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# Characterisation Of Reliability Indices For A Case Study Power Distribution Network In The South Eastern Nigeria

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***Abstract*— In this paper, characterisation of reliability indices for a case study power distribution network in the South Eastern Nigeria is presented. Specifically, the computation of distribution power transformer failure related reliability indices are presented along with modelling and forecasting of the yearly reliability indices based on the available dataset for a case study distribution power network in Aba, Abia State Nigeria. The reliability indices computed and modelled are the System Average Interruption Duration Index (SAIDI), the System Average Interruption Frequency Index (SAIFI), the Customer Average Interruption Duration Index (CAIDI) and the Average Service Availability Index (ASAI). The requisite data on the connected transformers and number of customers on the various injection substations on the network as well as transformer power outage historical data, the data on the customer hours and frequency due to the power outage histories are obtained for the case study electricity power distribution network for the years ranging from 2016 to 2020. The reliability indices were individually modelled using two period lagged dependent variable quadratic regression model. The study in this paper utilised the results of the yearly network wise reliability indices for year 2016 to 2020 to determine the model constants and hence develop the regression models that are used to forecast the values of each of the reliability indices for the years ahead of the available dataset, namely 2021, 2022 and 2023. The results of forecast using the models show that at the end of 2023, the SAIDI value would have increased to value of 462.6984 which amounts to 189.2504 % of the value of SAIDI on the base year, 2016, the SAIFI value would have increased to 5.907975 which amounts to 259.1217% of the base year, the CAIDI value would have decreased to 62.8498 which amounts to 90.95485 % of the base year and the ASAI value would have decreased to 90.74365 which amounts to 93.34903 % of the base year, 2016. In all, the forecast results show that the values of SAIDI and SAIFI keep increasing while the values of CAIDI and ASAI keep decreasing with time and these trends are all indication of increasing transformer failure. Hence, there is need to take proper steps in the power distribution network to address the issues.**

***Keywords*— *Reliability Indices, Transformer Failure, Power Distribution Network, System Average Interruption Duration Index (SAIDI), the System Average Interruption Frequency Index (SAIFI),***

## 1. Introduction

Effective and sustained functioning of power distribution network components is essential for sustainable power supply. However, there are numerous failures in many of the power distribution networks across Nigeria and this has worsened the problem in the Nigerian power sector [1,2,3,4,5,6,7,8,9]. Notably, the generated electric power from the national grid is far below the demand across the nation [10,11,12,13,14,15,16,17,18,19]. As such, any failure on the distribution network aggravates the already existing power problem in the country. Moreover, there is growing dependence of human begins on electricity due to the growing technology-driven solutions upon which our daily activates depend on [ 20,21, 22,23, 24,25, 26,27, 28,29, 30,31, 32,33, 34,35, 36]. As such, the electric energy demand will continue to grow into the far future.

Nowadays, the electric power supply across Nigeria comprises of the supply from the national grid along with individual and institutional installed alternative power supply systems which includes diesel and fossil fuel electric power generating systems, wind energy systems, biomass energy supply systems, solar photovoltaic power systems, mini and micro hydro power systems, and hybrid combinations of the different energy sources [37,38,39,38,39,40,41, 42,43, 44,45, 46,47,48,49,50,51,52,53,54,55,56,57]. While these alternative sources do serve their purposes, they are expensive when compared with the energy from the national grid. As such, many energy consumers still prefer to use the national grid supply whenever it is available [58,59]. Consequently, reliability assessment of the power distribution network from the national grid is essential [60,61,62,63,64]. Accordingly, in this paper, characterisation of reliability indices for a case study power distribution network in Nigeria is presented. Specifically, the computation of distribution power transformer failure related reliability indices are presented along with modelling and forecasting of the yearly reliability indices based on the available dataset for the case study distribution power network [65,66]. The reliability indices computed and modelled are the System Average Interruption Duration Index (SAIDI), the System Average Interruption Frequency Index (SAIFI), the Customer Average Interruption Duration Index (CAIDI) and the Average Service Availability Index (ASAI). The ideas presented in this study is relevant for the power distribution management and enhancement decision.

## 2. Methodology

### 2.1 The power distribution transformer reliability indices

Reliability indices are analytical tools that generally used to quantify and monitor the reliability of a system and also for tracking the improvements or failures in the system reliability. In this paper, four key power distribution transformer reliability indices are considered and they include;

i. System Average Interruption Duration Index (SAIDI)
ii. System Average Interruption Frequency Index (SAIFI)
iii. Customer Average Interruption Duration Index (CAIDI)
iv. Average Service Availability Index (ASAI)

The four reliability indices are computed in terms of the following feeder and injection substation parameters;

i. the duration of power outage (in Hours) caused by transformer faults in feeder, i in the power injection substation (denoted as $Df_i$)
ii. the number of customers which are connected and hence affected by the fault in feeder, i in the power injection substation (denoted as Ni)
iii. the number of power outages caused by transformer related faults in feeder, i in the power injection substation (denoted as $\lambda f_{\text{i}}$).
iv. the total number of customers which are connected to all the feeders in an injection substation (denoted as Nt)

System Average Interruption Duration Index (SAIDI) is used to quantify the duration of time the costumers in a power distribution network stay without power supply because of fault that occurred on the feeder and it is computed as follows:

$$\text{SAIDI} = \frac{\sum(Df_i * Ni)}{Nt} \qquad (1)$$

System Average Interruption Frequency Index (SAIFI) is used to quantify the frequency with which the power distribution network consumers experience power outages and it is computed as follows:

$$\text{SAIFI} = \frac{\sum Ni}{Nt} = \frac{\sum \lambda f_{\text{i}} * Ni}{Ni} \qquad (2)$$

Customer Average Interruption Duration Index (CAIDI) is used to quantify the average power outage duration which would be experienced by any given customer and it is computed as follows:

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

Average Service Availability Index (ASAI) is used to quantify the customer expected duration of power availability or uninterrupted supply within a year or a given period and it is computed as follows:

$$\text{ASAI} = 1 - \frac{\text{SAIDI}}{8760} \qquad (4)$$

### 2.2 The case study power distribution transformer dataset

In the power distribution network, the injection substations serves as the point from which power is fed to the various final consumer substations. In this paper, the 33 kV input and 11 kV output voltage class injection substations are considered for a case study Aba District Electricity Distribution Network, in Abia State Nigeria. The single line diagram of Aba Area Electricity Distribution Network is shown in Figure 1.

Specifically, the reliability indices considered are those associated with power distribution transformer at the injection substations which are installed to service the final consumers and they have capacities in the range of 11kV and 33kV feeders. Accordingly, requisite data on the connected transformers and number of customers on the various injection substations on the network as well as transformer power outage historical data, the data on the customer hours and frequency due to the power outage histories are obtained for the case study electricity power distribution network for the years ranging from 2016 to 2020. A sample feeder wise transformer outage summary for the 2016 dataset is presented in Table 1. The injection substations wise transformer outage summary for year 2016 to 2020 are presented in Table 2.

Specifically, in this paper, the results of the yearly network wise reliability indices for year 2016 to 2020 are used to determine the time series regression model constants values and hence develop the regression models that are used to forecast the values of each of the reliability indices for the years ahead of the available dataset, namely 2021, 2022 and 2023.

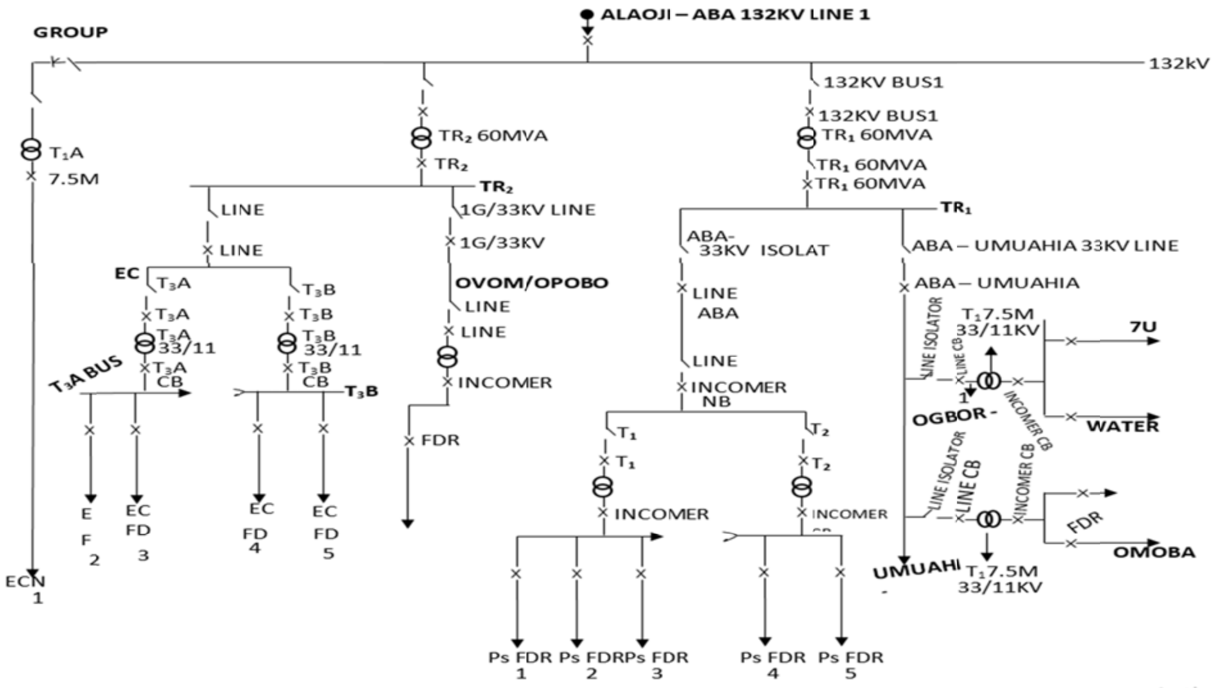


Figure 1 The single line diagram of the case study Aba Area Electricity Distribution Network

**Table 1 The feeder wise transformer outage summary for 2016**

| S/No | Feeder Name and injection substation | Voltage level | No. of Trfs | No of Customers (Ni) | Outage due to Trf Fault (λf) | Outage Duration due to Trf Fault (Df) | Customer Hrs due to Trf Fault (Ni*Df) | Customer Frequency due to Trf Fault (Ni*λf) |
|---|---|---|---|---|---|---|---|---|
| **1** | **Feeder: PS FDR-1** **Injection substation: Power Station** | 11KV | 27 | 5,002 | 0 | 0 | 0 | 0 |
| **2** | **Feeder: PS FDR-2** **Injection substation: Power Station** | 11KV | 59 | 8,814 | 7 | 302 | 2,661,828 | 61,698 |
| **3** | **Feeder: PS FDR-3** **Injection substation: Power Station** | 11KV | 27 | 3,251 | 6 | 134 | 435,634 | 19,506 |
| **4** | **Feeder: PS FDR-4** **Injection substation: Power Station** | 11KV | 70 | 7,530 | 8 | 385 | 2,899,050 | 60,240 |
| **5** | **Feeder: PS FDR-5** | 11KV | 62 | 5,535 | 7 | 284 | 1,571,940 | 38,745 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **Injection substation: Power Station** | | | | | | | |
| **6** | **Feeder: ECN FDR-1**<br>**Injection substation: ECN** | 11KV | 21 | 3,300 | 0 | 0 | 0 | 0 |
| **7** | **Feeder: ECN FDR-2**<br>**Injection substation: ECN**<br>**Injection substation: ECN** | 11KV | 82 | 16,546 | 17 | 1,160 | 19,193,3 60 | 281,282 |
| **8** | **Feeder: ECN FDR-3**<br>**Injection substation: ECN** | 11KV | 33 | 6,204 | 2 | 150 | 930,600 | 12,408 |
| **9** | **Feeder: ECN FDR-4**<br>**Injection substation: ECN** | 11KV | 72 | 7,656 | 12 | 902 | 6,905,71 2 | 91,872 |
| **10** | **Feeder: ECN FDR-5**<br>**Injection substation: ECN** | 11KV | 28 | 5,940 | 0 | 0 | 0 | 0 |
| **11** | **Feeder: 7UP FDR**<br>**Injection substation: Ogbor Hill** | 11KV | 81 | 8,316 | 12 | 1,560 | 12,972,9 60 | 99,792 |
| **12** | **Feeder: WATERSIDE**<br>**Injection substation: Ogbor Hill** | 11KV | 40 | 7,261 | 2 | 198 | 1,437,67 8 | 14,522 |
| **13** | **Feeder: IGI FDR**<br>**Injection substation: 33KV (IGI & Aba/Umuahia** | 33KV | 30 | 13,850 | 4 | 128 | 1,772,80 0 | 55,400 |
| **14** | **Feeder: ABA/UMUAHIA**<br>**Injection substation: 33KV (IGI & Aba/Umuahia** | 33KV | 104 | 13,150 | 9 | 806 | 10,598,9 00 | 118,350 |
| **15** | **Feeder: OVOM FDR**<br>**Injection substation: Ovom** | 11KV | 18 | 8,440 | 3 | 900 | 7,596,00 0 | 25,320 |
| **16** | **Feeder: OMOBA** | 11KV | 18 | 4,550 | 0 | 0 | 0 | 0 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **FDR**<br>**Injection substation: Omoba** | | | | | | | |
| **17** | **Feeder: OVUOJI FDR**<br>**Injection substation: Omoba** | 11KV | 58 | 4,153 | 13 | 1,970 | 8,181,410 | 53,989 |
| | TOTAL | | **830** | **129,498** | **102** | **8,879** | **77,157,872** | **933,124** |

**Table 2 The Injection substations wise transformer outage summary for year 2016 to 2020**

| TOTAL | No. of Transformer | No of Customers (Ni) | Outage due to Transformer Fault (λf) | Outage Duration due to Transformer Fault (Df) | Customer Hrs due to Transformer Fault (Ni*Df) | Customer Frequency due to Transformer Fault (Ni*λf) | Transformer failure percentage (%) |
|---|---|---|---|---|---|---|---|
| **2016** | **830** | **129,498** | **102** | **8,879** | **77,157,872** | **933,124** | **15.4** |
| **2017** | **830** | **130,516** | **101** | **7,798** | **63,306,989** | **859,568** | 15.0 |
| **2018** | **835** | **131,637** | **109** | **8,745** | **77,197,952** | **1,013,876** | 13.9 |
| **2019** | **853** | **134,778** | **123** | **8,889** | **85,156,308** | **1,140,322** | 19.6 |
| **2020** | **885** | **135,098** | **162** | **10,990** | **96,008,136** | **1,522,318** | 28.3 |

### 2.3 Development and prediction performance evaluation of the regression model

The reliability indices are individually modelled as $R_{a(t)}$ using two period lagged dependent variable quadratic regression model which is expressed as follows;

$$R_{a(t)} = a(t^2) + b(t) + c + d\left(R_{a(t-1)}\right) \quad (5)$$

Where $R_{a(t)}$ and $P_{a(t-1)}$ are the reliability index values estimated at time t and t-1. Also the, b, c and d denote constants values that are determined in this paper using Microsoft Excel Solver optimization tool. The error, $e_{(t)}$ resulting for the model prediction and the average of $P_{a(t)}$ computed for t = 1,2,3,…n are determined as follows;

$$e_{(t)} = R_{a(t)} - R_{p(t)} \quad (6)$$

$$\overline{R_a} = \left(\frac{1}{n}\right)\left(\sum_{t=1}^{n}\left(R_{a(t)}\right)\right) \quad (7)$$

In addition, the model prediction performance are evaluated using the following parameters;

$$MSE = \left(\frac{1}{n}\right)\left(\sum_{t=1}^{n}\left(e_{(t)}\right)^2\right) \quad (8)$$

$$RMSE = \sqrt[2]{\left[\left(\frac{1}{n}\right)\left(\sum_{t=1}^{n}\left(e_{(t)}\right)^2\right)\right]} \quad (9)$$

$$MAPE = \left(\frac{1}{n}\right)\left(\sum_{t=1}^{n}\left(\frac{R_{a(t)} - R_{p(t)}}{R_{a(t)}}\right)\right) \quad (10)$$

$$MPE = \left(\frac{100}{n}\right)\left(\sum_{t=1}^{n}\left(\frac{R_{a(t)} - R_{p(t)}}{R_{a(t)}}\right)\right) \quad (11)$$

$$MAD = \left(\frac{1}{n}\right)\left(\sum_{t=1}^{n}\left|R_{a(t)} - \overline{R_a}\right|\right) \quad (12)$$

Where MSE denotes the Mean Squared Error, RMSE denotes the Root Mean Squared Error MAPE denotes the Mean Absolute Percentage Error, MPE denotes the Mean Percentage Error and MAD denotes the Mean Absolute Deviation.

### 3. Results and Discussion

Notably, in this paper, the feeder wise transformer outage dataset for year 2016 to 2020 were used to compute the yearly feeder wise and network wise values for the four reliability indices considered in this paper. The study in this paper utilised the results of the yearly network wise reliability indices for year 2016 to 2020 to determine the model constants and hence develop the regression models that are used to forecast the values of each of the reliability indices for the years ahead of the available dataset, namely 2021, 2022 and 2023.

**Table 3 Results of the feeder wise reliability indices for year 2016**

| S/No | Feeder Name | SAIDI Transformer Fault | SAIFI Transformer Fault | CAIDI Transformer Fault | ASAI Transformer Fault (%) | CAIDI Transformer Fault |
|---|---|---|---|---|---|---|
| 1 | PS FDR-1 | 0.00 | 0.00 | 0.00 | 100.00 | 0 |
| 2 | PS FDR-2 | 88.34 | 2.05 | 43.14 | 98.99 | 43.14 |
| 3 | PS FDR-3 | 14.46 | 0.65 | 22.33 | 99.83 | 22.33 |
| 4 | PS FDR-4 | 96.21 | 2.00 | 48.13 | 98.90 | 48.13 |
| 5 | PS FDR-5 | 52.17 | 1.29 | 40.57 | 99.40 | 40.57 |
| 6 | ECN FDR-1 | 0.00 | 0.00 | 0.00 | 100.00 | 0 |
| 7 | ECN FDR-2 | 484.12 | 7.09 | 68.24 | 94.47 | 68.24 |
| 8 | ECN FDR-3 | 23.47 | 0.31 | 75.00 | 99.73 | 75 |
| 9 | ECN FDR-4 | 174.18 | 2.32 | 75.17 | 98.01 | 75.17 |
| 10 | ECN FDR-5 | 0.00 | 0.00 | 0.00 | 100.00 | 0 |
| 11 | 7UP FDR | 832.83 | 6.41 | 130.00 | 90.49 | 130 |
| 12 | WATERSIDE | 92.29 | 0.93 | 99.00 | 98.95 | 99 |
| 13 | IGI FDR | 65.66 | 2.05 | 32.00 | 99.25 | 32 |
| 14 | ABA/UMUAHIA | 392.55 | 4.38 | 89.56 | 95.52 | 89.56 |
| 15 | OVOM FDR | 900.00 | 3.00 | 300.00 | 89.73 | 300 |
| 16 | OMOBA FDR | 0.00 | 0.00 | 0.00 | 100.00 | 0 |
| 17 | OVUOJI FDR | 940.07 | 6.20 | 151.54 | 89.27 | 151.54 |
| | Average | 244.49 | 2.28 | 69.10 | 97.21 | 69.1 |

**Table 4 Results of the yearly network wise reliability indices for year 2016 to 2020**

| OPERATION YEAR | SAIFI TRANSFORMER FAULT | SAIDI TRANSFORMER FAULT | ASAI TRANSFORMER FAULT (%) | CAIDI TRANSFORMER FAULT |
|---|---|---|---|---|
| **2016** | 38.68 | 4,156.35 | 1,652.55 | 1,174.67 |
| **2017** | 37.79 | 3,334.43 | 1,661.94 | 1,319.18 |
| **2018** | 40.02 | 3,711.24 | 1,657.63 | 1,259.30 |
| **2019** | 48.12 | 3,927.06 | 1,655.17 | 1,026.72 |
| **2020** | 65.65 | 4,975.33 | 1,643.20 | 1,123.65 |
| **TOTAL** | **230.26** | **20,104.41** | **8,270.50** | **5,903.52** |

The results of the actual and predicted values of the System Average Interruption Duration Index (SAIDI) transformer fault reliability index are shown in Table 5 and Figure 2 which shows the model constants values and the SAIDI forecast values for the years 2021 to 2023. The resulting two period lagged dependent variable quadratic regression model for SAIDI is given in Equation 13. The results of SAIDI forecast using the model in Equation 13 show that at the end of 2023, the SAIDI value would have increased to value of 462.6984 which amounts to 189.2504 % of the value of SAIDI on the base year, 2016.

$$\mathbf{SAIDI}_{a(t)} = 0.32t^2 + 37.15638t + 0.13 + 0.333563\left(\mathbf{SAIDI}_{a(t-1)}\right) \quad (13)$$

Table 5 The Actual and predicted values of the System Average Interruption Duration Index (SAIDI) Transformer Fault

| Year | Year index, t | Actual SAIDI Transformer Fault, SAIDI $_{a(t)}$ | a | b | c | d | Predicted SAIDI Transformer Fault , SAIDI $_{p(t)}$ | Percentage relative to the base year value |
|---|---|---|---|---|---|---|---|---|
| 2016 | 1 | 244.49 | 0.32 | 37.156 | 0.13 | 0.333563 | 244.49 | 100 |
| 2017 | 2 | 196.14 | 0.32 | 37.156 | 0.13 | 0.333563 | 196.14 | 80.22414 |
| 2018 | 3 | 218.31 | 0.32 | 37.156 | 0.13 | 0.333563 | 218.8403 | 89.5089 |
| 2019 | 4 | 231 | 0.32 | 37.156 | 0.13 | 0.333563 | 242.7509 | 99.28868 |
| 2020 | 5 | 292.67 | 0.32 | 37.156 | 0.13 | 0.333563 | 288.9521 | 118.1857 |
| 2021 | 6 | | 0.32 | 37.156 | 0.13 | 0.333563 | 338.3585 | 138.3936 |
| 2022 | 7 | | 0.32 | 37.156 | 0.13 | 0.333563 | 402.0253 | 164.4343 |
| 2023 | 8 | | 0.32 | 37.156 | 0.13 | 0.333563 | 462.6984 | 189.2504 |
| | **MSE: 30.4375** | | | **MAD: 3.19982** | | | **MAPE: 0.01320** | |
| | **RMSE: 5.517022** | | | | | | **MPE: -0.00812** | |

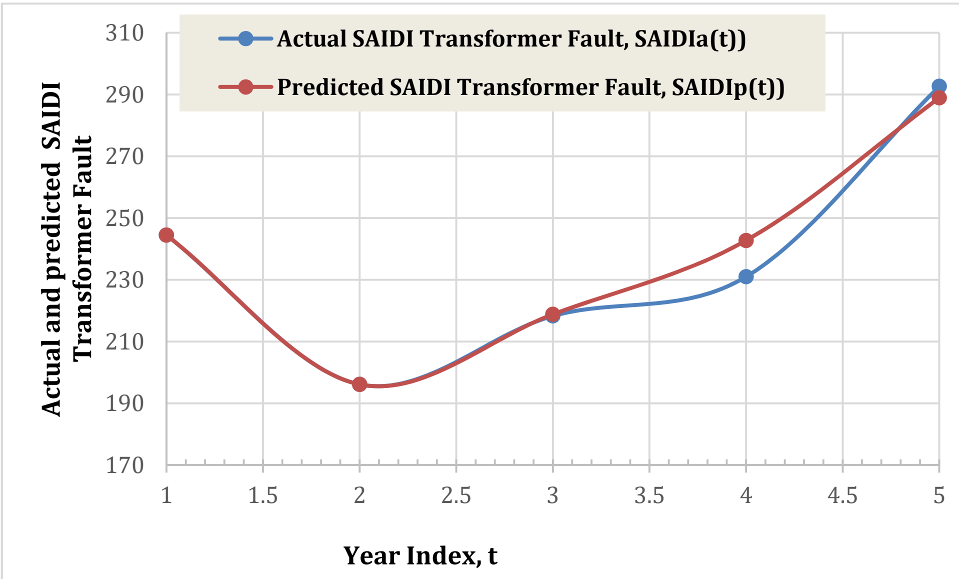


**Figure 2 The graph of the actual and predicted values of the System Average Interruption Duration Index (SAIDI) Transformer Fault**

The results of the actual and predicted values of the System Average Interruption Frequency Index (SAIFI) transformer fault reliability index are shown in Table 6 and Figure 3 which shows the model constants values and the SAIFI forecast values for the years 2021 to 2023. The resulting two period lagged dependent variable quadratic regression model for SAIFI is given in Equation 14. The results of SAIFI forecast using the model in Equation 14 show that at the end of 2023, the SAIFI value would have increased to a value of 5.907975 which amounts to 259.1217% of the value of SAIFI on the base year, 2016.

$$\text{SAIFI}_{a(t)} = \mathbf{0.13}t^2 + \mathbf{0.645284}t + \mathbf{0.14}(\text{SAIFI}_{a(t-1)}) \quad (14)$$

**Table 6 The Actual and predicted values of the System Average Interruption Frequency Index (SAIFI) Transformer Fault**

| Year | Year index, t | Actual SAIFI Transformer Fault, $SAIFI_{a(t)}$ | a | b | c | d | Predicted SAIFI Transformer Fault, $SAIFI_{p(t)}$ | Percentage relative to the base year value |
|---|---|---|---|---|---|---|---|---|
| 2016 | 1 | **2.28** | **0.13** | **0.645284** | **0** | **0.14** | 2.28 | 100 |
| 2017 | 2 | **2.22** | 0.13 | 0.645284 | 0 | 0.14 | 2.22 | 97.36842 |
| 2018 | 3 | **2.35** | 0.13 | 0.645284 | 0 | 0.14 | 2.385051 | 104.6075 |
| 2019 | 4 | **2.83** | 0.13 | 0.645284 | 0 | 0.14 | 3.021935 | 132.541 |
| 2020 | 5 | **3.86** | 0.13 | 0.645284 | 0 | 0.14 | 3.685418 | 161.6411 |
| 2021 | 6 | 4.397902 | 0.13 | 0.645284 | 0 | 0.14 | 4.397902 | 192.8904 |
| 2022 | 7 | 5.187385 | 0.13 | 0.645284 | 0 | 0.14 | 5.187385 | 227.5169 |
| 2023 | 8 | 5.907975 | 0.13 | 0.645284 | 0 | 0.14 | 5.907975 | 259.1217 |
| | **MSE: 0.0137** | | | **MAD: 0.08031** | | | **MAPE: 0.0256** | |
| | **RMSE: 0.1171** | | | | | | **MPE:- 0.0075** | |

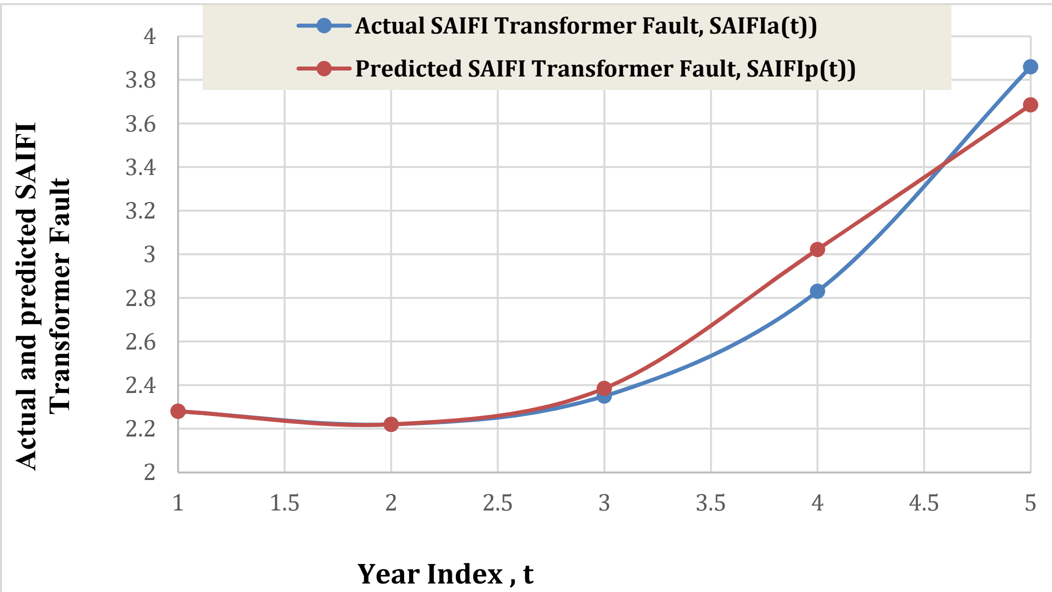


**Figure 3 The graph of the actual and predicted values of the System Average Interruption Frequency Index (SAIFI) Transformer Fault**

The results of the actual and predicted values of the Customer Average Interruption Duration Index (CAIDI) transformer fault reliability index are shown in Table 6 and Figure 3 which show the model constants values and the CAIDI forecast values for the years 2021 to 2023. The resulting two period lagged dependent variable quadratic regression model for CAIDI is given in Equation 15. The results of CAIDI forecast using the model in Equation 15 show that at the end of 2023, the CAIDI value would have decreased to a value of 62.8498 which amounts to 90.95485 % of the value of CAIDI on the base year, 2016.

$$\mathrm{CAIDI}_{a(t)} = 96.655t^2 + 0.1t + 0.6 + 0.07\left(\mathrm{CAIDI}_{a(t-1)}\right) \quad (15)$$

Table 6 The Actual and predicted values of the Customer Average Interruption Duration Index (CAIDI) Transformer Fault

| Year | Year index, t | Actual CAIDI Transformer Fault, $R_{a(t)}$ | a | b | c | d | Predicted CAIDI Transformer Fault, $R_{p(t)}$ | Percentage relative to the base year value |
|---|---|---|---|---|---|---|---|---|
| 2016 | 1 | **69.1** | **96.655** | **0.1** | **0.6** | **0.07** | 69.1 | 100 |
| 2017 | 2 | **77.6** | 96.65513 | 0.1 | 0.6 | 0.07 | 77.6 | 112.301 |
| 2018 | 3 | **74.08** | 96.65513 | 0.1 | 0.6 | 0.07 | 55.23213 | 79.93073 |
| 2019 | 4 | **60.4** | 96.65513 | 0.1 | 0.6 | 0.07 | 58.03913 | 83.99296 |
| 2020 | 5 | **66.1** | 96.65513 | 0.1 | 0.6 | 0.07 | 66.10073 | 95.65953 |
| 2021 | 6 | 61.82313 | 96.65513 | 0.1 | 0.6 | 0.07 | 61.82313 | 89.46908 |
| 2022 | 7 | 64.88825 | 96.65513 | 0.1 | 0.6 | 0.07 | 64.88825 | 93.90485 |
| 2023 | 8 | 62.8498 | 96.65513 | 0.1 | 0.6 | 0.07 | 62.8498 | 90.95485 |
| | **MSE: 72.163189** | | | **MAD: 4.2419** | | | **MAPE: 0.058705** | |
| | **RMSE: 8.494899** | | | | | | **MPE: 0.0587** | |

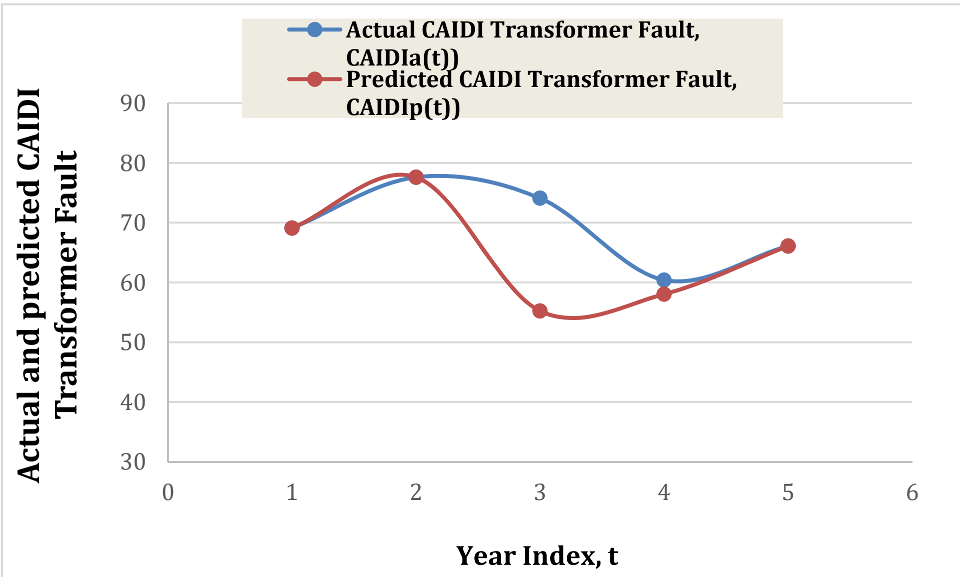


**Figure 4 The graph of the actual and predicted values of the Customer Average Interruption Duration Index (CAIDI) Transformer Fault**

The results of the actual and predicted values of the Average Service Availability Index (ASAI) transformer fault reliability index are shown in Table 6 and Figure 5 which show the model constants values and the ASAI forecast values for the years 2021 to 2023. The resulting two period lagged dependent variable quadratic regression model for ASAI is given in Equation 16. The results of ASAI forecast using the model in Equation 16 show that at the end of 2023, the ASAI value would have decreased to a value of 90.74365 which amounts to 93.34903 % of the value of ASAI on the base year, 2016.

$$\mathrm{ASAI}_{a(t)} = \mathbf{1.61E-07}t^2 + \mathbf{0.050355}t + \mathbf{1.00556}\left(\mathrm{ASAI}_{a(t-1)}\right) \quad (16)$$

In all, the forecast results show that the values of SAIDI and SAIFI keep increasing while the values of CAIDI and ASAI keep decreasing with time and these trends are all indication of increasing transformer failure. Hence, there is need to take proper steps in the power distribution network to address the issue.

Table 6 The actual and predicted values of the Average Service Availability Index (ASAI) Transformer Fault

| Year | Year index, t | Actual ASAI Transformer Fault, $R_{a(t)}$ | a | b | c | d | Predicted ASAI Transformer Fault, $R_{p(t)}$ | Percentage relative to the base year value |
|---|---|---|---|---|---|---|---|---|
| 2016 | 1 | **97.209** | **1.61E-07** | **0.050355** | **0** | **1.00556** | 97.209 | 100 |
| 2017 | 2 | **97.7609** | 1.61E-07 | 0.050355 | 0 | 1.00556 | 97.54811 | 100.3488 |
| 2018 | 3 | **97.5079** | 1.61E-07 | 0.050355 | 0 | 1.00556 | 97.8513 | 100.6607 |
| 2019 | 4 | **97.363** | 1.61E-07 | 0.050355 | 0 | 1.00556 | 97.24441 | 100.0364 |
| 2020 | 5 | **96.6591** | 1.61E-07 | 0.050355 | 0 | 1.00556 | 96.64551 | 99.42033 |
| 2021 | 6 | 95.38379 | 1.61E-07 | 0.050355 | 0 | 1.00556 | 95.38379 | 98.12238 |
| 2022 | 7 | 93.44677 | 1.61E-07 | 0.050355 | 0 | 1.00556 | 93.44677 | 96.12975 |
| 2023 | 8 | 90.74365 | 1.61E-07 | 0.050355 | 0 | 1.00556 | 90.74365 | 93.34903 |
| | **MSE: 0.03549** | | | **MAD: 0.1377** | | | **MAPE: 0.00141** | |
| | **RMSE: 0.188389** | | | | | | **MPE: 2.69751E-06** | |

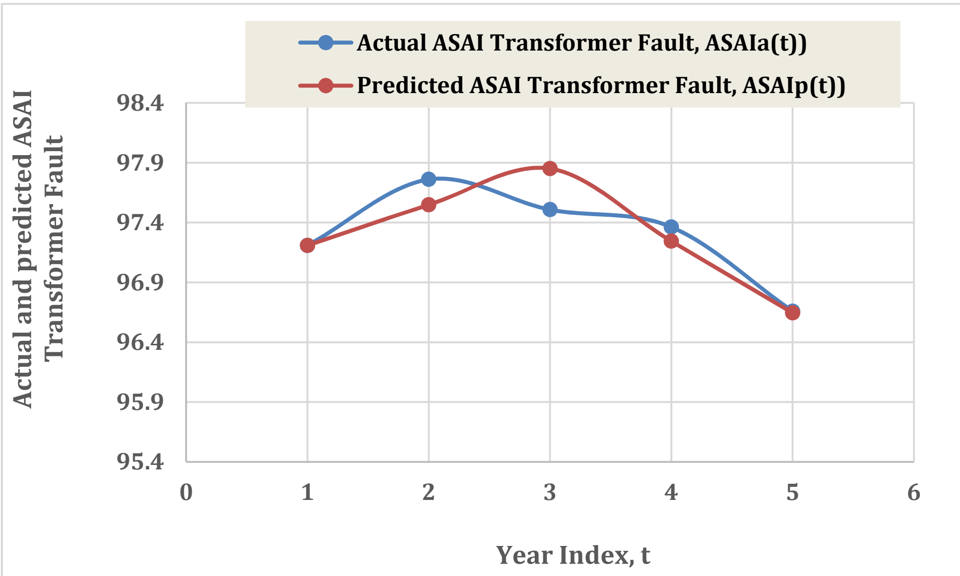


**Figure 5 The graph of the actual and predicted values of the Average Service Availability Index (ASAI) Transformer Fault**

## 4. Conclusion

In the paper, the computation of distribution power transformer failure related reliability indices are presented along with modelling and forecasting of the yearly reliability indices based on the available dataset for a case study distribution power network in Aba, Abia State Nigeria. The reliability indices computed and modelled are the System Average Interruption Duration Index (SAIDI), the System Average Interruption Frequency Index (SAIFI), the Customer Average Interruption Duration Index (CAIDI) and the Average Service Availability Index (ASAI). In all, the forecast results show that the values of SAIDI and SAIFI keep increasing while the values of CAIDI and ASAI keep decreasing with time and these trends are all indication of increasing transformer failure. Hence, there is need to take proper steps in the power distribution network to address the issues.

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