was made possible by advancements in communication technology which has resulted in very reliable, self-healing power systems that respond quickly to system outages and device failures as the happen.

Indonesia is among countries were the distribution network has been automated, especially the Semarang district, a small area where the automation was successfully implemented in 2010,circuit breakers and switches in the distribution substation network are monitored and controlled remotely and in real time. [2], [3], [4].

This work investigates and measures the indices for network efficiency, performance, reliability and quality of service of the distribution networks of Ahoada main town,in Ahoada East Local Government Area and Egi in Ogba/Egbema/Ndoni Local Government Area, both of Rivers State, Nigeria. It also proposed an indigenous automatic distribution system that can be adopted in local distribution systems.

When distribution networks are automated it brings about enhanced efficiency, reliability and improved power quality of electricity supply.

A similar work done by [5], carried out an investigation evaluating the reliability of the Onitsha power distribution network. Their results show that the smooth operation of the entire power system may be marred by unreliable distribution network. Their study was carried out for three years (2009-2011).Analytical technique was used to quantify the performance of the network over the years by evaluating the power outage data from Power Holding Company of Nigeria (PHCN) for various feeders that constituted the network. The effects of introducing Photo-Voltaic/inverter interconnection with the distribution network for improved system reliability were also evaluated. The result of the study revealed poor reliability of the network without the PV/inverter interconnection. They suggested that automating the network would lead to improved system reliability.

## 2 Research Methods

The research methodologies adopted for this work are survey and analytical method as looked into in the following sub-sections.

### 2.1 Analytical Method

This research evaluated system reliability using analytical methods as shown in equations 1-5 obtained from [6] as follows:

System Average Interruption Frequency Index (SAIFI)

$$SAIFI = \frac{\Sigma(\lambda_i N_i)}{N_T} = \frac{\text{Total number of customer interrupted}}{\text{Total number of customer served}} \quad (1)$$

System Average Interruption Duration Index (SAIDI)

$$SAIDI = \frac{\Sigma(U_i * N_i)}{N_T} = \frac{\text{Sum of all customer interruption duration}}{\text{Total number of customers served}} \quad (2)$$

Customer Average Interruption Duration Index (CAIDI)

$$CAIDI = \frac{\Sigma(U_i * N_i)}{\Sigma(\lambda_i N_i)} = \frac{\text{Sum of all customer interruption duration}}{\text{Total number of customer interrupted}} \quad (3)$$

Customer Average Interruption Frequency Index (CAIFI)

$$CAIFI = \frac{\Sigma(N_0)}{\Sigma(N_i)} = \frac{\text{Total number of customer interruptions}}{\text{Number of district customers interruption}} \quad (4)$$

Average Service Availability Index (ASAI)

$$ASAI = 1 - \frac{\Sigma(U_i * N_i)}{(N_T * T)} * \frac{100}{1}$$

$$ASAI = \frac{\text{customer hours demanded} - \text{customer hours off}}{\text{customer} - \text{hours demanded}} * \frac{100}{1} \quad (5)$$

Where, $\lambda_i$ is failure rate, $U_i$ is minutes or hour lost, $N_i$ is total number of customers interrupted, $N_T$ is total number of customer served, $N_0$ is total number of interruptions, and T is time period under study (168 hours).

These indices were calculated using data obtained from the Ahoada and Egi distribution network for a period of four months covering December 2015- March 2016.

### 2.2 Distribution Networks Surveyed

The Ahoada distribution network (ADN) covers over thirty (30) communities. The Ahoada business unit of PHEDC operates without a functional injection substation. It transmits 33KV to 33kv/415v distribution substation transformers in the communities.

The Egi Distribution System on the other hand covered a total of seventeen (17) communities. This network was not connected to the National Grid, it was serviced by a private Gas turbine owned by Total Exploration & Production company located in Ogba/Egbema/Ndoni Local Government Area of Rivers State, Nigeria.

## 3 Results and Analysis

The reliability evaluation was carried out on two distribution networks, and each was studied independently.

### 3.1 Reliability Assessment of Ahoada Distribution Network

The assessment covered all the areas of Ahoada Distribution Network in Ahoada Main Town with 4900 customers served although this number varied in some weeks in January and February out of 5320 customers in location as would be seen in Table 1. The indices were evaluated using data obtained from PHEDC Ahoada business unit, which was used to compute the respective reliability indices in Table 2 specifically for the month of March 2016, and the average system reliability indices for the four months covered were reflected in Table 3.

Table 1: Ahoada distribution network weekly activity report

| Wk | No. of interruption | Customers Hours interrupted | Customers Hours of available supply | Customers served |
|---|---|---|---|---|
| December | | | | |
| 1 | 17 | 77 | 91 | 4900 |
| 2 | 20 | 105 | 63 | 4900 |
| 3 | 15 | 42 | 126 | 4900 |
| 4 | 21 | 56 | 112 | 4900 |
| January | | | | |
| 1 | 6 | 14 | 154 | 4250 |
| 2 | 5 | 14 | 154 | 4259 |
| 3 | 12 | 21 | 147 | 4900 |
| 4 | 15 | 28 | 140 | 4900 |
| February | | | | |
| 1 | 14 | 73.22 | 94.78 | 4900 |
| 2 | 8 | 77.46 | 90.54 | 4900 |
| 3 | 9 | 28.02 | 139.98 | 4820 |
| 4 | 11 | 42 | 126 | 4820 |
| March | | | | |
| 1 | 7 | 88.04 | 79.96 | 4900 |
| 2 | 2 | 81.11 | 86.89 | 4900 |
| 3 | 10 | 38.12 | 129.88 | 4900 |
| 4 | 12 | 90.00 | 78 | 4900 |

The data from table I was used to develop table 2 for all the months but only the month of March is reflected in table 2. The summary of the average indices calculated for the four months is shown in table 3.

Table 2: Ahoada distribution network average system

| WK | λi (%) | Ui | Ni | $N_T$ | SAIFI (%) | SAIDI (%) | CAIDI | ASAI (%) | CAIFI |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 52.4 | 88.04 | 5320 | 4900 | 56.897 | 95.586 | 1.68 | 43.103 | 0.0010 |
| 2 | 48.28 | 81.11 | 5320 | 4900 | 52.418 | 88.062 | 1.68 | 47.582 | 0.0004 |
| 3 | 22.69 | 38.12 | 5320 | 4900 | 24.635 | 41.387 | 1.68 | 75.365 | 0.0020 |
| 4 | 53.57 | 90.00 | 5320 | 4900 | 58.163 | 97.714 | 1.68 | 41.837 | 0.0020 |
| MAR. AVERAGE | | | | | 48.028 | 80.687 | 1.68 | 51.972 | 0.0010 |

Table 3: ADN Average System Reliability Indices for the Four Months Covered

| Month | SAIFI | SAIDI | CAIDI | ASAI | CAIFI |
|---|---|---|---|---|---|
| Dec. | 45.238 | 76 | 1.68 | 54.761 | 0.004 |
| Jan. | 13.127 | 22.053 | 1.68 | 86.867 | 0.002 |
| Feb. | 35.845 | 60.219 | 1.68 | 64.154 | 0.002 |
| Mar. | 48.028 | 80.687 | 1.68 | 51.972 | 0.001 |

Fig. 1 to 5 shows the graphical representation of the various system reliability indices for the period covered for the Ahoada Distribution Network. Fig. 1, shows System Average Interruption Frequency Index (SAIFI) graph for the period, the interruption rate was at its maximum in the month of March and minimum in the month of January. System Average Interruption Duration Index (SAIDI) in Fig. 2 shows that the duration outages was highest in the month of March which was about 80% and at its minimum in the month of January.

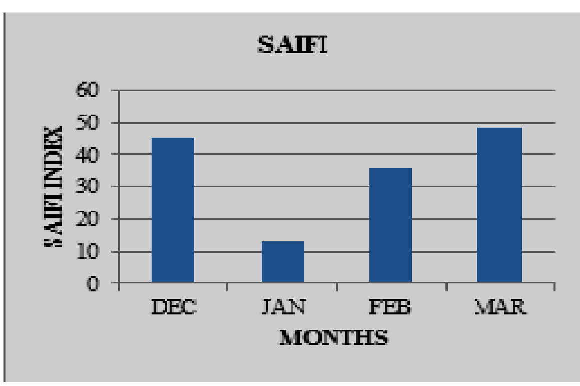


Fig. 1: Ahoada SAIFI index for four months

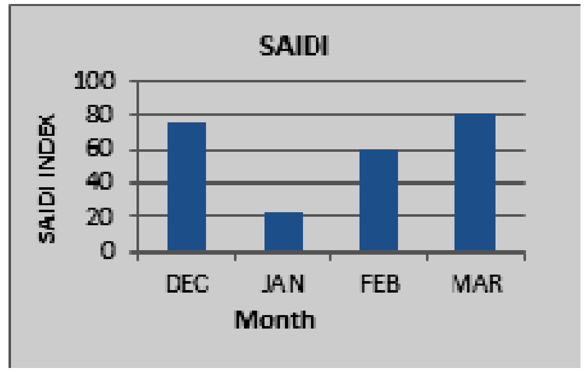


Fig. 2: Ahoada SAIDI for four months

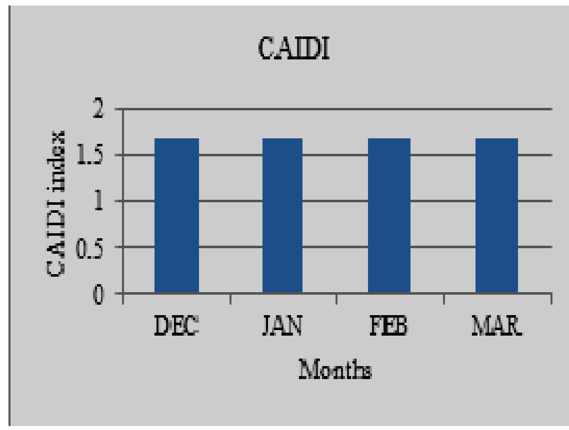


Fig. 3: Ahoada CAIDI

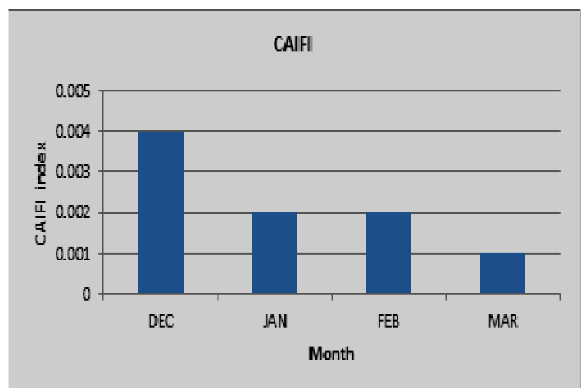


Fig. 4: Ahoada CAIFI

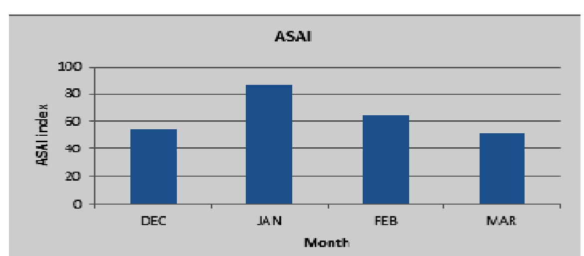


Fig. 5: Ahoada ASAI

Fig. 3 gives detailed information of Customer Average Interruption Duration Index (CAIDI), which was the same in the four months investigated. The Customer Average Interruption Frequency Index (CAIFI) is designed to show trends in customers interrupted and helps to show the number of customer affected out of the whole customer base. Fig. 4 is CAIFI of Ahoada Distribution System. It shows that customers experienced most interruptions in the month of December. Fig. 5, shows Average Service Availability Index (ASAI) graph for each of the month evaluated. Ahoada distribution network based on the ASAI standard of 99.99% proved unreliable with an average ASAI of about 64.44% for the four months. The networks reliability got worse every passing month as availability dropped from 86.867 in January to 51.972 in March 2016.

### 3.2 Reliability Assessment of Egi Power Distribution Network (EPDN)

The assessment covered only the feeder 1 package 4, and the communities under this feeder include Ede, Amah, Egita, Akabta, Obiozimini, Obukegi, Obiyebe, Erema and Itu with 3341 consumers served out of 3500 and additional two customers from third week of February through March as shown in Table 4, the Egi distribution network weekly activity report. The results obtained from the data was used in computation of the reliability indices shown in Tables 5 weekly for a single month, December 2015 and table VI shows the reliability indices for the four months from December 2015 to March 2016.

Table 4: Egi Distribution Network Weekly Activity Report

| Wk | No. of interruptions | Customers Hours interrupted (Hrs) | Customers Hours of available supply(Hrs) | **Customers in location** | **Customers served** |
|---|---|---|---|---|---|
| | | | **DECEMBER** | | |
| 1 | 7 | 42.58 | 125.42 | 3500 | 3341 |
| 2 | 8 | 40.37 | 127.63 | 3500 | 3341 |
| 3 | 7 | 40.01 | 127.99 | 3500 | 3401 |
| 4 | 7 | 40.11 | 127.89 | 3500 | 3490 |
| | | | **JANUARY** | | |
| 1 | 4 | 28.47 | 139.53 | 3500 | 3491 |
| 2 | 7 | 35.00 | 133 | 3500 | 3484 |
| 3 | 7 | 39.09 | 128.91 | 3500 | 3345 |
| 4 | 9 | 41.41 | 126.59 | 3500 | 3341 |
| | | | **FEBRUARY** | | |
| 1 | 11 | 50.11 | 117.89 | 3500 | 3341 |
| 2 | 10 | 49.00 | 119 | 3500 | 3341 |
| 3 | 7 | 39.44 | 128.56 | 3502 | 3343 |
| 4 | 12 | 45.24 | 122.76 | 3502 | 3343 |
| | | | **MARCH** | | |
| 1 | 10 | 49.16 | 118.84 | 3502 | 3343 |
| 2 | 16 | 61.09 | 106.91 | 3502 | 3343 |
| 3 | 7 | 39.11 | 128.89 | 3502 | 3343 |
| 4 | 7 | 29.41 | 138.59 | 3502 | 3343 |

Table 5: EPDN Average System Reliability Indices for December

| WK | $\lambda_i$(%) | Ui | Ni | $N_T$ | SAIFI (%) | SAIDI (%) | CAIDI | ASAI (%) | CAIFI |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 25.342 | 42.58 | 3500 | 3341 | 26.548 | 44.606 | 1.6802 | 73.449 | 0.002 |
| 2 | 24.029 | 40.37 | 3500 | 3341 | 25.173 | 42.291 | 1.6800 | 74.827 | 0.002 |
| 3 | 23.815 | 40.01 | 3500 | 3341 | 24.948 | 41.186 | 1.651 | 75.484 | 0.002 |
| 4 | 23.875 | 40.11 | 3500 | 3490 | 23.943 | 40.224 | 1.6800 | 76.057 | 0.002 |
| DEC AVERAGE | | | | | 25.153 | 42.076 | 1.673 | 74.954 | 0.002 |

The data from Table 4 was used to develop Table 5 for all the months reviewed but only the month of December was reflected in Table 5. The summary of the average indices calculated for the four months is shown in Table 6. Using the details of the indices computed in Table 6, Fig. 6 - 10 shows the graphical representation of SAIFI, SAIDI, CAIDI, ASAI and CAIFI respectively of Egi Distribution Network (EDN) for the surveyed period.

Table 6: Egi Distribution Network Average System Reliability Indices

| Month | SAIFI | SAIDI | CAIDI | ASAI | CAIFI |
|---|---|---|---|---|---|
| Dec. | 25.153 | 42.076 | 1.673 | 74.954 | 0.002 |
| Jan. | 22.022 | 36.996 | 1.6800 | 77.979 | 0.002 |
| Feb. | 28.651 | 48.132 | 1.68 | 71.349 | 0.003 |
| Mar. | 27.868 | 46.556 | 1.673 | 72.132 | 0.003 |

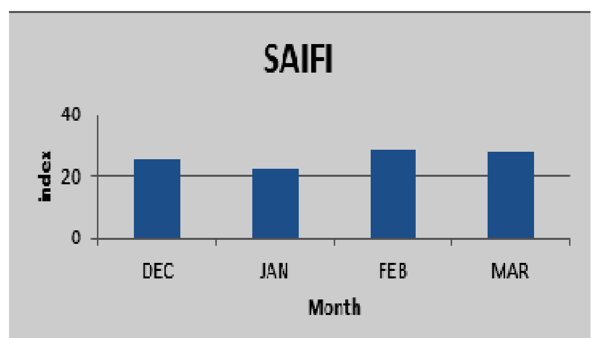


Fig. 6: Egi SAIFI

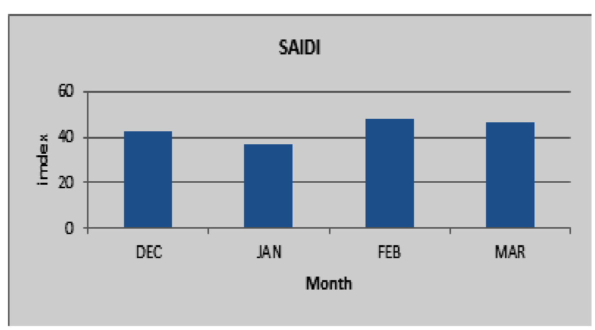


Fig. 7: Egi SAIDI

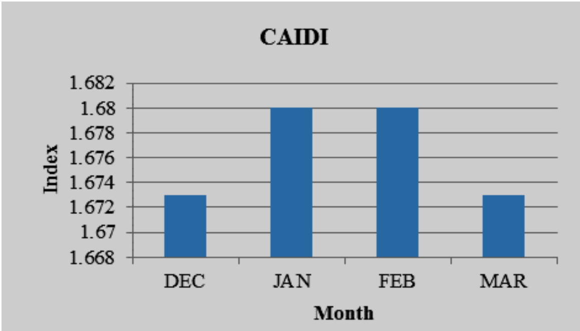


Fig. 8: Egi CAIDI

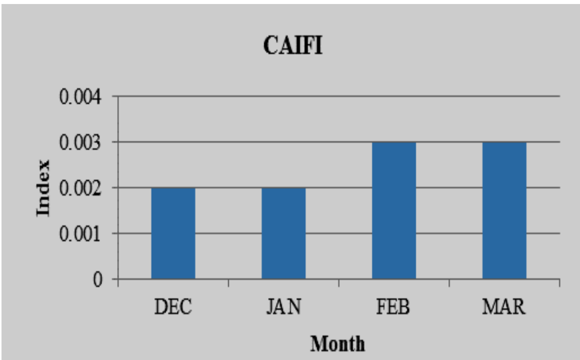


Fig. 9: Egi CAIFI

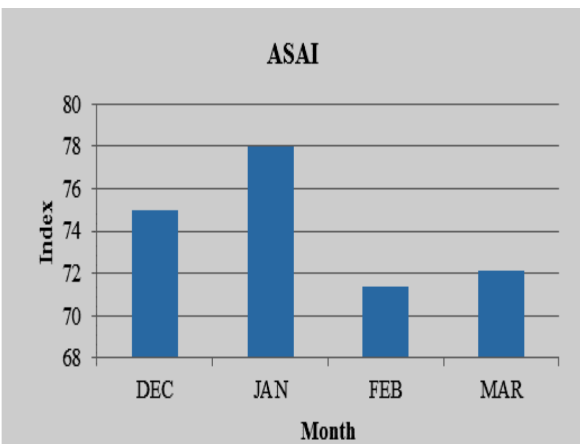


Fig. 10: Egi ASAI

Fig 6, shows System Average Interruption Frequency Index (SAIFI) graph for the period, the interruption rate was at its maximum in the month of February and minimum in the month of January. The average SAIFI for the period under study was about 25% which was relatively high as compared to 0.02% experienced in developed countries. Fig 7, displays System Average Interruption Duration Index (SAIDI) for the months evaluated, it shows that customers experienced quit a lot of interrupted power for hours in all the months, but it is observed that the month of February recorded the highest average of almost 50%. Fig. 8, shows the Customer Average Interruption Duration Index (CAIDI) graph for the period. The month of January and February were equal with average index of 1.68%. The Average Service Availability Index (ASAI) in fig. 10 for Egi distribution network revealed that its maximum index occurred in January with an index of about 77.98%. The systems average ASAI for the period under study was about 74% which is relatively low as compared 99.99% experienced in developed countries. The networks performed poorest in the month of February based on all the indices evaluated.

### 3.3 Performance /Efficiency Assessment

Performance evaluation establishes quality of electricity served [8]**,** this was done looking at two key areas: operational performance and customer Service.

For operational performance, the availability, reliability, and quality of power delivered to consumers, was observed to be very poor as seen in the indices while for customer Service, provision of key customer services such as connection and re-connection services, information and complaints handling, consumer education activities, were observed to be below average. For a proper performance evaluation to ascertain the reliability of a distribution system three key indices SAIDI, SAIFI and CAIDI are plotted together on a graph. The Figures 11 and 12 below shows the SAIDI, SAIFI and CAIDI plotted together in a graph for the distribution networks studied, Ahoada and Egi respectively.

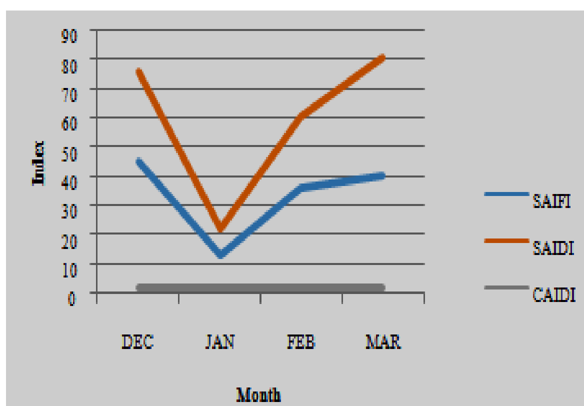


Fig. 1: Performance of Ahoada distribution System

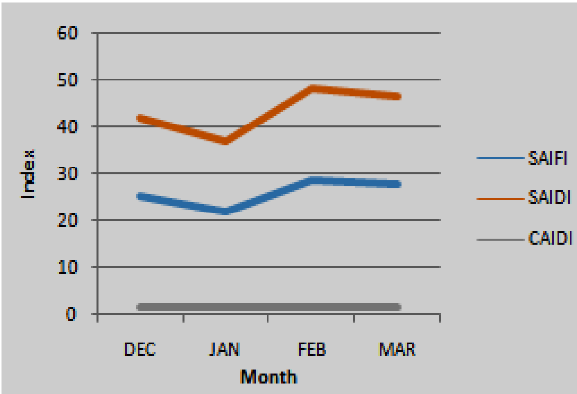


Fig. 2: Performance of Egi Distribution System

In Fig 11, the Ahoada case the system fared badly with each passing month from January to March as indicated by the upward value in SAIFI and SAIDI, although the Egi network improved slightly from values in February as at March but the values are still far from the desired values as shown in Fig 12.

### 3.4 Quality of Service

Here the characteristics of supply delivered to customers' premises are considered. Assessment of quality of service involves reliability measures, technicality of supply, and customer service. The ASAI industry standard of 99.99% was used gauge the quality of service for the two networks under study and the fell below expectation with the Ahoada network giving an average of 64.4% and the Egi network having an average of 74.1%.Fig 13 shows the combination of the ASAI graph for the two networks. The Egi network fared better of the two networks due to the fact that it was supplied by a private turbine yet its reliability was still lower than the standard. Poor reliability performance was recorded by [5] as well in their study of the Onitsha Business Unit distribution network in Onitsha, Anambra State, Nigeria).

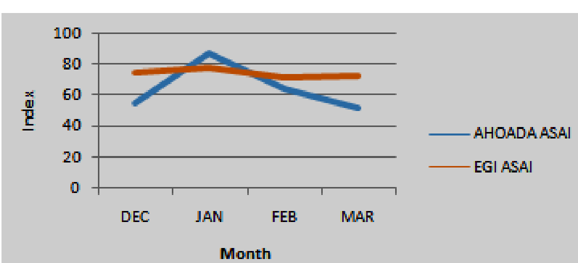


Fig. 3: ASAI Quality of service for Ahoada & Egi

Assessing the reliability of the two Distribution Networks, three of the indices calculated were used [8] [9]. An ASAI goal standard of 99.99% was used as the benchmark. In this work, Ahoada distribution network's saw their ASAI value decrease to 51.97% in March 2016 a very poor value when compared to the set point of comparison, while that of Egi was 72.13% in March 2016. Although this value for Egi in the month of March was slightly higher than for February but it was lower than the standard value of 99.99% used to guage a reliable network. Therefore, reliability for the two networks studied was very poor.These poor ASAI values suggest a need for improvement in the networks which automation would bring about. The customers in Ahoada pay bills despite voltage fluctuations and low voltage of supply most of the time.

### 3.5 Proposed Indigenous Automated Distribution System

Unreliability of the present power distribution network in Ahoada in Ahoada East Local Government Area and Egi in Ogba/Egbema/Ndoni Local Government Area, both of Rivers State has been shown in the above results discussed. A Conceptual Indigenous Real-time Monitoring System based on European protocol is proposed. This was developed in Akure Electricity Power Distribution System (AEPDS), it consists of three levels, the process level, the bay level and the station level as shown in Fig 15 [11].

The Graphic User Interface (GUI), the Electricity Power Distribution System (EPDS) Display and Distribution Central Controller (DCC), make up the Station Level; these are instruments that reside in the Electricity Distribution Stations. Global System for Mobile Communication (GSM) and Remote Terminal Unit (RTU) forms the Bay Level that transport information from various remote distribution sub stations (feeder pillars) to the DCC. Current Sensors (CS) and Voltage Sensor (VS) make-up process level, they detect any drop or seizures of power experienced by customers and transmit information to the RTU.

The detection of interruption is sensed by VS and CS which sends the information to the RTU which communicates the DCC through text message via a GSM communication network. The DCC performs fault evaluation processing using the received data and predetermined faults signatures to determine the nature of disturbance and presents the result in graphic user interface environment or EPDC display.

The set-up for collecting data on outages from the various remote sub-stations is shown in Fig 16. The voltage sensors seen in Fig 16 are used to sense any form of interruption experienced in each phase of the 33/0.415KVA transformer output. The RTU is a microprocessor controlled electronic device that interfaces sensed signals from the substations to a distributed control system or Supervisory Control and Data Acquisition (SCADA) system. The transmission of information in the proposed system is a two way communication. The SCADA or DCC system can send instruction to the RTU for it to control its sub units.

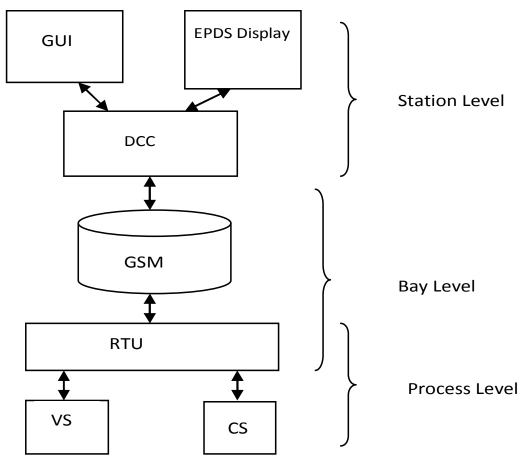


Fig. 14: Conceptual indigenous real-time monitoring system

Overall performance of the existing manual distribution system in the country can be made smart by deploying the process level of Fig 15, in all remote substations within the distribution network. Also the station level would have to be deployed in their respective distribution stations to improve reliability, controllability and ultimately achieve automation of the network.

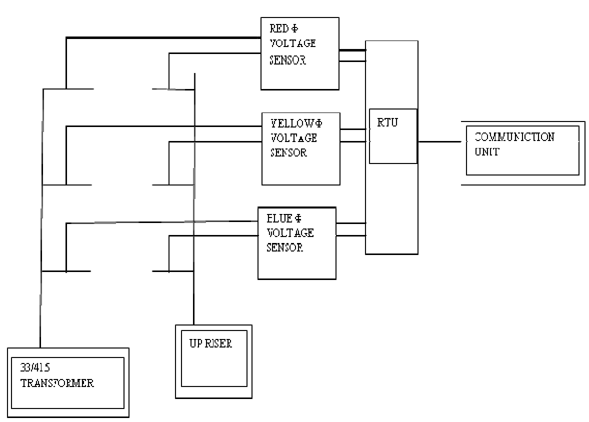


Fig. 15: Block diagram of an automated distribution system [11]

The Conceptual Indigenous Real-Time Monitoring System (CIRTMS) in Fig 16, is an adopted system proposed for the two power distribution networks under study. This will ensure a better and more reliable distribution network as it will limit the effects of interruption and increase power availability by reducing repair down time. The suggested system will provide real time information on the network status to aid in its management and thus improve its overall performance. The operation of the suggested automated distribution system is highly dependent on a reliable communication network. The reliability of communication networks especially in remote villages is usually not as high as that in urban areas. The offered solution also suffers from many component parts (VS, CS, RTU, etc) that may be hard to implement (for distribution networks without injection sub stations like Ahoada) and maintain over time. A central data collection system and the use of Internet of Things (IoT) can be used to improve this drawback.

# 4 Conclusion

This paper assesses the performance of two electricity distribution networks in Ahoada and Egi in Ogba/Egbema/Ndoni Local Government of River State Nigeria. The conventional performance indices SAIFI, SAIDI, CAIDI, ASAI and CAIFI were used to access the performance of the networks. The result of an average SAIFI for the period under study was about 37% for Ahoada and 25% for Egi which is relatively high as compared to the standard 0.02% expected.Similarly the average ASAI for Ahoada and Egi networks were of 64.44% and 74.10% respectively as against the ASAI goal of 99.99%. The poor performances of the distribution networks studied looking at efficiency, quality of service and reliability makes it imperative that the Nigerian power distribution needs to be automated. Adoption of a real-time monitoring system for automating the networks was proposed. Further work can be done by evaluating the index studied over a longer period of time and compare the system performance with existing automated distribution system in Nigeria.

*Acknowledgment:*
We wish to acknowledge the tremendous help offered by all the staff of Port Harcourt Electricity Distribution Company (PHEDC), Ahoada branch, Agogo's Services Egi Power Distribution Network and Obite Gas Plant (OGP), electrical department who provided us with the raw data and information used for this research.

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