International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 04, April-2017

Appraisal of Electric Power Distribution Feeders Reliability in the Region unit in Nigeria

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***Abstract* - Feeders are devices that convey electric power to Substations for electricity distribution. Its performance in 24 hours consistent daily delivery of energy is centered around reliability of electric power distribution systems. This article appraises the reliability of electric power distribution feeders of a regional Unit, in Southwestern, Nigeria. Each of this Business Hub has a 33kV feeder with two or more 11kV feeders. An annual data on daily power interruption for the year 2016 were collected from the central unit were analyzed to obtain reliability indices using a spreadsheet package. The results were compared to smart grid adopted few cities in the developed economy. This is to illustrate or illuminate the inefficiency (or problems) in the current distribution grid in Nigeria and the need to adopt smart devices in the electric power distribution grid. The finding revealed that the annual total outage duration (SAIDI), Outage frequency (SAIFI) and the percentage Availability (ASAI) were 2470.16 hours, 695 times, and 71.88%, respectively. The results obtained were too far from the international acceptable standard values (IASV) of 2.5 hours, 0.01, and 99.98%, respectively. The result showed that power supply services in the regional unit were unreliable and unpredictable despite the four years unbundling effects. However, adoption of smart grid (SG) technologies in lieu of conventional grid network will improve the reliability and efficiency of power distribution.**

Keywords: Reliability, Electricity distribution, Reliability indices, Smart grid technology

1.0 INTRODUCTION

The electric power grid is one of the most complex and expensive investments made by mankind all over the world. An electrical grid is a vast, interconnected network for transporting electricity from suppliers to consumers of electric power (Folarin, Sakala, Jeffrey, and Matlotse, 2016). The electric power distribution system is the last stage in the delivery of electric power; it carries electricity from the transmission system to individual consumers (Folarin, et al., 2016)). Its constant and reliable performance is important to economy stability of a nation and citizens' way of life (Haughton & Heydt, 2010; Thomas, 2006).

The electricity situation in Nigeria can be described as epileptic in its present state. The erratic power supply affects the manufacturing, commercial services and residential sectors of the economy which in turn affects the nations' economic growth (Sambo, Garba, Zarma, & Gaji, 2012).

The inconsistent power supply and moribund power sector can be attributed to inadequate and inefficient power plants, poor transmission and distribution facilities, and outdated metering system used by electricity consumers. In general, the distribution network together with the voltage profile coupled with imperfection of the billing system is not in a sustainable and manageble condition. Besides, the billing system as it relates to the public needs improvement while, the need to ensure adequate network coverage and provision of constant and quality power supply are quite relevant to economic development of a nation. Some of the drawbacks or challenges identified include, weak and inadequate network coverage, overloaded transformers, bad feeder pillars, substandard distribution lines, poor billing system, unwholesome practices and poor staff training, poor customer relations, poor maintenance culture and inadequate logistic facilities such as tools,working vehicles, poor and obsolete communication equipment (Sambo et al., 2012).

The ever increasing use of alternative sources like generating set, power inverter and solar inverter at consumer end are effort to enhance availability of electric power supply. It is a reality that all these alternatives are more expensive than power utility services. Hence the need to ensure power supply stability (Ogheneovo, 2015).

The reliability of electric distribution systems is critically essential for both utilities and customers. Electric reliability affects public health and safety, economic growth and development, and social well- being. Various utilities estimate the value of electric services to consumers to measure the benefits of investments to improve reliability (Sullivan, 2009).

Majority of power outages are caused by weather- related damage to overhead power lines. High winds can cause trees to bridge power lines, and from time to time can cause breaking of lines and poles. Animal contact, vehicle accidents, equipment failure, and human mistake also add to power outages.

Power outages in electric distribution systems are known and classified by the number of customers affected and the duration of time that power is unavailable. The Institute of Electrical and Electronic Engineers (IEEE) identifies three types of outages (Bhavaraju, et al., 2005):

i). Major Interruptions: includes those that exceed the reasonable design and/ or operational limits of the electric power system and affect a large fraction of the customers served by the utility.

ii). Sustained Interruptions: those are outages not classified as temporary events and last for more than five minutes.

iii). Momentary Interruptions: those involve short loss of power to one or more customers caused by opening and closing of interruption devices.

Reliability indices are commonly used to assess outages and appraise the performance of electric systems. These are the

standard indices used by the electric power industry and provide a uniform methodology for data collection and analysis. Major event days are excluded from the indices to better reveal trends in daily operations.
The indices used for the analysis include(Brown, Haughton, Heydt, & Suryanarayanan, 2010):
i). System Average Interruption Duration Index (SAIDI)
ii). Customer Average Interruption Duration Index (CAIDI)
iii). System Average Interruption Frequency Index (SAIFI)
iv). Average System Availability Index (ASAI).
The above indices are explored to evaluate the performance of the current utility services in the whole Osun region of Ibadan Electricity Distribution Company (IBEDC) to illustrate the inefficiency of the electric distribution grid in Nigeria and ascertain the need for smart grid technology. The need are essentials to curb the problems of electric power supply in Nigeria and improve the reliability and quality of electricity in the entire region of South Western Zone of the nation. Ogheneovo, 2015 assessed the reliability of Ede township feeder of IBEDC in Osun region as 78.48% compared with IASV. However, the work only explored one part of Ede business hub which could not display the actual appraisal of the whole Osun regional unit of IBEDC. The appraisal in this paper contain all the entire five business hubs where the National Control Centre (NCC) located to justify the true representation of South Western region of Nigeria.

2.0 METHODOLOGY

2.1. Data acquisition and processing

Outage data for twelve months from January to December, 2016 were gathered from Osun Regional Centre of IBEDC. This is one of the eleven companies approved to provide electricity distribution services in Nigeria. The company is the utility services that are serving the entire Osun, Oyo, Ogun, Kwara and certain part of Ekiti, Niger and Kogi States in Nigeria.
The data collected are:
(i) Numbers of feeders (33kV, 11/0.415kV)
(ii) Numbers of outages on each feeders
(iii) Duration of each outages
(iv) Causes of outages
(v) Number of customers affected by each outage
(vi) Number of consumers on each feeder
(vii) Equipment in the reserve (transformer, feeder pillar, fuse, pole, overhead cables etc)
(viii) Age of distribution equipment/item.
The soft and hard copy of the above data were collected with due comparison to authenticate the genuiness of the data. The outage data comprises a 24 hours daily record of all the feeders with the exact time of outage occurrence, restoration, number of affected customers, nature of outage, and remark of personnel on duty. All these information were collected in all urbans, cities, towns and villages of the study region. The comparison of the two sources indicated accuracy of the data.
The data covered the entire year 2016 are on the 33kV and 11kV feeders supplying all the above mentioned locations of Osun regions of IBEDC. Reliability indices like SAIDI, CAIDI, SAIFI and ASAI are use to appraise the performance of the distribution feeders.

2.2 Location/Background of the Study

The research is conducted on Power distribution infrastructure and services of Osun regional services of IBEDC in South Western Zone in Nigeria. This region is selected because of its true representative model of electric power supply system in the major three regions of Nigeria being the sitting of NCC.
Osun regional services comprises of Ede, Ikirun, Ile ife, Ilesa and Osogbo Business Hubs. Each of this business hub has two or more 33kV feeders from NCC, Osogbo. It is further step down by either 15MVA or 7.5MVA transformer to 11kV at an injection substation from which two or more 11kV feeders are radiated to feed consumers base on the span of the community. In some cases (more than 200 customers) in a location, the voltage is further step-down to 415V utility voltage.
Majority of the electricity users are residentials, commercials and industrial consumers that comprises of civil servants, traders, students, offices, public buildings, events centre and industries. Each of the above mentioned locations hosts major users as listed with Osogbo being the mega city that host the main control centre as the hearth of the national supply unit serve as the main reason for choosen Osun region as the case study for the research focus.

2.3 Measuring of System Reliability

The most common metrics used to assess utility reliability performance are SAIDI, CAIDI, SAIFI and ASAI [(Brown et al., 2010); (Haughton & Heydt, 2010)]. SAIDI measures average outage duration per customer, CAIDI measures average restoration time, SAIFI measures frequency of outage and ASAI measures percentage of supply availability. Besides, CMI, MAIFI, ASIFI, ASIDI etc are as well explored. One of this indices is insufficient to give complete measure of reliability of power supply because each focus on a specific aspect of reliability. In this study, four are used to determine and quantify reliability of electric power supply of the case study. Each of the indices can be expressed as:
(i) SAIDI (System average interruption duration index) : is a measure of duration. It measures the number of minutes/hours over a period of time (day, month or year) that the average customer is without electricity. It is expressed as

$$\text{SAIDI} = \frac{\sum N_{i*d}}{N_t} \quad \text{......} \quad (1)$$

(ii) SAIFI (System average interruption frequency index) : is a measure of numbers of times (frequency). It is the average number of time that a consumer experiences an interruption of supply in a particular period of time (day, month or year). It is dimensionless and express as

$$\text{SAIFI} = \frac{\sum N_i}{N_t} \quad \text{......} \quad (2)$$

(iii) CAIDI (Customer average interruption duration index): is a measure of time. It is the average time required to restore service to the average customer per sustained interruption. It provides the average amount of time a customer is out of power supply per interruption. it is expressed as the ratio of SAIDI TO SAIFI.

$$CAIDI = \frac{SAIDI}{SAIFI} = \frac{\sum N_{i*d}}{N_i} \quad \text{...} (3)$$

(iv) ASAI (Average system availability index): is also reffered to System Reliability Index (SRI). It is a measure of the overall reliability of the system. It represents the percentage of time during the year (8784 hours) or month (720 hours) or day (24 hours) that the average customer has power supply. It is express as

$$ASAI = 100 * \left[1 - \sum \frac{N_{i*d}}{N_{t*T}}\right]$$

$$= 100 * [1 - \{ \frac{\text{SAIDI}}{(8784\text{hours per year})} \}] \text{.......................................} (4)$$

Where N_i is the number of customers affected by an outage, d is the duration of the outage, r_i is the restoration time of an outage, N_t is the total number of customers served and T is the customer hour service demand (24 or 720 or 8760 hours). But 2016 is a leap year hence 366days (8784hours). Usually outages of less than 1-3 minutes are not counted towards the SAIDI or SAIFI metrics.

3.0 ANALYSES AND DISCUSSIONS OF RESULT

From Table 1a to e, indices were obtained as illustrated mathematically above using the spread sheet. The result for SAIDI, CAIDI, SAIFI and ASAI were obtained for the months of Janurary to December, 2016 and overall year equally determined for each business hub for Osun region of IBEDC. It was observed that Ile-ife business hub has the worst result with SAIDI of 265.79 hours with reliability of 0.64 which and as well with worst OVERALL ASAI of 59.98%. However, Ilesa business hub has the best result with SAIDI of 92.53 hours in the month of February while its overall ASAI is 86.71% of which the reliability is 0.87. Others are Ede, Ikire and Osogbo with results as SAIDI: 198.94 for month of February, 229.23 for August, 232.96 for May, with ASAI of 70.76% of reliability of 0.71; ASAI of 69.19% of reliability of 0.69 and ASAI of 68.69% with reliability of 0.69 respectively. However, all these results were very poor as compared with the advanced city of developed nations where smart grid technology is in placed as depicted in table 3. Hence, there is need to consider gradual transition to grid of future with application of smart grid technology to improve the quality of electric power supply.

Table1a: Ede business hub reliability index

Month	SAIDI(hours)		CAIDI(hours)		SAIFI		ASAI(%)	
	11kV	33kV	11kV	33kV	11kV	33kV	11kV	33kV
January	188.96	104.15	3.70	2.02	51.02	51.67	74.6	86.00
February	198.94	109.87	3.95	1.47	50.35	74.94	71.42	84.21
March	122.66	164.56	3.48	2.02	35.28	81.30	83.51	77.88
April	132.21	143.09	3.01	1.88	43.86	76.03	81.64	80.13
May	34.56	135.54	2.69	1.72	12.87	78.89	95.35	81.78
June	89.32	72.65	2.03	1.07	44.03	67.76	87.6	89.91
July	92.26	130.11	3.18	1.88	29.01	69.33	87.6	82.51
August	82.71	72.65	2.66	1.07	31.13	67.76	88.88	90.24
September	25.27	130.11	1.80	1.88	14.05	69.33	96.49	81.93
October	40.21	129.50	2.78	2.34	14.49	55.44	94.59	82.59
November	45.90	121.61	2.12	2.07	21.67	58.66	93.63	83.11
December	71.81	130.10	2.54	1.82	28.25	71.36	90.35	82.51
Total =	1124.81	1443.95	33.93	21.24	376.02	822.46	87.14	83.57

Overall SAIDI=	2568.76
SAIFI	1198.48
ASAI=	70.76%

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 04, April-2017

Table 1b: Ikire business hub reliability index

Month	SAIDI(hours)		CAIDI(hours)		SAIFI		ASAI(%)	
	11kV	33kV	11kV	33kV	11kV	33kV	11kV	33kV
January	55.85	58.69	4.09	3.07	13.67	19.09	92.49	92.11
February	58.83	59.99	3.56	2.53	16.54	23.67	91.55	91.38
March	32.12	64.34	4.40	2.12	7.31	30.35	95.68	91.35
April	112.12	82.22	3.01	2.75	37.22	29.88	84.43	88.58
May	36.69	64.82	4.32	1.40	19.35	26.70	85.56	91.29
June	29.52	57.53	3.37	1.81	8.76	31.86	95.90	92.01
July	17.54	152.30	2.50	4.15	7.02	0.22	97.64	79.53
August	229.23	57.25	3.23	2.23	71.00	25.67	69.19	92.31
September	13.60	72.09	2.49	3.25	5.45	22.15	98.11	89.99
October	13.87	59.37	2.43	2.45	5.70	24.19	98.14	92.02
November	23.12	61.08	3.29	2.23	7.04	27.38	96.79	91.52
December	32.12	47.37	3.21	2.06	10.00	23.00	95.68	93.63
Total	654.60	837.06	39.90	30.07	209.05	284.17	91.76	90.48
Overall	SAIDI	1491.66						
SAIFI		493.22						
ASAI		83.02%						

Table 1c: Ile- Ife business hub reliability index

Month	SAIDI(hours)		CAIDI(hours)		SAIFI		ASAI(%)	
	11kV	33kV	11kV	33kV	11kV	33kV	11kV	33kV
January	265.79	69.17	6.87	5.36	38.71	12.91	64.28	90.70
February	213.40	77.42	6.89	9.68	30.96	8.00	69.34	88.88
March	199.13	228.92	6.88	10.34	28.94	22.15	74.24	69.23
April	132.85	165.99	6.95	9.03	19.11	18.39	81.55	76.95
May	102.23	220.38	7.40	6.49	13.82	33.97	86.26	70.38
June	129.70	257.81	8.87	6.64	14.63	38.83	81.99	64.19
July	102.13	100.98	5.74	3.75	17.79	26.91	86.27	86.43
August	201.29	91.77	7.40	2.74	27.20	33.49	72.94	87.66
September	210.63	71.55	5.67	3.69	24.37	19.39	87.50	90.06
October	111.14	108.83	5.05	3.04	21.99	35.80	85.06	85.37
November	85.42	108.06	6.34	4.03	13.48	26.84	88.14	84.99
December	183.41	77.14	6.06	4.42	30.26	17.45	75.35	89.63
Total	1937.12	1578.02	80.12	69.20	281.24	294.14	79.41	82.04
Overall	SAIDI	3515.13						
SAIFI		575.37						
ASAI		59.98%						

Table 1d: Ilesa business hub reliability index

Month	SAIDI(hours)		CAIDI(hours)		SAIFI		ASAI(%)	
	11kV	33kV	11kV	33kV	11kV	33kV	11kV	33kV
January	90.98	57.02	7.17	6.65	12.70	8.60	87.77	92.32
February	92.53	54.23	6.15	5.25	10.26	6.22	90.45	95.72
March	46.02	42.70	5.62	5.05	8.20	8.46	93.81	94.38
April	69.90	63.95	5.65	5.12	12.37	12.48	90.29	91.11
May	63.15	40.65	5.70	3.55	11.08	11.45	91.51	94.54
June	55.85	65.01	5.76	5.01	9.69	12.98	92.24	90.97
July	70.90	106.34	7.17	8.40	9.89	12.66	90.47	85.71
August	38.39	40.79	4.52	4.08	8.49	10.00	94.84	94.52
September	34.97	34.09	4.08	3.69	8.56	9.23	95.14	95.27
October	24.62	42.56	2.43	3.48	10.14	12.24	96.69	94.28
November	23.84	46.44	2.41	2.31	9.90	20.13	96.69	93.55
December	46.12	50.13	3.71	2.89	12.43	17.37	93.80	93.26
Total	657.28	643.90	60.38	55.47	123.68	141.78	92.80	92.97

Overall	SAIDI	1301.18
SAIFI		265.47
ASAI		85.19%

Table 1e: Osogbo business hub reliability index

Month	SAIDI(hours)		CAIDI(hours)		SAIFI		ASAI(%)	
	11kV	33kV	11kV	33kV	11kV	33kV	11kV	33kV
January	148.46	136.24	3.58	0.16	41.48	25.02	80.04	99.48
February	170.52	13.37	3.87	0.31	44.11	43.76	75.5	98.08
March	208.29	46.98	4.39	1.38	47.41	34.10	72.00	93.69
April	775.56	18.80	7.40	0.89	104.75	21.11	80.50	97.39
May	232.96	24.90	4.45	0.65	52.35	38.11	68.69	97.59
June	148.95	18.55	3.58	0.54	41.61	34.42	79.31	97.42
July	170.52	12.13	3.87	0.58	44.11	21.05	77.08	98.37
August	112.39	17.94	4.14	1.04	27.13	17.32	84.89	97.59
September	94.190	25.59	3.57	0.97	26.38	26.33	86.92	96.45
October	775.56	25.10	7.40	0.89	104.75	28.17	87.40	96.63
November	107.92	24.27	3.32	0.98	32.50	24.82	85.01	96.63
December	152.21	12.66	3.50	0.67	43.54	18.94	79.54	98.30
Total	3097.54	376.53	53.07	9.04	610.11	333.14	79.74	97.30

Overall	SAIDI	3474.06
SAIFI		943.25
ASAI		60.45

From table 2a;
This means that (SAIDI) overall interruption for each of the business hub for 11kV and 33kV are as shown in columns 2 and 3 of table 2a respectively as depicted in Figure 1. This is an average of 4.1 hours in a day for 11kV feeder and average of 2.7 hours daily for 33kV feeder. This clearly indicate that there will be average of outage for 6.8 hours daily since an outage on 33kV feeder simply indicated no power supply on 11kV being the main source compared to 2.5 hours outage per year in developed nations of the globe where smart grid technology is existing. Figure 1 shows the graph of the illustration and overall effect is depicted in Figure 4.

Table 2a: Overall result of reliability index of Osun region of IBEDC

Business hub	SAIDI(hours)		CAIDI(hours)		SAIFI		ASAI(%)	
	11kV	33kV	11kV	33kV	11kV	33kV	11kV	33kV
Ede	1124.81	1443.95	33.93	21.24	376.02	822.46	87.14	83.57
Ikirun	654.60	837.06	39.90	30.07	209.05	284.17	91.76	90.48
Ile-Ife	1937.12	1578.02	80.12	69.19	23.44	24.51	79.41	82.04
Ilesa	657.28	643.90	60.38	55.47	10.31	11.82	92.81	92.97
Osogbo	3097.54	376.53	53.07	9.04	50.84	27.76	79.74	97.30
Total	7471.35	4879.46	267.40	185.01	133.93	234.14	86.17	89.27

Table 2b: Summary of overall result of reliability index of Osun region of IBEDC

Business hub	SAIDI	SAIFI	ASAI
Ede	2568.76	1198.48	70.76
Ikirun	1491.66	493.22	83.02
Ile-Ife	3515.13	575.37	59.98
Ilesa	1301.18	265.47	85.19
Osogbo	3474.06	943.25	60.45
Overall	2470.16	695.16	71.88

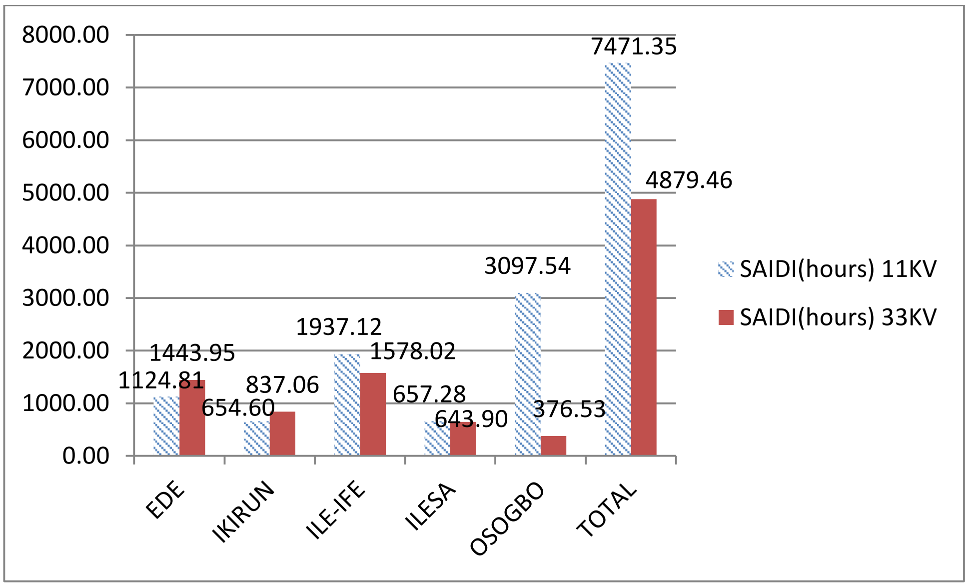

Fig. 1: SAIDI (outage duration) of each business hub for Osun region of IBEDC for year 2016

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 04, April-2017

For the overall frequency of outage SAIFI as depicted in table 2a are 320.02 and 375.138 for 11kV and 33kV feeders respectively. This shows that overall frequency of outage is 695 times as compared to 0.01 of the developed nations where smart technologies are used. Figure 2 shows the graphical representation of each of the feeders while the overall result graphically display in Figure 5.

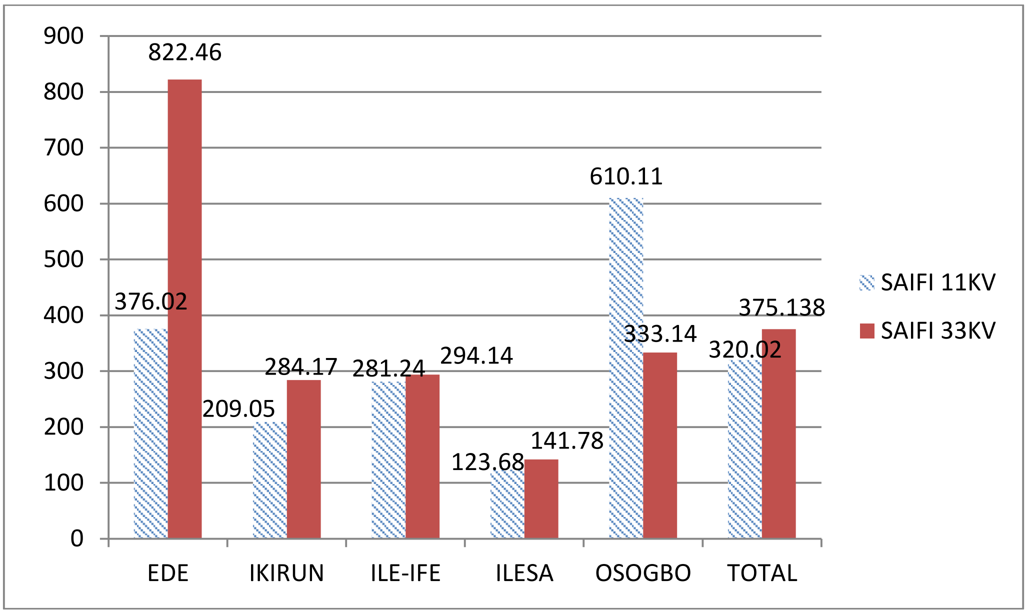

Fig. 2: SAIFI (outage frequency) of each business hub for Osun region of IBEDC for year 2016.

For overall average electric power supply reliability as shown on table 2b is 71.88%. This is very low compared with 98.99% of developed smart city of advanced country as depicted in table 3. Figure 3 below shows the bar chart of ASAI, Average Supply Availability Index for Osun region zone of each business hub of IBEDC. The overall result of ASAI is shown in Figure 6.

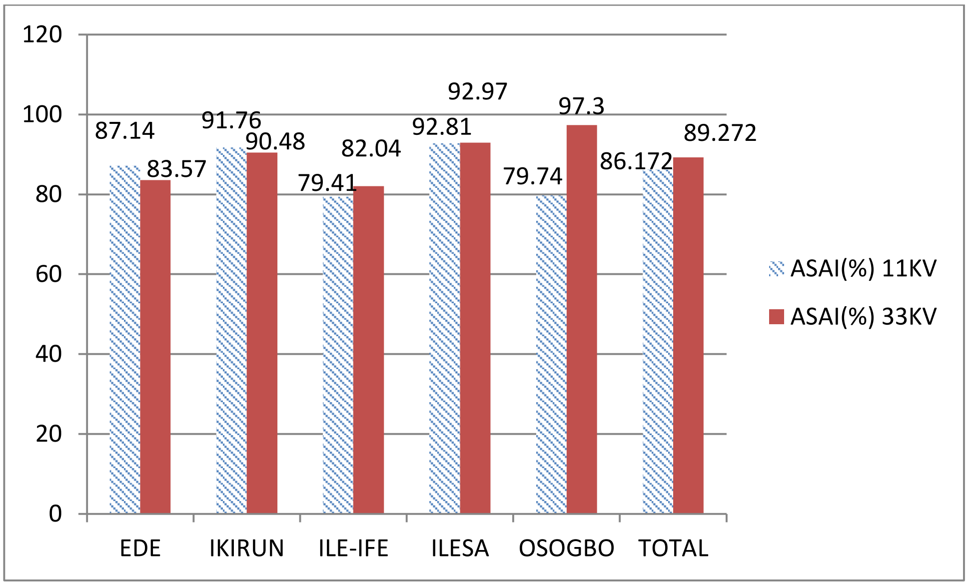

Fig. 3: ASAI (percentage availability of supply) of each business hub for Osun region of IBEDC for year 2016

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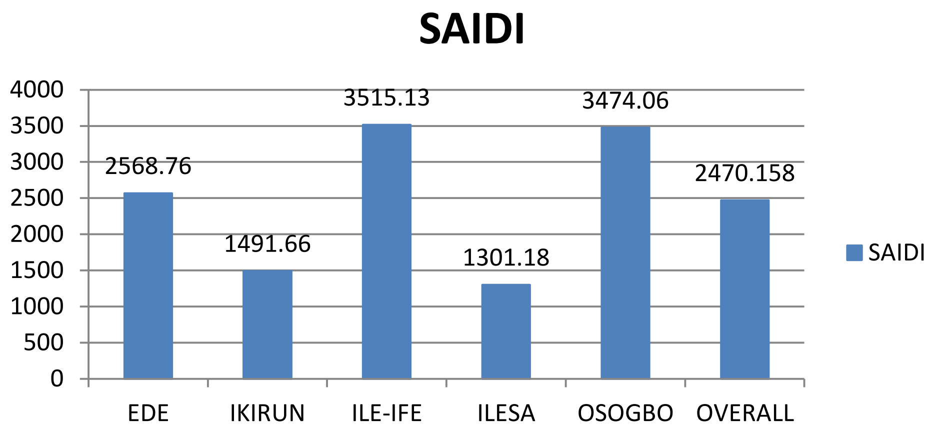

Fig. 4: Overall SAIDI of Osun region of IBEDC power supply for year 2016

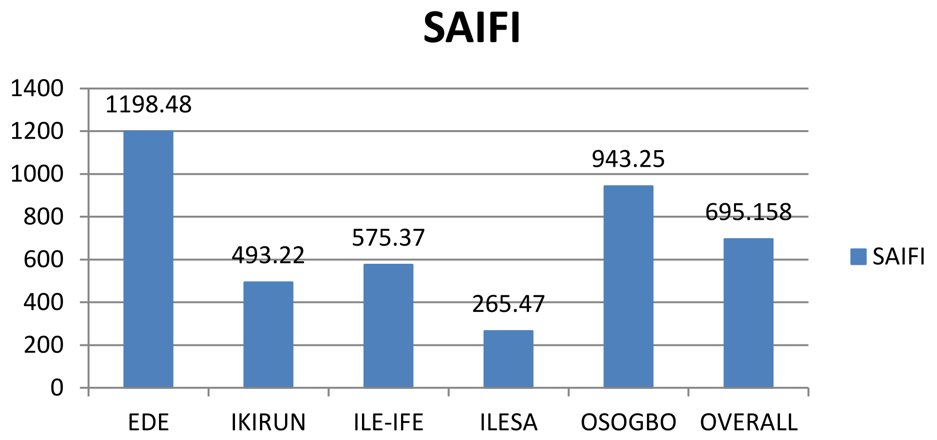

Fig. 5: Overall SAIFI of Osun region of IBEDC power supply for year 2016

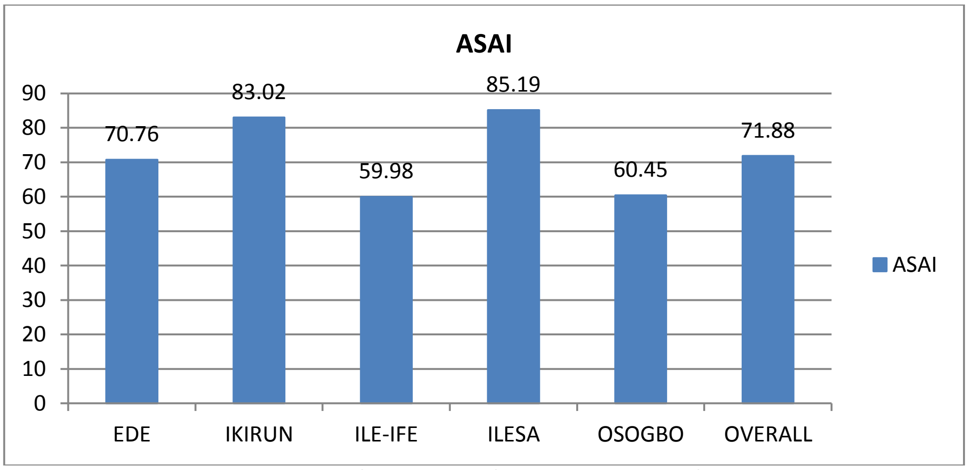

Fig. 6: Overall ASAI of Osun region of IBEDC power supply for year 2016

3.1 Comparison of reliability Indices

Table 3 is used to compare power supply reliability in Osun Region of South Western, Nigeria that comprises of five Business Hubs to other countries' cities' average. It should be noted that interruption indices are not homogenous and the comparisons between countries and companies should be done with caution as the input data vary tremendously. We also observed that there are variations in approach to basic calculation procedure from one utility to another (Kueck, Kirby, Overholt, & Market, 2004). Henceforth, the values available should be used with caution and benchmarking these values could result to inaccurate conclusions (Sumper,2006).

However, there is a clear indication that reliability indices in these countries are far much better than in Nigeria. Table 2b gives the national mean values of interruption duration, outage frequency and percentage availability in a year. This represent a region in Nigeria which hosted the NCC located in Osogbo, Osun State of Nigeria. The consumption analysis shows major concentration that is actually the average true representation of reliability indices of power supply in Nigeria.

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ISSN: 2278-0181
Vol. 6 Issue 04, April-2017

Table 3: Comparison of reliability indices of developed countries with Nigeria

S/N	COUNTRIES	SAIDI (Hour)	SAIFI	ASAI (%)
1	Austria	0.59	0.59	99.99
2.	Belgium	0.70	0.90	99.99
3.	France	0.89	1.21	99.99
4.	Germany	0.62	0.27	99.99
5.	Great Britain	1.17	0.77	99.99
6.	Netherlands	0.46	0.38	99.99
7.	Barcelona City	1.79	2.28	99.98
8.	Sweden	1.65	2.07	99.98
9.	USA	1.36	0.97	99.98
10.	Finland	3.04	4.06	99.97
11.	Ireland	3.93	1.34	99.97
12.	Spain	2.55	2.98	99.97
13.	Italy	3.38	3.83	99.96
14.	Norway	3.63	2.73	99.96
15.	Nigeria (IBEDC, Osun region)	2470.16	695.16	71.88

Sources: [Sumper, 2006; Sullivan, 2009].

However, there is a clear indication that reliability indices in these countries are far much better than in Nigeria. Table 2b gives the national mean values of interruption duration, outage frequency and percentage availability in a year. This represent a region in Nigeria which hosted the NCC located in Osogbo, Osun State of Nigeria. The consumption analysis shows major concentration that is actually the average true representation of reliability indices of power supply in Nigeria.

4.0 CONCLUSIONS

It was observed that the reliability obtained from the result of the analysis of the feeders indicated that outage duration, frequency of outage and period of restoration of power supply were very high. Henceforth, there is need to reduce all the values of indices; SAIDI, CAIDI and SAIFI in order to boost ASAI. This could be better achieved by putting the following in place:

i. Gradual adoption of transition to smart distribution grid;
ii. Feeder automation to enhance quick restoration of fault
iii. Routine maintenance of distribution lines is very essential, especially trimming and cutting of trees that causes earth fault via bridging of lines.
iv. Exploiting alternative sources of distribution to improve power supply availability i.e tapping the available distributed energy resources in term of renewables and use of Micro-grid in the rural area.

Finally, with adherent to the above suggestion, the reliability of power supply systems will drastically improve together driving home the economy status and productivity of the country.

ACKNOWLEDGEMENT

The authors would like to express their appreciation to the Management and Staff of Ibadan Electricity Distribution Company, IBEDC, Ibadan Head Office and Osogbo Regional Office for their support in providing necessary technical information required to carry out this research. We also grateful to Office of Research and Development (ORD), University of Botswana for her financial and moral assistance required for the accomplishment of this study.

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