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Reliability Assessment of Electrical Energy Distribution System – A Case Study of Port Harcourt Distribution Network

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Abstract:* This Paper Presents the Reliability Assessment of Electrical Energy Distribution System in Port Harcourt using the Analytical Technique and ETAP software as the simulation tool to run the reliability assessment of the System. The analysis was carried out using 2014 and 2015 historical data of Secretariat, Silver Bird, Water Works, UST and School of Nursing Injection Substations obtained from the Port Harcourt Electricity Distribution Company[PHEDC]. The results of the analysis revealed that Secretariat Injection Substation is the most reliable in the network when compared to the other four substations as it recorded system indices of ASAI: 99.90, SAIFI: 0.877, SAIDI: 8.11, CAIDI: 9.25 in 2014 and ASAI: 99.91, SAIFI: 0.873, SAIDI: 8.13, CAIDI: 9.14 in 2015. However, the overall reliability indices of the five substations under review as obtained from the analysis, revealed that the reliability of the distribution system is far below the set benchmark. System re-configuration and introduction of Photovoltaic Systems to re- supply interrupted loads at a shorter time are therefore recommended.
***Keywords —* Reliability Assessment, Electrical Energy, Distribution System, Reliability Indices, Load Point Indices, System Indices and ETAP.**

I. INTRODUCTION

The fundamental purpose of Electrical Power System is to provide an adequate electric power supply to all points of utilization at an economically acceptable rate with reasonable level of reliability.

Reliability of power supply has always been an important issue in the electric utility systems. Availability of high quality uninterrupted electric power is essential to the industrial and economic growth of a nation.

Electricity supply involves a very complex and highly integrated system. Failures in any part of it can cause interruptions which range from inconveniencing a number of local residents, to major and widespread catastrophic distruptions of supply. The economic impact of these outages is not restricted to loss of revenue by the utility or loss of energy utilization by the customer but include indirect costs imposed on the society and the environment due to the outage [9]

A power system consists of a generation, transmission and a distribution system. Traditionally, reliability analysis and evaluation techniques at the distribution level have been far less developed than at the generation or transmission levels since distribution outages are more localized and less costly than generation and transmission level outages.

However, analysis of the customer failure statistics of most utilities shows that the distribution system makes the greatest individual contribution to the unavailability of supply to a customer [9]. The distribution systems account for up to 80% of all customer reliability problems. Hence, improving distribution reliability is the key to improving customer reliability [9].

Since the primary purpose of the system is to satisfy customer requirements and the proper functioning and longevity of the system are essential requisites for continued satisfaction, it is necessary that both demand and supply considerations are appropriately viewed and included in the systems. Therefore, the distribution reliability is one of the most important in the electric power industry due to its high impact on the cost of electricity and its high correlation with customer satisfaction.

The rapid increase in the population of people migrating from the rural areas to the urban areas, particularly Port Harcourt, Rivers State has caused an unprecedented increase in energy demand. However, the power system facilities, particularly the distribution network has not witnessed a proportionate expansion nor adequate maintenance thus leading to;

A. Overloading of the system,
B. unreliable power supply to consumers
C. Transient behaviour of the systems.
D. Constant power outages leading to shutdown of production activities and eventual loss of revenue and gross profits.

There's therefore no doubt that there's an immense need for the improvement and the expansion of the distribution Network system in Port Harcourt but this will however not be achieved without a proper Reliability Assessment of the network.
This paper is therefore aimed at assessing the reliability of the Port Harcourt Town Distribution System using the Analytical Technique and the Electrical Transient Analyzer Program (ETAP) as the simulation tool. It further examines the determinants affecting the reliability of the distribution system and thus recommended some mitigation techniques in order to improve the reliability of the system.

II. MATERIALS AND METHODS

A. Materials

The materials utilized in this paper are the historical data of the five distribution injection substations that make up the network under review. These data, which covers a period of two years (2014 – 2015) were derived from the daily operational report/log book of the five substations under review which are owned by the Port Harcourt Electricity Distribution Company.

B. Method

There basically two techniques used in distribution system reliability assessment, namely; Numerical Simulation Technique otherwise known as Monte Carlo Simulation and the Analytical Technique.
The Numerical Simulation Technique estimates the reliability indices by simulating the actual process and random behaviour of the system. It is highly time consuming and expensive because it has to simulate a huge number of failures. Also, since the simulation of probabilistic events generate variable results, in effect generating the variable of real life, it is usually necessary to perform a number of runs in order to obtain estimates of means and variance of the output parameters of interest, such as availability, number of repairs arising and repair facility utilization [6].
The Analytical Technique represents the system by a simplified mathematical model and evaluates the reliability indices from this model using direct mathematical solutions. The analytical technique is however used in this paper and the Electrical Transient Analyzer Program (ETAP) was utilized for the system analysis.

C. Reliability Indices

A distribution system is that part of the power system which connects the bulk system to the individual customers. The distribution system reliability performance evaluation is normally concerned with the electric supply adequacy at the customer load point.
The basic distribution system reliability indices are the three load point indices of Average Failure Rate, (λ), the Average Outage Duration, (r) and the Annual Outage Duration, (μ).

D. Load Point Indices

For a radial system as it is the case in this study, the basic equations for calculating the reliability indices at each load point, P are thus;

E. Average Failure Rate at load point, p,

$$\lambda_p = \frac{\Sigma F}{T} \text{ (f/yr)} \quad (1)$$

where;
F = load point failure frequency
T = Operating Time (a calendar year. i.e., 365×24hrs = 8,760hrs)
Annual Outage Duration at load point, p,

$$\mu_p = \frac{\Sigma Tdx}{T} \text{ (hr/yr)} \quad (2)$$

Where;
T_{dx} = Load point annual Down time (in hours)
T = Operating Time
Average Outage Duration at Load Point, p

$$r_p = \frac{\mu_p}{\lambda_p} \text{ (hr)} \quad (3)$$

Load Point Mean Time Before Failure,

$$\text{MTBF} = \sum \frac{T}{F} \quad (4)$$

Where;

T = Operating Time and

F = failure frequency

Mean Time to Repair,

$$\text{MTTR} = \sum \frac{T\,dx}{F} \quad (5)$$

Where,

T_{dx} = Load point annual Down time (in hours)

F = Load point failure frequency

System IndicesThe system indices commonly used by utilities are SAIFI, SAIDI, CAIDI and ASAI. These indices can be calculated using the basic load point indices. I.e., Average Failure Rate, (λ), the Average Outage Duration, (r) and the Annual Outage Duration, (μ).

System Average Interruption Frequency Index,

$$\text{SAIFI} = \frac{\sum \lambda_P \cdot N_p}{\sum N_p} \text{ (f/cust-yr)} \quad (6)$$

Where;

λ_p = Failure rate

Np = No of customers connected to load point, p

System Average Interruption Duration Index,

$$\text{SAIDI} = \frac{\sum \mu_p \cdot N_p}{\sum N_p} \text{ (hr/cust-yr)} \quad (7)$$

Where;

μ_p= Annual Outage Duration at Load point, p

Np = No of customers connected to load point, p

Customer Average Interruption Index,

$$\text{CAIDI} = \frac{\sum \mu_p \cdot N_p}{\sum \lambda_p \cdot N_p} \text{ (hr/Cust-Int.)} \quad (8)$$

Average Service Availability Index,

$$\text{ASAI} = \frac{\sum Np \cdot 8{,}760 - \sum \mu_p \cdot N_p}{\sum Np \cdot 8{,}760} \text{ (\%)} \quad (9)$$

Where 8,760 is the operating time, (i.e., the No of hours in a calendar year, 365 x 24hrs)

III.CASE STUDY

As shown in figure 2 below, the five distribution substations under review in this paper are; Secretariat, Silver Bird, Water Works, UST and School of Nursing Injection Substations with 15 load points. However, the Secretariat Injection Substation shown in figure1 below was used as the sample system to show how the Electrical Transient Analyzer (ETAP) software calculates the indices. The system is a 33/11KV distribution injection substation consisting of primary and secondary bus systems, breakers and 2x15MVA 33/11kV parallel transformers. It has a total of 7,118 customers connected to it via its 4x11kV outgoing feeders herein marked as 'L_p'. It has been modeled and simulated using the reliability assessment module of ETAP software.

A. Calculation of Reliability Indices

The reliability indices for the sample system is manually calculated below to show how the reliability module of ETAP software calculates the indices. This is achieved using the historical data of the sample system as shown in table I and by applying equations (1) to (9).

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Table I: Historical Data of the Sample System

Load Point	Failure Freq.	Annual Downtime(hrs)	Annual Uptime(hrs)	No. of Customers	Customer Type	Average Load(mw)	Peak Load(mw)
Station Rd	791	4,413	3,890	2,120	Residential	3.9	4.8
Amadi .	440	4,530	4,230	1,308	Res/Ind.	4.2	5.3
Flour Mill	620	3,881	4,879	920	Comm./Res.	3.4	4.0
Borokiri	890	5,475	3,285	2,770	Residential	4.3	5.5

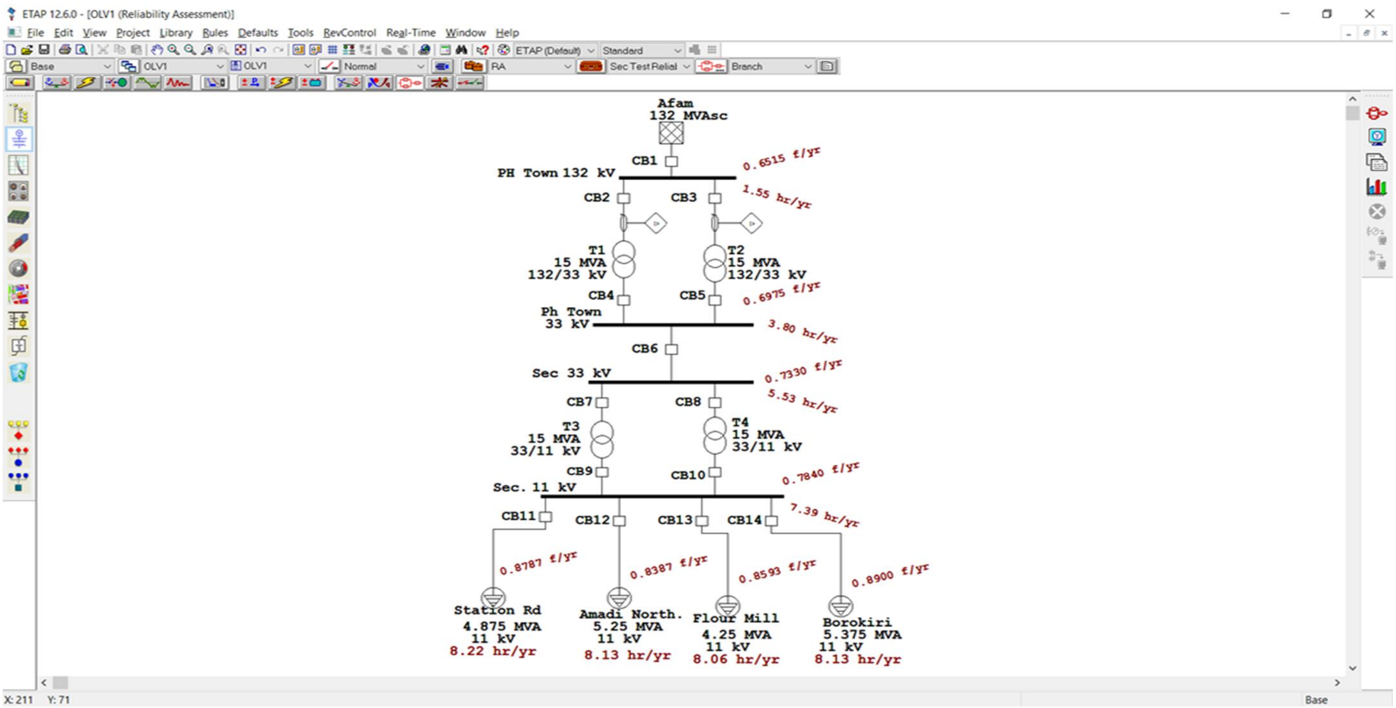

Fig.1 The Sample System in ETAP simulation Environment

B. Load Point Indices

Station Road;

Failure frequency, F = 791

Total Annual Downtime, ΣT_{dx} = 3,413

Operating Time, T = 365x24hrs = 8,760

Applying equation, (1) to (5), we have;

Load Point Failure Rate,

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

Annual Outage Duration,

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

Average Outage Duration,

$$r_p = \frac{\mu_p}{\lambda_p} = \frac{0.504}{0.0902} = 5.59 hrs$$

Mean Time Before failure,

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

Mean Time To Repair,

$MTTR = \sum \frac{T\,dx}{F} = \frac{4{,}413}{791} = 5.58hrs$

Applying the same equations and procedures to the other three load points of the sample system yields thus;

Amadi North;

$\lambda p = 0.0502f/yr$, $\mu_p = 0.517hrs/yr$, $r_p = 10.30hrs$; MTBF = 19.91hrs, MTTR = 10.29hrs

Flour Mill;

$\lambda p = 0.0708f/yr$, $\mu_p = 0.4430hrs/yr$; $r_p = 6.28hrs$; MTBF = 14.13hrs, MTTR = 10.29hrs

Borokiri;

$\lambda p = 0.0934f/yr$, $\mu_p = 0.511hrs/yr$; $r_p = 5.47hrs$; MTBF = 10.71hrs, MTTR = 5.47hrs

Other component failure rates are;

Transformer;

132/33kv = 0.002; 33/11kv = 0.003

Circuit Breaker;

132kv = 0.001; 33kv = 0.015; 11kv = 0.006

Bus Bar;

132kv = 0.001; 33kv = 0.001; 11kv = 0.015

Table II: Load Point Indices of the Sample System

Load Point	λ_T (f/hr)	r_T (hours)	μ_T (hr/yr)
Station Rd-Lp1	0.8787	9.29	8.1661
Amadi N. – Lp2	0.8387	9.70	8.1391
Flour Mill - Lp3	0.8593	9.38	8.0631
Borokiri - Lp4	0.8900	9.14	8.1325

C. System Indices

The system indices of the sample system are calculated using equation (6) to (9).

Applying these equations yields;

System Average Interruption Frequency Index,

$$SAIFI = \frac{\sum \lambda_P \cdot N_P}{\sum N_P} = \frac{\{(0.8787\times 2{,}120)+(0.8387\times 1{,}308)+(0.8593\times 920)+(0.8900\times 2{,}770)\}}{2{,}120+1{,}308+920+2{,}770}$$

SAIFI = 0.873f/cust-yr.

System Average Interruption Duration Index,

$$SAIDI = \frac{\sum \mu_p \cdot N_p}{\sum N_p} = \frac{\{(8.166\times 2{,}120)+(8.139\times 1{,}308)+(8.063\times 920)+(8.132\times 2{,}770)\}}{2{,}120+1{,}308+920+2{,}770}$$

SAIDI = 8.134hrs/cust-yr.

Customer Average Interruption Index, CAIDI

$$CAIDI = \frac{\sum \mu_p \cdot N_p}{\sum \lambda_p \cdot N_p} = \frac{\{(8.166\times 2{,}120)+(8.139\times 1{,}308)+(8.063\times 920)+(8.132\times 2{,}770)\}}{\{(0.8787\times 2{,}120)+(0.8387\times 1{,}308)+(0.8593\times 920)+(0.8900\times 2{,}770)\}}$$

CAIDI = 9.317hrs/cust-Int.

Average Service Availability Index,

$$ASAI = \frac{\sum Np \cdot 8{,}760 - \sum \mu_p \cdot N_p}{\sum Np \cdot 8{,}760} = \frac{(7{,}118\times 8{,}760)-\{(8.166\times 2{,}120)+(8.139\times 1{,}308)+(8.063\times 920)+(8.132\times 2{,}770)}{7{,}118\times 8{,}760}$$

ASAI = 0.99901 × 100

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ASAI = 99.91%

IV. RESULTS AND DISCUSSION

As stated in the previous section, the distribution network under review has been simulated using the Reliability Assessment Module of ETAP as shown in figure 2. The historical data of the substations as shown in Tables III were used for the simulation and the reliability results obtained are shown in Tables IV and V, and Figures 3 to 11 below.

Table III: Load Points Historical Data for the Period Under Review

Load Point	Failure Freq. (f/yr)	Annual Downtime (Hrs)	Annual Uptime (Hrs)	Failure Freq. (f/yr)	Annual Downtime Hrs)	Annual Uptime (Hrs)
	2015			2014		
Lp1 [Station Rd]	791	4,413	3,891	766	4,126	4,634
Lp2 [Amadi North]	440	4,530	4,230	578	4,941	3,819
Lp3 [Flour Mill]	620	3,881	4,879	693	3,928	4,832
Lp4 [Borokiri]	890	4,475	3,285	879	4,332	4,428
Lp5 [Abonnema W.]	682	7,698	1,062	672	6,780	1,980
Lp6 [Ikwerre Rd]	1,104	5,285	3,476	1,211	5,310	3,450
Lp7 [Udi]	691	4,799	3,961	698	4,801	3,959
Lp8 [Nsukka]	820	5,113	3,647	802	5,103	3,657
Lp9 [Ojoto]	1,266	6,893	1,867	1,338	6,930	1,830
Lp10 [Ust]	900	6,323	2,437	972	6,402	2,358
Lp11 [Federal]	1,966	7,510	1,250	1,951	7,311	1,449
Lp12 [Wokoma]	1,838	7,499	1,261	1,899	7,503	1,257
Lp13 [Agip]	890	6,273	2,487	903	5,977	2,783
Lp14 [Abacha]	701	6,352	2,408	733	5,974	2,783
Lp15 [Sch. of Nursing]	627	6,031	2,729	638	5,606	3,154

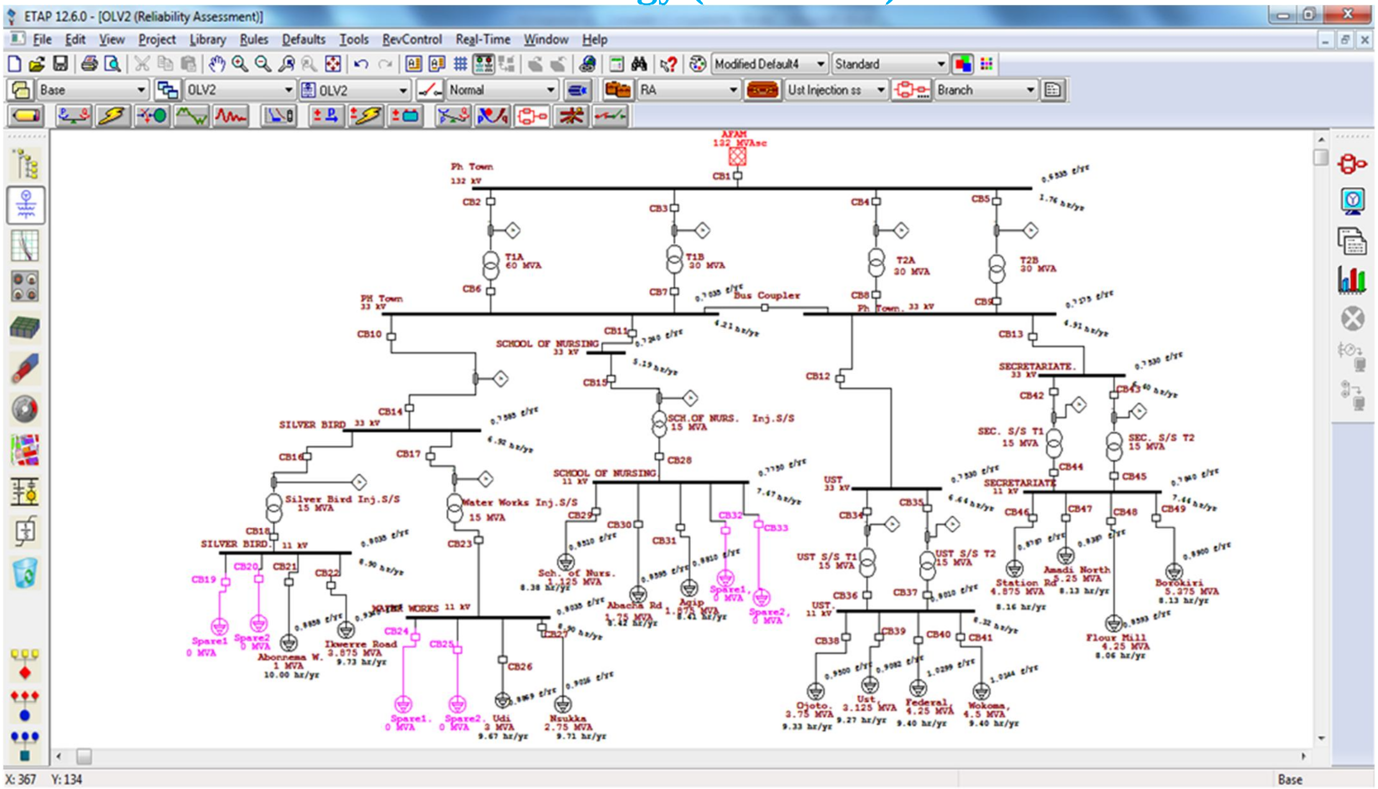


Fig. 2 PH Town Distribution Network in ETAP Simulation Environment

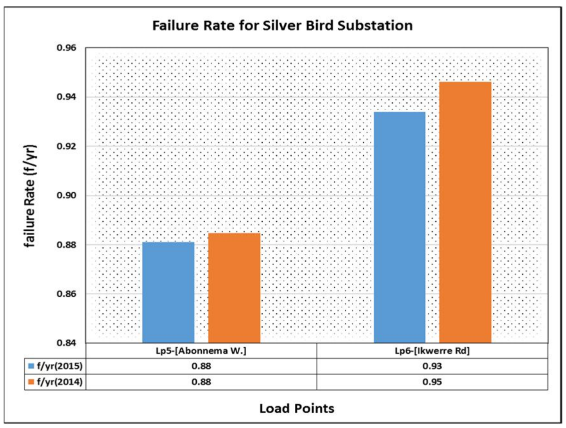
Table IV Load Point Indices of the Distribution Network

Load Point	λ_T (f/yr)	r_T (hrs)	μ_T (hrs/yr)	λ_T (f/yr)	r_T (hrs)	μ_T (hrs/yr)
	2015			**2014**		
Lp1 [Station Rd]	0.8787	9.29	8.17	0.8789	9.23	8.08
Lp2 [Amadi North]	0.8387	9.70	8.14	0.8544	9.58	8.19
Lp3 [Flour Mill]	0.8593	9.38	8.06	0.8676	9.30	8.07
Lp4 [Borokiri]	0.8900	9.14	8.13	0.8888	9.14	8.12
Lp5 [Abonnema W.]	0.8810	11.29	10.00	0.8847	11.19	9.90
Lp6 [Ikwerre Rd]	0.9340	10.41	9.73	0.9462	10.28	9.73
Lp7 [Udi]	0.8869	10.90	9.67	0.8877	10.89	9.67
Lp8 [Nsukka]	0.9016	10.77	9.71	0.8995	10.79	9.70
Lp9 [Ojoto]	0.9500	9.82	9.33	0.9582	9.75	9.34
Lp10 [Ust]	0.9082	10.21	9.27	0.9164	10.12	9.28
Lp11 [Federal]	1.0299	9.13	9.4	1.0282	9.12	9.38
Lp12 [Wokoma]	1.0144	9.27	9.40	1.0222	9.20	9.40
Lp13 [Agip]	0.8810	9.55	8.41	0.8676	9.49	8.38
Lp14 [Abacha]	0.8595	9.80	8.42	0.8632	9.71	8.38
Lp15 [Sch. of Nursing]	0.8510	9.85	8.38	0.8523	9.78	8.34

Table V System Indices of the Substations Under Review

	System Indices (2015)				System Indices (2014)			
SUBSTATION	SAIFI (Int./yr)	SAIDI (Hrs/yr)	CAIDI (Hrs/Cust-Int.)	ASAI (%)	SAIFI (Int./yr)	SAIDI (Hrs/yr)	CAIDI (Hrs/Cust-Int.)	ASAI (%)
Secretariat	0.873	8.13	9.14	99.91	0.877	8.11	9.25	99.90
Silver Bird	0.932	9.74	10.45	99.88	0.944	9.74	10.32	99.88
Water Works	0.895	9.69	10.83	99.89	0.894	9.68	10.84	99.88
UST	0.992	9.93	9.45	99.89	0.997	9.37	9.42	99.89
Sch. Of Nursing	0.873	8.41	9.64	99.90	0.866	8.38	9.68	99.90

Fig. 3 Load Point Failure Rate for Secretariat Substation Fig. 4 Load Point Failure Rate for Silver Bird Substation



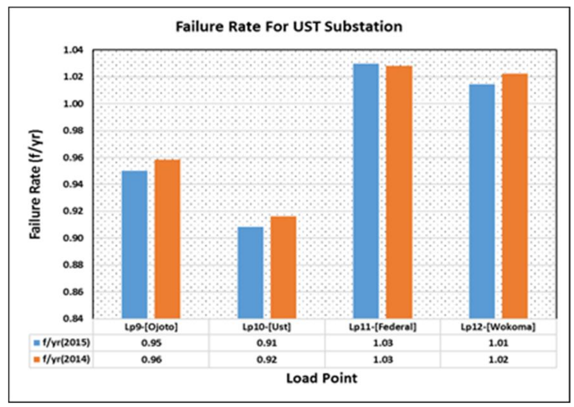
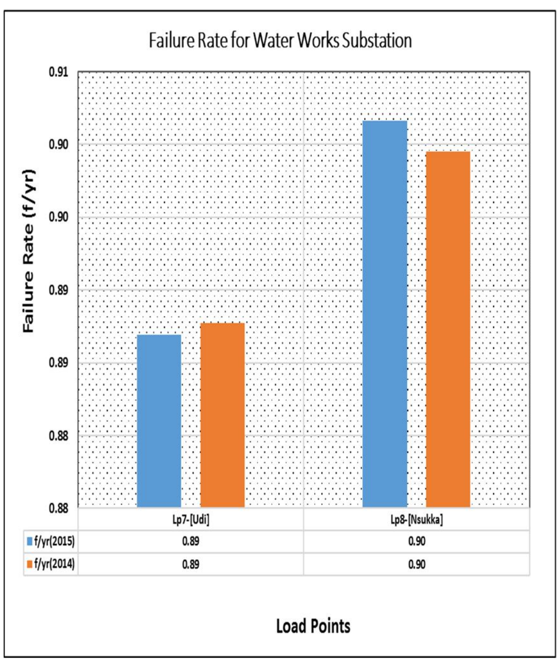
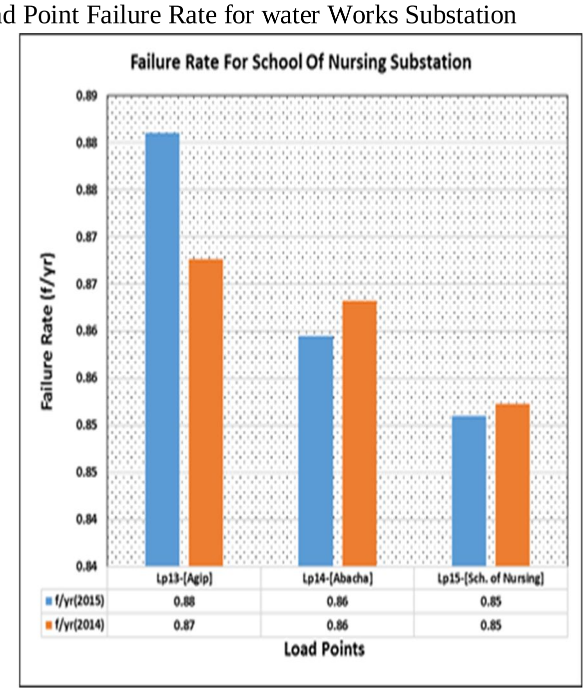


Fig. 6 Load Point Failure Rate for UST Substation Fig. Fig. 5 Load Point Failure Rate for water Works Substation





7 Load Point Failure Rate for School of Nursing Substation Fig. 8 SAIFI with Respect to the Substations

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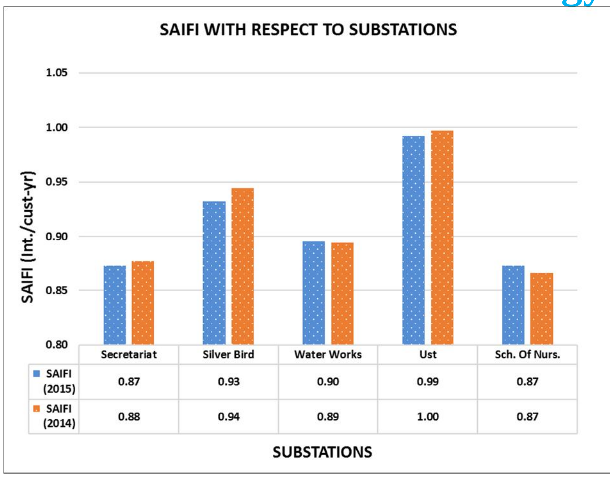


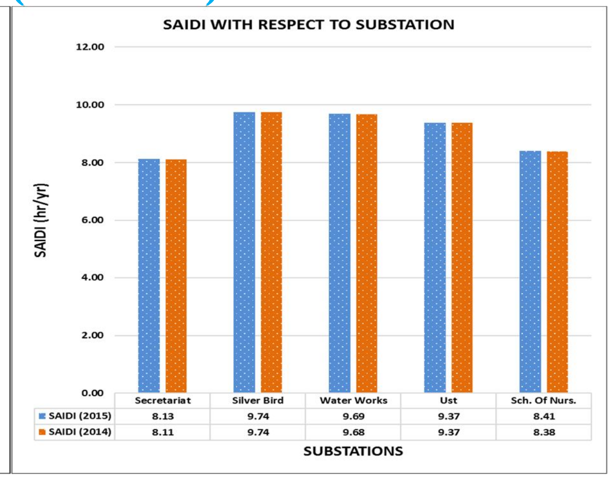
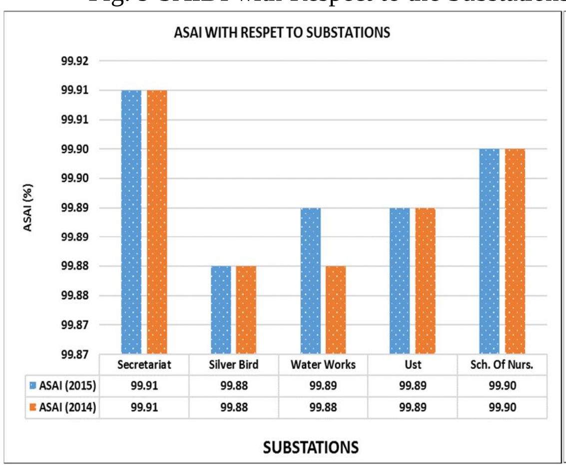


Fig. 9 SAIDI with Respect to the Substations Fig. 11 ASAI with Respect to the Substations



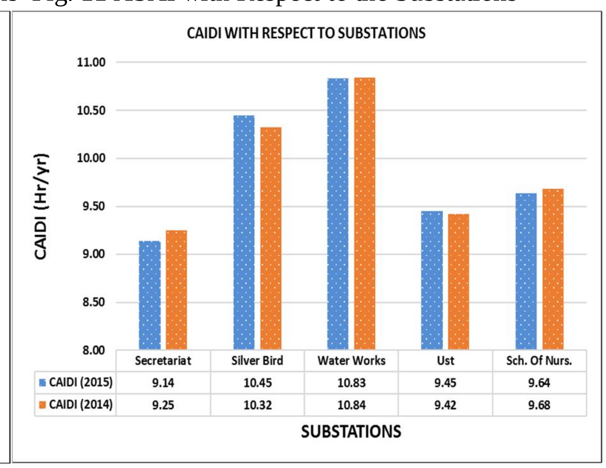


Table IV and Figures 3 to 7 shows the Load Point Indices result of the system. From the result as presented in Table IV and Fig. 3 to 7, its apparent that load points 11 [Federal] and 12 [Wokoma] are the most deficient and have the highest failure rate. The result also shows that UST Injection Substation has the highest failure rate. This is as a result of the large number of customers connected to it which obviously leads to overloading of the system, the age factor of the system components, lack of Reliability Centered Maintenance and delay in the response of the utility for fault rectification.

Figures 8 to 11 above compares the results of the System Indices as obtained with respect to the substations under review.

V. CONCLUSION AND RECOMMENDATIONS

The results of this paper as presented have shown that Secretariat Injection Substation is the most reliable in the network.

However, reliability indices of the system as presented above shows that the reliability of the entire system is below internationally set benchmark for utilities. Hence, the system can be termed unreliable.

Based on the findings of this paper, the following recommendations are therefore made in order to improve the reliability of the distribution network;

A. Installation of Photovoltaic systems or other forms of distributed generation at the different load points in other to re-supply interrupted loads at a shorter time

B. System Reconfiguration should be considered in other to reduce the number of customers connected to some of the overloaded feeders.

C. Expansion of the network should be considered by PHEDC so as to mitigate the overloading problem on the system.

D. Replacement of faulty or aged system components with quality ones so as to reduce failure frequency.

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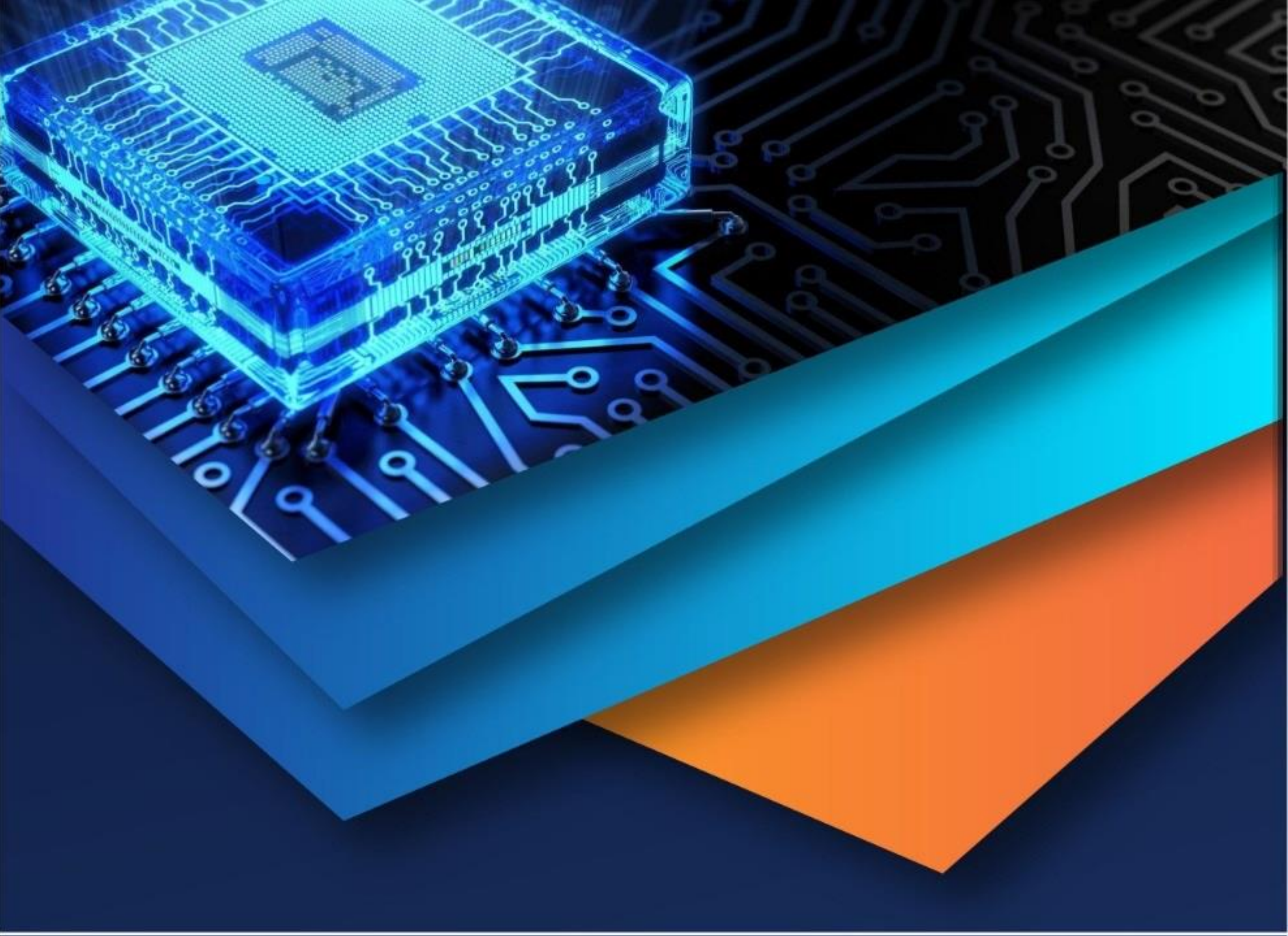

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