Reliability Assessment of Power Distribution System in the Nigerian Aviation Industry

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Abstract: Airport terminals are the most energy intensive type of buildings due to their size, designs, activities and twenty-four hours operation. Due to recent development in airport design, incessant power failures and ineffective power distribution systems have emerged as an area of concern in the Nigerian aviation industry. To resolve these challenges, energy audit was performed by collecting energy data from three major aviation sites (airports) in Nigeria by means of data loggers, powerhouse documents and personal communication. Using collected energy data, analysis was performed to determine the reliability of these airports thereby informing the proposition of a power distribution system model for future loads. The study has contributed to the aviation industry through the development of a steady power distribution model and if implemented, the airports under evaluation would be among the leading aviation sites in the world in terms of power distribution reliability and sustainable design.

Keywords: Reliability indices, Airport, Power distribution, Power interruptions

تقييم موثوقية نظام توزيع الطاقة في صناعة الطيران النيجيرية

الملخص: مباني المطارات هي أكثر أنواع المباني كثافة في استخدام الطاقة نظرًا لحجمها وتصميمها وأنشطتها وتشغيلها لمدة ٢٤ ساعة. نظرًا للتطور الأخير في تصميم المطار، ظهرت حالات مستمرة لانقطاع التيار الكهربائي وأنظمة توزيع الطاقة غير الفعالة صارت موضوعا مثيرا للقلق في صناعة الطيران النيجيرية. لحل هذه التحديات، تم إجراء تدقيق للطاقة من خلال جمع بيانات الطاقة من ثلاثة مواقع طيران رئيسية (المطارات) في نيجيريا عن طريق مسجلات البيانات ووثائق محطة توليد الكهرباء والاتصالات الشخصية. باستخدام بيانات الطاقة التي تم جمعها، تم إجراء تحليل لتحديد موثوقية هذه المطارات وبالتالي اقتراح نموذج لنظام توزيع الطاقة للأحمال المستقبلية. ساهمت الدراسة في صناعة الطيران من خلال تطوير نموذج لتوزيع ثابت للطاقة، وفي حالة تنفيذها، ستكون المطارات قيد التقييم من بين مواقع الطيران الرائدة في العالم من حيث موثوقية توزيع الطاقة والتصميم المستدام.

1. Introduction

Power supply in Nigeria has been unreliable and unsteady, of which the aviation industries are not left out; hence the transformation currently taking place in terms of reliability, controllability and visibility. Moreover, the Nigeria government is committed to reducing overall carbon emissions by 45% by 2030 [1] and to meet renewable energy generation target of 50% demand for electricity by 2020 [2]. In order to achieve these targets set by the Nigerian government, there will be need to integrate renewable energy into the existing power system, as well as overhaul the power system infrastructure [3-5]. These functionalities will help power distribution companies in Nigeria and Distribution Network Operators (DNOs) to plan and alleviate network congestion in other to provide lower costs for electricity consumers (residential and commercial) in the airport (AP) and its environs. In this work, detailed examination of the three (3) major airports in Nigeria will be considered which include: Murtala Muhammed International Airport (MMIA) Lagos, Malam Aminu Kano International Airport (MAKIA) Kano and Nnamdi Azikwe International Airport (NAIA) Abuja. These airports have both residential and non-residential buildings. Inspection of their energy audit (facility by facility), consumption pattern, reliability of their energy distribution network configurations and energy quality of supply assessment of these airports will be closely examined so as to develop an enhanced and synchronized network distribution system for these airports [6].

In spite of the unparalleled investment in the power sector to restore the decayed distribution network facilities, the power situation in Nigeria has not improved. The gap between supply and demand keeps widening in the urban areas, while supply has not really improved in the Nigerian airports to cater for its high level of passenger traffic and operations. Ironically, experts on power generation, transmission and distribution are always giving excuses for the power crisis, which has defamed and hampered Nigeria’s effort in becoming one of the most developed and industrialized nation of the world by 2020. Inadequate gas supply due to vandalism and theft, shortage of reserved water in the dams, destruction of power equipment, poor funding by private and government agencies and others, have been identified as major causes of incessant outages in these airports [7]. The Transmission Company of Nigeria (TCN) claimed that the massive load shedding/systems collapse experienced nationwide has been caused by the destruction of two major gas pipelines conveying gas to eight power generating stations in the country to run their turbines. The generating stations, which include the Olorunsogo, Egbin/AES thermal stations, Omotosho, Geregu NIPP, AFAM

IV and VI thermal power stations and Rivers State Independent Power Station were affected, resulting in drastic reduction of power supply by 1,598 MW from the current claim of 7,000MW capacity; while TCN has only been able to wheel out 5,222.3MW, the highest ever into the economy [8].

Despite all these problems and challenges affecting power system in Nigeria, management of the available energy has been of little or no concern to the power sector in Nigeria. For example in the aviation industry as at today, old underground power cables, appliances, machines, etc. that have been in operation for more than 40years are still being used in these airports. This reduces the reliability of the airport's distribution network and thereby increases its System Average Interruption Frequency Index (SAIFI) due to incessant failure and lot of energy loss along these distribution paths.

In view of the new regulation for Nigerian airports, the distribution network operator (DNO) in Nigeria, need to be able to optimize the installation and utilization of their reserve capacity in the system. This optimization is required since there is a great need to reduce cost and maximize reliability. Estimating the impact of using reserve capacity configuration, it becomes easier to determine when the risk taken is acceptable [9], so that effective planning is inevitable. Authors have suggested the use of multi-criteria dynamic optimization [10, 11], embedded generation and demand management system planning [12], system based level using energy and maximum load etc. without considering long term losses [13, 14]. The importance of considering continuous power losses in all major network planning studies based on peak load conditions, which is accepted as the basic model in calculation of power losses was presented in [15]. In [16], the author observed that efficiency of electricity systems in conjunction with cost of power losses is another important driver in reduction of network losses and should be given serious consideration. Among opportunities for loss reduction, the author described higher distribution voltages and load shifting (or system reconfiguration) as the best methods.

Series of work have been carried out on reliability assessment in electric distribution network, distribution system with distributed generation and electric transmission network [17-20]. However, the reliability assessment of the Nigerian aviation industry has not been investigated. Reliability indices used mostly are system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI) and customer average interruption index (CAIDI), which will also be considered in this work. This work was necessitated based on: no available information on the energy demand, consumption pattern, reliability of the distribution network, no chart to indicate the reliability indicators with proper network planning scheme for future loads in the three major airports.

From the foregoing, the main task of electric power systems operators is to provide their customers with a reliable and economically feasible supply of electricity [21]. As a means of providing reliable power supply, there is need to build in reserve capacity within the airports distribution substation network to cope with contingencies, increased demand for power supply at various places within the airports due to its dynamic activities and scheduled maintenance. The reserve capacity for Lagos, Abuja and Kano international airports must be designed and constructed in the most technical and economically optimal way as a viable means of having efficient and reliable power distribution at cheapest possible cost. An enhanced network planning scheme for these airport networks to improve power availability in the airport and to reduce incessant load shedding will be presented. Hence, commonly used method of reliability analysis will be adopted in this work.

2. Methodology

The procedure used in order to execute this work is explained in this section.

The probability distributions instead of simple average techniques and standard deviations will be used to evaluate the effect on reliability indicators (e.g. **System Average Interruption Duration Index (SAIDI), Consumer Average Interruption Duration Index (CAIDI),** and **System Average Interruption Frequency Index (SAIFI)** of the different cases to be examined. Different cases were examined for Lagos, Abuja and Kano airports through SAIFI, SAIDI, CAIDI and frequency of interruptions in these airports.

Tables would be developed for each case for the data obtained in 2016 for the airports under consideration and these tables would be used to form charts for each case using reliability indices. These tables would also be used to plot graphs of reliability indices for each airport, identify which, what and why, then what can be done to improve the systems reliability for short time and for future expansion. For the future expansion, new airport would be modeled for Lagos and recommendation will be made in relation to the other two airports.

2.1 Data Collection and Collation

Energy survey and data gathering from the three (3) major airports in Nigeria using both primary and secondary data, energy audit of these airport so as to determine their load capacity, quality of supply assessment, energy consumption pattern and energy performance score for these airport as means of determining the airport that has the most reliable distribution network. The use of value of consumers' reliability indices to develop a more efficient power system networks for these airports was carried out.

From the survey carried out on buildings and offices in the airports, data collected from electrical system control rooms, energy audit and manufacturers' label on equipment were collated and presented as in Tables 1, 2, 3 and 5. Furthermore, graphs were developed as presented in Figures 1, 2, 3 and 4 for interruptions and reliability indices for the airports under consideration.

2.2 Reliability Indices

Consumers' based reliability indices considered in this work are SAIDI, SAIFI and CAIDI. SAIDI is defined as the total duration of sustained interruptions in a year per total number of consumers as given in (1) [20,21] and its unit is 'minutes'; SAIFI is defined as the total number of sustained interruptions in a year per total number of consumers as given in (2) [20] and its unit is 'interruptions per consumers'; CAIDI is defined as the total duration of sustained interruptions in a year per total number of interruptions and it is also the ratio of SAIDI to SAIFI and is given by the expression in (3) [20]. The unit of CAIDI is 'minutes'.

$$SAIDI = \frac{Sum\ of\ consumers\ interruptions\ duration}{Total\ number\ of\ consumers\ served} \tag{1}$$

$$SAIFI = \frac{Total\ number\ of\ consumers\ interrupted}{Total\ number\ of\ consumers\ served} \tag{2}$$

$$CAIDI = \frac{Sum\ of\ consumers\ interruptions\ duration}{Total\ number\ of\ consumers\ interrupted} = \frac{SAIDI}{SAIFI} \tag{3}$$

In this work, SAIFI, SAIDI and CAIDI are used since they are the reliability indices related to consumer supply calculated using annual field data.

2.3 Reliability

Reliability in power system is the ability of the system to satisfy the consumer demand. In this work reliability will be calculated using (4) [22] and it will be used to validate the reliability of the three airports under consideration.

$$Reliability = \frac{(Total\ minutes\ in\ year - Total\ minutes\ without\ supply) \times 100}{Total\ minutes\ in\ year}$$

$$= \frac{\left(365\ days\ \times \frac{24\ Hours}{day}\ \times \frac{60 minutes}{Hour} - Duration\ of\ outages(minute)\right) \times\ 100}{\left(365\ days\ \times \frac{24\ Hours}{day} \times\ 60 \frac{minutes}{Hour}\right)} \tag{4}$$

3. Results and Discussion

The Lagos airport has two supplies from ISOLO and EJIGBO power substations. The ISOLO power station consists of a 132/33kV, 1 x 60MVA step down On Load Transformer Changer (OLTC) transformers, while the Ejigbo substation has 132/33kV, 2 x 100MVA step down OLTC transformers. The secondary of these transformers were fed to Lagos airport via a 33kV panel having a breaker capacity of 1250A. This energy is first received by a network of UG cables that were fed to copper bus coupler, then connected to 33kV/11kV step down transformer for further handling of the energy. Evaluated data for the year 2016 showing interruptions frequency and duration is shown in Table 1 for Lagos, while Table 2 and Table 3 show that for Abuja and Kano respectively.

Table 1: Lagos unplanned and planned long consumers interruptions

From energy data recordings of 12,236 consumers
Voltage level (99.86% at 0.415kV)

Months in 2016	Consumers Interruption		SAIFI (Interruption /Consumers)	SAIDI (Minutes)	CAIDI (Minutes)
	No. Interruption	Duration (minutes)			
January	368	52,293	0.03	4.27	142.10
February	704	51,036	0.06	4.17	72.49
March	822	59,803	0.07	4.89	72.75
April	1,014	62,651	0.08	5.12	61.79
May	1,172	81,483	0.10	6.66	69.52
June	1,494	75,627	0.12	6.18	50.62
July	225	41,924	0.02	3.42	186.33
August	364	47,335	0.03	3.87	130.04
September	322	44,211	0.03	3.61	137.30
October	469	55,027	0.04	4.50	117.33
November	544	53,312	0.04	4.36	98.00
December	562	58,998	0.05	4.82	104.98
Total	8,060	683,700	0.67	55.87	1243.25

From Table 1, the highest number of interruption occurred in the month of June with the least consumers' interruption duration index, while the highest period of interruption in minutes occurred in the month of May. It is observed that, the number of interruption is not directly proportional to the duration of interruption. Since SAIFI and SAIDI are functions of interruption, it is observed that, the higher the number of interruption, the higher the magnitude of SAIFI and SAIDI.

Table 2: Abuja unplanned and planned long consumers interruptions

From energy data recordings of 4,589 Consumers Voltage level (99.53% at 0.415kV)					
Months in 2016	Consumers Interruption		SAIFI (Interruption /Consumers)	SAIDI (Minutes)	CAIDI (Minutes)
	No. Interruption	Duration (minutes)			
January	352	37,814	0.07	8.24	107.43
February	372	50,968	0.08	11.11	137.01
March	411	63,067	0.09	13.74	121.28
April	351	42,571	0.08	9.28	153.45
May	241	39,332	0.05	8.57	163.20
June	105	34,668	0.02	7.55	330.17
July	140	36,746	0.03	8.01	262.47
August	237	39,668	0.05	8.64	167.38
September	229	40,739	0.05	8.88	177.90
October	276	39,893	0.06	8.69	144.53
November	276	42,738	0.06	9.31	154.85
December	350	47,835	0.08	10.42	136.67
Total	3,340	516,136	0.72	112.44	2056.34

From Table 2, the highest number of interruption occurred in the month of March with the highest period of interruption duration in minutes, while the least consumers' interruption duration index is in January. It is also observed that, the number of interruption is not directly proportional to the duration of interruption. Similarly, SAIFI and SAIDI increases relative to the number of interruptions.

Table 3: Kano unplanned and planned long consumers interruptions

From energy data recordings of 3,019 Consumers
Voltage level (99.91% at 0.415kV)

Months in 2016	Consumers Interruption		SAIFI (Interruption/ Consumers)	SAIDI (Minutes)	CAIDI (Minutes)
	No. Interruption	Duration (minutes)			
January	163	10,414	0.05	3.45	63.89
February	167	15,482	0.06	5.13	92.71
March	172	17,336	0.06	5.74	100.79
April	148	15,435	0.05	5.11	104.29
May	142	14,996	0.05	4.97	105.61
June	113	10,325	0.04	3.42	91.37
July	122	10,052	0.04	3.33	82.39
August	128	12,528	0.04	4.15	97.88
September	134	11,047	0.04	3.66	82.44
October	149	12,974	0.05	4.30	87.07
November	153	13,222	0.05	4.38	86.41
December	157	13,749	0.05	4.55	87.57
Total	1,748	157,560	0.58	52.19	1,082.42

From Table 3, the highest number of interruption occurred in the month of March with the highest period of interruption duration in minutes, while the least consumers' interruption duration index is in January. It is also observed that, the number of interruption is not directly proportional to the duration of interruption. In a similar vein, SAIFI and SAIDI increase with increasing number of interruption. From Tables 1 to 3, it can be seen that Lagos, Abuja and Kano airports followed the same pattern in terms of interruption, duration and reliability indices.

Plotting the graph of outages in Lagos, Abuja and Kano against twelve calendar months in the year 2016, the number of interruptions, SAIFI, SAIDI and CAIDI are shown in Figures 1 - 4.

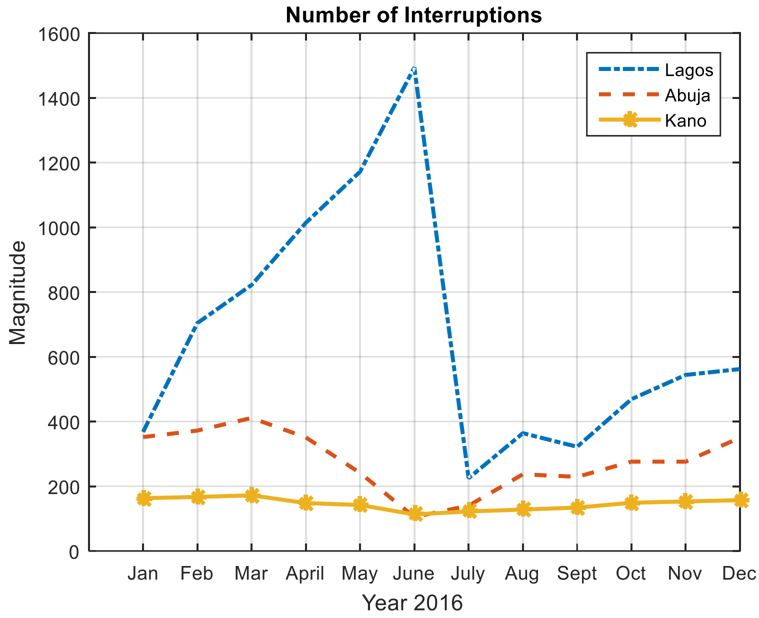

Figure 1: Lagos, Abuja and Kano graph of number of interruption.

Figure 1 shows behaviors of Lagos, Abuja and Kano interruptions in the year 2016. Kano has peak interruption in the month of March which is less than 200 times. Abuja has peak interruption in the month of March too but a little bit above 400 times, while Lagos with the least interruption in the month of July which is a little above 200, but has highest peak in the month of June and frequency of about 1500 times indicating instability in the distribution system.

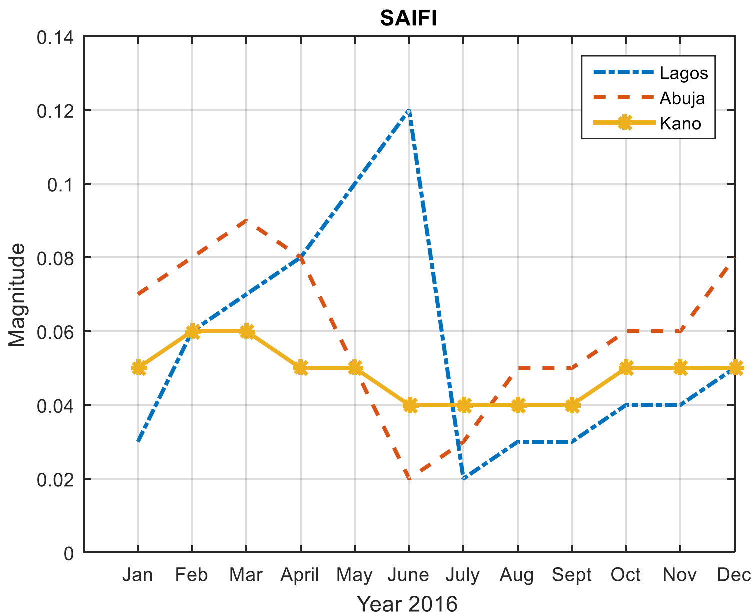

Figure 2: Lagos, Abuja and Kano SAIFI graph.

Looking at the behaviors in Figure 2, Kano airport has the most improved SAIFI oscillating between 0.04 and 0.06 which is the ratio of the number of interruption to the number of consumers. This means that, Kano airport is the most stable airport among the three airports followed by Abuja airport. Lagos has the highest number of interruptions indicating an unstable power distribution system.

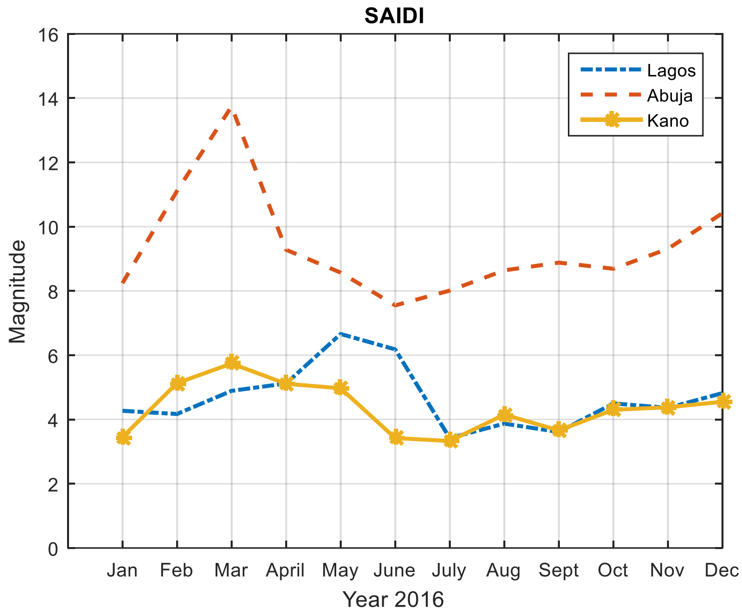

Figure 3: Lagos, Abuja and Kano SAIDI graph

In Figure 3, Kano airport has the least SAIDI followed by Abuja, while Lagos has the highest system of interruption in the year 2016. Lagos still remains unstable with this reliability index, due to the high number of consumers when compared with the other airports.

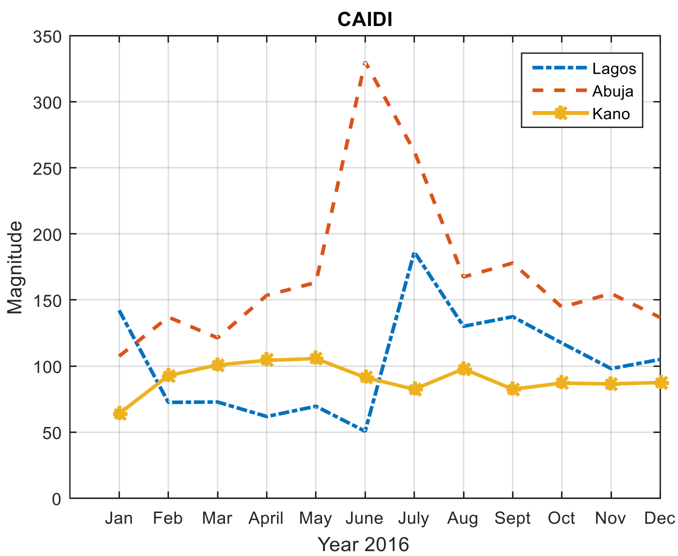

Figure 4: Lagos, Abuja and Kano CAIDI graph.

Although the CAIDI graph behaviors found Abuja consumers interrupted the most with highest index of about 340. However, from the data presented in Table 1, Lagos has the highest number of interruptions when compared with Abuja, still making it the most unstable airport due to the large number of consumers in it. Kano remains the most stable airport among the three airports as depicted in Figure 4.

To validate the reliability of the airports, we use the mathematical equation in (4). The reliability for Lagos, Abuja and Kano is calculated as follows:

a. Lagos airport having 683,700minutes of outages, has a reliability of:

$$Reliability_{Lagos} = \frac{\left(365\ days \times \frac{24\ Hours}{day} \times \frac{60minutes}{Hour} - 683{,}700\right) \times 100}{\left(365\ days \times \frac{24\ Hours}{day} \times 60\frac{minutes}{Hour}\right)}$$

$$= \frac{(525{,}600 - 683{,}700) \times 100}{(525{,}600)} = -30\%$$

b. Abuja airport having 516,136minutes of outages, has a reliability of:

$$Reliability_{Abuja} = \frac{\left(365\ days \times \frac{24\ Hours}{day} \times \frac{60minutes}{Hour} - 516{,}136\right) \times 100}{\left(365\ days \times \frac{24\ Hours}{day} \times 60\frac{minutes}{Hour}\right)}$$

$$= \frac{(525{,}600 - 516{,}136) \times 100}{(525{,}600)} = 1.8\%$$

c. Kano airport having 157,560 minutes of outages, has a reliability of:

$$Reliability_{Kano} = \frac{\left(365\ days \times \frac{24\ Hours}{day} \times \frac{60minutes}{Hour} - 157{,}560\right) \times 100}{\left(365\ days \times \frac{24\ Hours}{day} \times 60\frac{minutes}{Hour}\right)}$$

$$= \frac{(525{,}600 - 157{,}560) \times 100}{(525{,}600)} = 70\%$$

The reliability indices and the reliability for Lagos, Abuja and Kano are presented in Table 4.

Table 4: Summary of reliability indices for Lagos, Abuja and Kano airports

Year, 2016	No. of Consumers	No. of interruption	Duration of interruption (minutes)	SAIFI	SAIDI	CAIDI	Calculated Reliability
LAGOS	12,236	8,060	683,700	0.67	55.87	1,243.25	-30%
ABUJA	4,589	3,340	516,136	0.72	112.44	2,056.34	1.8%
KANO	3,019	1,748	157,560	0.58	52.19	1,082.42	70%

From all indication, considering Table 4, Lagos airport takes second position in the table in terms of SAIFI, SAIDI and CAIDI but needs more attention considering the fact that it is the most unstable, as well as the most patronized airport among the three with the highest number of consumers and having the negative index of (-30%) calculated reliability (the calculated reliability validates the fact that Lagos is unstable/unreliable). Attention would be on Lagos airport in order to relate causes of interruption both planned and unplanned as they affect planning, reliability and quality of power distribution systems.

4. Projected Lagos Airport Consumers

The major causes of power outage in Lagos aside from power failure from national grid that are recurrent, which results in its being the most unstable among the airports despite the fact that the airport is the most patronized, would be singled out for year 2017 with a projected increased number of consumers to 13,000. Table 5 is the Lagos 2017 isolated causes of interruption, number of interruption (274), duration (10,120 minutes) and reliability indices (SAIFI, SAIDI and CAIDI); while Table 6 shows differences between Lagos 2016 and selected 2017 reliability parameters.

Table 5: Lagos power house internal planned and unplanned interruption (interruption causes)

Lagos	From energy data recordings of 13,000 Consumers Voltage level (99.86% at 11kV)							
Year 2017	Interruption Causes			Customer interruption		SAIFI (Interruption /Consumers)	SAIDI (Minutes)	CAIDI (Minutes)
	Cable	Load shedding	Water	No.	Duration (minutes)			
January	14	8	0	22	1,603	0.0017	0.1233	72.86
February	7	13	0	20	660	0.0015	0.0508	33.00
March	4	40	0	44	1,273	0.0034	0.0979	28.93
April	2	15	0	17	588	0.0013	0.0452	34.59
May	8	8	3	19	897	0.0014	0.0690	47.21
June	2	0	8	10	512	0.0008	0.0394	51.20
July	4	0	13	17	562	0.0013	0.0432	33.06
August	0	3	0	3	9	0.0002	0.0006	03.00
September	2	0	14	16	1,147	0.0012	0.0882	71.69
October	9	20	1	30	1,213	0.0023	0.0933	40.43
November	10	25	0	35	1,505	0.0027	0.1158	43.00
December	11	30	0	41	151	0.0032	0.0116	03.68
Total	73	162	39	274	10,120	0.0296	0.5080	469.65

Table 6: Summary of Lagos 2016 and 2017 Parameters

LAGOS	No. Of Consumers	No. of interruption	Duration of interruption (minutes)	SAIFI (Interruption/ Consumers)	SAIDI (Minutes)	CAIDI (Minutes)
Year, 2016	12,236	8,060	683,700	0.67	55.87	1,243.25
Year, 2017	13,000	274	10,120	0.0296	0.5080	469.65

It can be seen in Table 1 for year 2016 that, the total number of approximated consumers connected to the 11kV feeders is 12,236 with total number of interruption of 8,060 having a duration of 683,700minutes, while that of selected causes has 13,000 consumers with total number of interruption of 274 having duration of 10,120minutes. It is observed that, there is reduction in the number of outages and interruption despite increment in the number of consumers in 2017 even though it was selected compared to 2016. It can be seen from the Tables and Figures that the chart follows the same pattern, although there is abnormality in the data of Table 1 where there is high number of interruption between May and July with peak in June. This was as a result of gas pipelines vandalism when the change of Nigeria Government took place. From Table 5, the factors responsible for major outages between six months of October and March are typical of the characteristic dry season of those periods. The transmitted power to the injection stations is always on the low owing to the limited energy generated as a result of low volume of water at the generation end, even though the energy generated through gas turbines would be distributed to transmission lines which would not be enough. If no power is transmitted to injection substation, there would be no power supply to the end users.

In the dry season, consumers tend to use more of energy consuming equipment like air conditioning systems as a result of more passenger traffic and the heavy heat during the period. The air conditioners inspected both at the residential and commercial areas are very powerful thereby consuming more energy, hence resulting in overloading of the system. In addition to these air conditioners energy consumptions, newly built hanger, commercial centers like car park and terminals are the contributory factors to the system overloading. Since there are only two 8MVA transformers, the new developments are adding to the accumulated load on a daily basis; and to avoid system collapse since combined capacity of the two transformers cannot power more than 13MW, load shedding is unavoidable. On an hourly basis, the total load is usually monitored and documented in the power house log book. When the load is above 12.5MW, load shedding done by mechanically opening/de-energizing the breakers of the feeders supplying some substations is usually carried out because demand exceeds power supply.

5. Remodeling of the Airports with Reserved Capacity

Following directly from the identified challenges, the Lagos airport was remodeled as presented in Figure 5 to help improve the network quality and reliability.

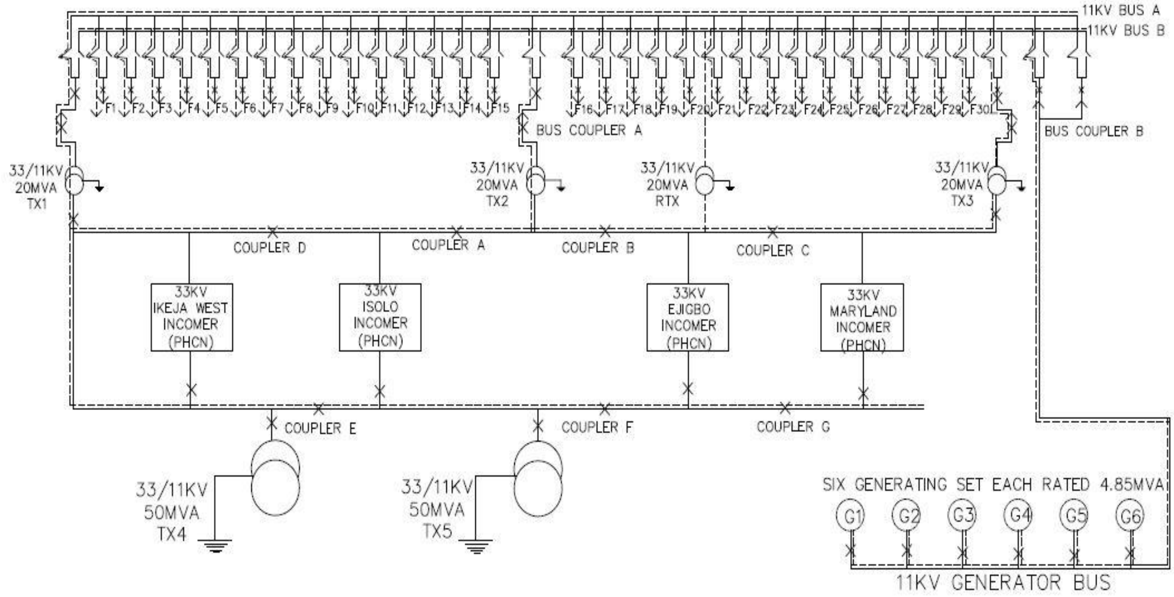

Figure 5: Lagos remodeled airport.

Figure 5 presents the remodeled Lagos airport for the forecasted load. The remodeled airport is a modification of the existing airport to accommodate current excess power consumption and to cater for future load for the next decade. When power equipment were evaluated across airports, Lagos was seen to be the busiest among all Nigerian airports, as a result, load predictions were made for this airport. Based on the load prediction, reliability and quality of power distribution were considered in remodeling the system. The airport has more additional power sources which are IKEJA WEST and MARYLAND power substations to complement existing EJIGBO and ISOLO power sources. The additional sources will increase the system quality of power supply resulting in higher reliability. Only a single source can be used at a time, while the remaining sources are redundant. From existing Lagos airport diagram, the two functional transformers having total output of 15MW is replaced with three numbers of 20MVA transformers which would produce a total output of 48MW. This shows that even with 40MW forecasted, there is 8MW tolerance to cater for unplanned circumstances.

Power supply from ISOLO and EJIGBO substation was via UG 2x33kV, 1x240mm^2 XLPE armored cable for ISOLO and 3x240mm^2 for EJIGBO, both lengths of approx. 100km in duct. Cables with dry season continuous rating of 437A (~8MVA) each are presently energized at 11kV. This same rating of armored XLPE cable would be used for newly introduced Ikeja West and Maryland in Lagos. Aside from the three numbers of 20MVA proposed in the remodeled airport in Lagos, one 20MVA is placed as redundant should there be fault in any of the three numbers of 20MVA as represented with dotted transformer and labeled RTX. Two numbers of

50MVA are placed to serve as transformer reserve capacity for future expansion or to be restored to the system in case we have worst scenarios when two numbers of 20MVA collapsed or are not synchronize-able. The current system has 13 functional distribution feeders feeding different sections of the airport in Lagos. The loads on these feeders are much and complex as a result of many organizations, companies along the same line that are looped; hence the need for more flexible system with more feeders to serve areas looped together under the same feeder currently. The feeders F1, F2, …F13 as they are currently constituted in Lagos, is modeled to 30 feeders F1, F2, …F30 with a redundant cable line along each feeder to serve as backup in case there is cable fault along the line. All the cable lines duplicated in dotted line are redundant cable lines to prevent power outage, reduce the down time and also reduce restoring time since consumers are ready to pay for their consumptions. The case of Abuja and Kano airport as cross examined, the two numbers of 2MVA transformers used in Abuja delivering a total output of 4MW is not enough to accommodate for the network and its reserve capacity. By audit, the total load that will conveniently feed the whole airport is estimated at 7MW, while the case of Kano having two numbers of 800kVA transformers will not adequately feed its 3.2MW load capacity. Therefore, there is need for upgrade in these airports to accommodate more load and reserve capacity. The existing distribution network can be modified to accommodate more loads. The Abuja 2.5MVA can be replaced with two numbers of 8MVA and 800kVA can be replaced with equivalent 2.5MVA transformers in Kano airport. The power transformers used in the existing airports are presented in Table 7.

Table 7: Existing airport transformers.

Airports	Transformers	Power output	Energy Audit Peak Load
Kano	2 × 800kVA	3.2MW	1.39MW
Abuja	2 × 2MVA	4MW	2.87MW
Lagos	2 × 8MVA	12.8MW	12.6MW

When the capacity loads of these airport are being increased, it will be possible to design a more reliable distribution network configuration for these airports.

Table 8: Remodeled airport transformers with reserve capacity.

Airports	Transformers	Power output	Energy Audit Peak Load	Reserve capacity
Kano	2 × 2.5MVA	3.7MW	5MW	-
Abuja	2 × 8MVA	12.8MW	8MW	-
Lagos	3 × 20MVA	48MW	15MW	1x20MVA - 2x50MVA

Table 8 shows the summary of transformers modeled for 2025 forecasted load for Lagos, Abuja and Kano airports (to cater for the airports upgrade and increased number of consumers). Since there is lesser activities in MAKIA Kano airport and it is the most reliable airport among the three airport under survey, there is need for little power distribution upgrade. The Abuja airport present load is used to forecast and model future power consumption which is pegged at 10MW. This will accommodate future load with reserve capacity. Lagos forecasted load for 2025 is pegged at 40MW. As a result of Lagos airport importance, being the commercial centre of the nation, the newly remodeled airport has redundant plant of 20MVA with reserve capacity 2x50MVA. From the foregoing, increased load of 40MW, 10MW and 3.7MW is projected for Lagos, Abuja and Kano airports respectively in the future to cater for airport growth in terms of commercial and industrial developments (see Table 8).

This robust airport proposal is to accommodate various unplanned loads and to ensure network security through this planning, reliability and quality. If this remodeled airport is implemented, Lagos would be one of the leading airports in the world in terms of reliability and quality of power distribution resulting in system security.

6. Conclusion

In this work, reliability assessment of power distribution in three major airports was considered. From the survey carried out, data was collected and collated for the airports for the first time, which can be used by other researchers. This work has conducted energy audit in selected airports in the aviation industry of Nigeria and has identified some grey areas in the distribution network indicative of poor reliability of the system. From the reliability indices (SAIFI, SAIDI and CAIDI) obtained from the data and the calculated reliability, it was observed that Lagos airport is the most unstable/unreliable due to the large traffic experienced (most patronized) and the highest number of consumers in the airport. An expanded model with redundant links has been proposed for reliable and sustainable energy in the aviation sector by running a predictive model for future energy expansion up till 2025.

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