Assessment of Operational Reliability of Some Fossil Energy Driven Power Stations

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***ABSTRACT* -- Due to the benefit of the vital nature of electric power, both to our economic, personal well-being and other purposes, a power system is expected to supply electrical energy as economical as possible and with a high degree of quality and reliability. A reliable power station is one which would supply the required power within its installed capacity at any time within the specified voltage and frequency limits. Essential for this evaluation are the station's installed capacity and available generation. This work is to assess the past data for performance of some power stations in Nigeria from 2006 to 2017 to determine if they are supplying electric energy within their installed capacities in line with energy global best practices. The combined installed capacity of these power plant is 37% of the twenty-one thermal power plants connected to the national power grid. A historical operational data of these selected plants over a period of twelve years was obtained and evaluated based on power plant performance indices analytical techniques. Results obtained from these analysis shows that, the equivalent availability factor which is accepted as the relative index of equipment reliability in this study, for Afam I-V, Afam VI, Delta and Egbin are (17.13, 78.57, 34.42, & 70.17) percent accordingly. It also shows that Afam VI and Egbin power stations have a good workable preventive maintenance programmes that upholds availability of their generators whereas, Afam I-V and Delta power stations were always faced with corrective maintenance.**

***Index Terms*: Reliability, Operational Assessment, Fossil Energy, Driven Power Statins, Availability Factor, Performance Indices, Reliability.**

I. INTRODUCTION

The high rate of electricity demand requires stable and continuous supply of electrical power to consumers. Hence improvement of the operational performance of a nation’s electric supply is vital for its economic and social developments. Because electricity is used for the twenty four (24) hours of the day, it has come to play an important role in all aspects of our life. It has been observed that the energy generated by the major hydro-electric power stations in Nigeria does not meet up with the demand [1, 2].

Bulk Electric power supply system comprises three functional subunits that could be separately analyzed. These three subunits are the power generation, power transmission and power distribution [1, 3]. The work focus mainly on the determination of the reliability of generation system.

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Gas turbine power generators produces over 81.5% of energy on the national power grid [1, 3]. This brings into focus the importance and reliance on thermal power plants in Nigeria power sector. The economics of fossil fueled turbine generating plants in Nigeria is very attractive due to the abundance of natural gas reserves.

The selected power plants are Afam I-V, Afam VI, Delta, and Egbin power plants. The years of these power plants covers old generation fossil fuel operated power plants, middle generation and new generation power. This represents three generations of thermal power projects in Nigeria. Afam I-V fossil fuel power station falls under the old generation power plant in Nigeria power sector. Afam I-V had an initial installed capacity of 972.8 MW which as at present is about 351MW with twenty power generator units (GT1 – GT20). [3, 5]. Ughelli Power Station (formerly called Delta power station) had an initial installed capacity of 912MW. It also have twenty simple cycle gas turbines generator units (GT1-GT20) initially, the first two generator units were out of service since 2002. The current installed capacity of is 900MW. Also, Egbin Power Station has six fossil energy fired steam turbines generator units (from ST1 to ST6), with a total installed capacity of 1320 MW. Each generator set is designed to operate on dual fuel (that is, gas and high pour fuel oil) and have a single reheat and six stages of regenerative feed heating steam generators [6].

Afam VI Power Station belongs to Shell Petroleum Development Company of Nigeria Limited (SPDC), and has three combined cycle gas turbines (labeled GT11 – GT13), each rated 150MW and one 200MW steam turbine generator (ST1). This gives a total installed capacity in Afam VI power plant as 650MW [1, 5].

A. Purpose of Power Station/Plant Reliability Evaluation

Power system reliability studies can be conducted for two purposes:

1. Long-term reliability evaluations may be performed to assist in long-range system planning,
2. Short-term reliability predictions may be sought to assist in day-to-day operating decisions.

II. RELIABILITY CONCEPTS OF POWER GENERATING PLANT/STATION

The power sector is undergoing an era of transition. Cheap natural gas, lower cost renewable power and increased use of energy efficiency and distributed generation are leading to a transformation. As more of these generators have retired in recent years and been replaced with new sources of power and energy efficiency, there have been questions about how to sustain the current level of reliability.

In analyzing the power generation indices, the analytical technique of forced outages is adopted in the assessment of the four major chosen thermal power generating plants in the Nigerian power sector. The emphasis on assessing the performance of thermal power plants is due to the fact that, fossil energy power plants constitute 82.7 percent of the total installed power generation capacity on the national electrical power network. The challenges of extreme electricity shortage over the years has been facing the Nigeria citizens especially those in academic. System components are categorized into different sensitive critical levels such that when failures occur, shutdown or just an alarm is triggered. A thermal power generator arrangement consist of several systems, subsystems and auxiliaries that are designed and programed to operate in unison. As a result, component failure rate affects the availability, reliability and capacity utilization of the plant. Reliability assessment on power station are usually tackled from two perspectives; either power plant competence and or power plant security. Power Plant competence is interpreted as having sufficient facilities to generate the required power demand from consumers under static conditions. On the other hand, power plant security hinges on the capability of the plant to absorb both dynamic and transient disturbances prevalent in bulk power supply systems [4, 8].

Reliability assessments are aimed at investigating the performances of existing facilities with a view to planning for either operational adequacy requirements of the power supply in the future or applying corrective actions to enhance the reliability of the existing equipment. Reliability of an equipment is the probability that the equipment will sustain operations in accordance with its designed specifications at a given period. Power generation reliability evaluations have been dominated by deterministic and probabilistic methods of modeling [9, 11, 12]. To achieve a standard degree of reliability at the customer level, each of these systems must provide an even higher degree of reliability. However as systems grew larger and more complex, the need for rigorous analysis in the form of formal concepts and methods of reliability theory have been applied to almost every aspect of power system reliability evaluations.

The popular probabilistic indices are: i) LOLP: This describes the probability of the system load exceeding the available generation under the assumption that the peak load of each day lasts all day. It is expressed in units of day/year. ii) LOLE: This describes the expected number of days in a year when loss of load occur [12].

The probabilistic modelling method depend on either statistical analysis of data gathered to identify events and the performance of power system components Though probabilistic approach queries the operational data accumulated over the years on the facility, to tackle system failures [12, 13]. Probabilistic indices such as, Loss-of-Load Expectation (LOLE), Forced Outage Rates, Loss-of-Load Probabilistic (LOLP), Mean Time between Failure, and Failure Rate, are very popular for evaluating equipment reliability indices. As a result, Equivalent Availability Factor (EAF) will be used as the reliability index in computing the operational reliability of the thermal and hydroelectric power plants because, it is impossible to separate the load models for the two different systems that are synchronized onto a common power grid. The research instrument is the Generating Availability Data System (GADS) gathered and compiled in the National Control Centre (NCC) [2, 5, 14].

III. METHODOLOGY

The analytical technique of forced outages is adopted in the assessment of generation indices of the four major chosen thermal power generating plants in the power sector. The number of generator units that were included in the assessment for annual rating of the respective plant are (i) Afam I-V, (ii) Afam VI, (iii) Delta, and (iv) Egbin generator units.

Out of twenty generator units in Afam I-V power station, seven had been scrapped off. Afam VI had four generator units, Egbin had six generator units and Delta out of twenty generator units two are scuffled. Equivalent Availability Factor (EAF) will be used as the reliability index in computing the operational reliability of the thermal and hydroelectric power plants.

A. *Presentation of Data*

Generating Availability Data System (GADS) is recognized as a valuable source of reliable information for total unit and major equipment groups and is widely used by industry analysts in a variety of applications. The parameters acquired from GADS-NCC was used for the evaluation of performance indices in the chosen power plants. The parameters are: (i) generator availability; (ii) summaries of the maximum capacities and the average loads of the four chosen power stations. (iii) number of generator trips per year. The summaries of the maximum capacities of the chosen power plants and the average load of each are presented in Table I. The data collected are presented in Tables II to V for 2007 to 2017.

TABLE I
MAXIMUM CAPACITY AND ANNUAL AVERAGE LOAD SUMMARY OF THE POWER STATIONS (MW)

Year		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Afam I-V	Average Load (MW)	80.28	228.11	82.12	63.52	21.56	64.84	95.32	58.57	80.68	96.34	57.87	81.08
	Rate Capacity MW	797.80	931.60	931.60	931.60	516.00	351.00	351.00	351.00	351.00	351.09	351.09	351.09
Afam VI	Average Load (MW)	NA	NA	56.38	322.82	435.64	56.38	322.82	435.64	486.16	604.70	467.94	554.29
	Rate Capacity MW	NA	NA	331.50	497.25	650.00	331.50	497.25	650.00	650.00	650.00	650.00	650.00
Delta	Average Load (MW)	492.49	338.80	211.67	255.33	342.95	246.78	246.23	246.78	409.10	246.23	246.78	409.10
	Rate Capacity MW	882.00	882.00	882.00	882.00	900.00	900.00	900.00	900.00	900.00	900.00	900.00	900.00
Egbin	Average Load (MW)	1005.48	735.53	694.97	980.89	819.55	939.11	1022.56	976.77	970.41	1022.56	976.77	970.41
	Rate Capacity MW	1320.00	1320.00	1320.00	1320.00	1320.00	1320.00	1320.00	1320.00	1320.00	1320.00	1320.00	1320.00

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TABLE II
AFAM I-V POWER STATION GENERATOR UPTIME (IN DAYS)

Unit Capacity		Afam-II (4x23.9MW)				Afam-III (2x27.5MW)		Afam-IV (5x75MW)					Afam-V (2x138MW)		Total Run Days					
Unit Tag		GT5	GT6	GT7	GT8	GT9	GT10	GT14	GT15	GT16	GT17	GT18	GT19	GT20	Afam-II	Afam-III	Afam-IV	Afam-V	Total Days	P/S Aval.
Year	2006	5	150	226	0	0	0	0	0	0	144	0	358	351	376	0	144	709	1229	246
	2007	61	0	0	0	0	0	0	0	0	3	112	348	298	61	0	115	646	822	274
	2008	9	0	0	0	0	0	0	0	0	271	0	46	53	9	0	271	99	379	95
	2009	3	0	0	0	0	0	0	0	0	182	0	0	0	3	0	182	0	185	93
	2010	0	0	0	0	0	0	0	0	0	37	0	0	0	0	0	37	0	37	37
	2011	0	0	0	0	0	0	0	0	0	23	286	0	0	0	0	309	0	309	155
	2012	0	0	0	0	0	0	0	0	0	200	336	0	0	0	0	536	0	536	268
	2013	0	0	0	0	0	0	0	0	0	0	267	0	0	0	0	267	0	267	267
	2014	0	0	0	0	0	0	0	0	0	88	316	0	0	0	0	404	0	404	202
	2015	89	21	0	0	0	0	0	0	0	314	0	161	309	110	0	314	470	1190	238
	2016	0	112	151	0	0	49	0	0	0	284	168	339	313	263	49	452	652	1616	231
	2017	0	266	0	0	0	0	0	0	0	326	0	16	276	266	0	326	292	984	246

TABLE III
AFAM VI POWER STATION GENERATOR UPTIME (IN DAYS) WITH UNIT CAPACITY OF 200MW

Unit Capacity		3x150MW			200MW	P/S Uptime	Total days	Total days
Unit Tag		GT11	GT12	GT13	ST1		(150 MW)	(200 MW)
Year	2010	310	342	341	N/A	331	993	0
	2011	336	306	298	198	285	940	198
	2012	336	351	360	331	345	1047	331
	2013	334	282	342	286	311	958	286
	2014	335	358	355	317	341	1048	317
	2015	338	385	350	303	307	976	374
	2016	340	333	353	316	337	1049	303
	2017	341	380	351	291	303	994	289

TABLE IV
DELTA POWER STATION GENERATOR UPTIME (IN DAYS)

Unit Capacity		Delta-II (6x25MW)				Delta-III (6x25MW)						Delta-IV (6x100MW)								
Unit Tag		GT 3	GT 4	GT 5	GT6	GT 7	GT 8	GT 9	GT 10	GT 11	GT 12	GT 13	GT 14	GT15	GT16	GT 17	GT 18	GT 19	GT 20	Total Days (25MW)	Total Days (100MW)	P/S Aval.
Year	2007	0	0	0	358	311	344	353	348	355	358	351	282	90	0	253	358	0	316	3060	1017	314
	2008	0	0	0	102	79	121	313	213	343	291	0	324	163	0	0	25	0	226	1786	414	200
	2009	0	0	0	102	63	10	215	187	262	236	0	236	0	0	0	295	0	333	1421	628	205
	2010	0	0	0	251	307	78	326	125	324	349	57	269	51	276	49	270	199	148	2086	993	205
	2011	0	0	0	63	42	65	206	103	320	209	135	197	136	302	135	114	237	294	1340	1218	171
	2012	0	349	0	**0**	**0**	318	366	0	309	295	0	0	0	0	0	76	300	296	1637	672	289
	2013	0	175	0	0	0	331	0	0	0	246	0	0	0	183	126	0	73	349	752	731	212
	2014	0	365	0	0	365	346	0	323	275	328	92	0	0	336	363	0	0	351	2094	1050	314
	2015	0	245	0	0	338	339	0	271	61	47	42	0	0	225	346	0	0	106	2385	1174	209
	2016	0	243	351	21	365	358	0	9	9	34	32	0	0	265	365	0	0	116	2412	1221	319
	2017	0	231	0	0	365	336	0	9	11	35	32	0	0	184	136	0	0	243	2029	1059	157

TABLE V
GENERATOR UPTIME (DAYS) IN EGBIN POWER TATION

Unit Capacity		6x220MW							
Unit Tag		ST1	ST2	ST3	ST4	ST5	ST6	Total	P/S Avail
Year	2007	277	351	28	337	63	3 0	1356	271
	2008	316	246	94	276	331	0	1263	253
	2009	312	354	302	331	310	0	1609	322
	2010	24	351	346	358	338	0	1417	283
	2012	360	356	313	327	320	0	1676	335
	2013	340	363	340	328	355	0	1726	345
	2014	307	339	313	343	299	0	1601	320
	2015	322	344	347	314	279	0	1606	321
	2016	337	335	347	357	343	352	2067	346
	2017	328	335	334	347	355	357	2078	346

B. Reliability Indices of Power System Plants

Evaluation of the reliability and availability of generator units in the chosen power stations are carried out using the GADS of NCC from 2007 to 2017. Each equipment has designed in-built availability (AI) which is defined as:

$$A_r = \frac{MTBF}{MTBF + MTTR} \quad (1)$$

Where: MTBF is Main Time Between failure and MTTR is Main Time to Repair expressed as:

$$MTBF = \frac{Total\ Equipment Uptime\ (Days)}{Total\ Number\ of\ \ Equipment Failure} \quad (2)$$

$$MTTR = \frac{Total\ Equipment\ Downtime\ (Days)}{Total\ Number\ of\ \ Equipment Failure} \quad (3)$$

Unavailability or downtime complements availability or uptime. Also, total time is equal to uptime plus downtime. Total Time (1 year) = Uptime + Downtime (Unplanned +Planned)
Uptime = Total Time – Downtime (Unplanned +Planned) (4)
Note; Total time applied in this paper is either 365days (or 366days if it's a leap year). With the annual trip data collected, the MTBF's and MTTR's were calculated. GT6 had 8 trips in 2006 whereas, GT7 had 0 trip and operated for 226days and 0 day. Therefore, the MTBF and the MTTR of GT6 and GT7 in 2006 are calculated using Eqs. (2 & 3) as follows:

$$\text{MTBF for } GT6 = \frac{226(Days)}{8} = 28 days$$, and

$$MTTR\ for\ GT6 = \frac{(365-226)(Days)}{0} = 0days$$

$$MTBF\ \ for\ GT7 = \frac{0(Days)}{0} = 0\ days$$, and

$$MTTR\ for\ GT7 = \frac{365-0(Days)}{0} = 0\ days$$

The calculated MTBFs are as shown in Tables VI-VII, and Tables VIII-VIX represent the generators' MTTRs for Afam I-V, Afam VI, Delta and Egbin power stations respectively.

TABLE VI
AFAM I-V POWER STATION GENERATOR UNIT YEARLY TRIPS

Unit Capacity		Afam-II (4x23.9MW)				2x27.5MW		Afam-IV (5x75MW)					2x138MW	
Unit Tag		GT5	GT6	GT7	GT8	GT9	GT10	GT14	GT15	GT16	GT17	GT18	GT19	GT20
Year	2006	4	8	NA	NA	NA	NA	NA	NA	NA	3	NA	1	3
	2007	5	1	NA	NA	NA	NA	NA	NA	NA	3	3	2	2
	2008	2	NA	NA	NA	NA	NA	NA	NA	NA	7	NA	2	2
	2009	1	NA	NA	NA	NA	NA	NA	NA	NA	19	NA	NA	NA
	2010	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4	NA	NA
	2011	NA	NA	NA	NA	NA	NA	NA	NA	NA	7	18	NA	NA
	2012	NA	NA	NA	NA	NA	NA	NA	NA	NA	23	15	NA	NA
	2013	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	15	NA	NA
	2014	NA	NA	NA	NA	NA	NA	NA	NA	NA	7	12	NA	NA
	2015	NA	1	NA	NA	NA	NA	NA	NA	NA	13	12	NA	NA
	2016	NA	NA	NA	NA	NA	NA	NA	NA	NA	1	14	NA	2
	2017	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	10	2	NA

TABLE VIII
AFAM I-V POWER STATION GENERATOR MTTR

Unit Capacity		Afam-II (4x23.9MW)				Afam-III (2x27.5MW)		Afam-IV (5x75MW)					Afam-V (2x138MW)		P/S
Unit Tag		GT5	GT6	GT7	GT8	GT9	GT10	GT14	GT15	GT16	GT17	GT18	GT19	GT20	Avr. MTTR
Year	2006	91	17	365	365	365	365	365	365	365	74	365	7	5	217
	2007	61	365	365	365	365	365	365	365	365	121	84	9	34	248
	2008	183	366	366	366	366	366	366	366	366	14	366	160	157	293
	2009	362	365	365	365	365	365	365	365	365	10	365	365	365	337
	2010	365	365	365	365	365	365	365	365	365	82	365	365	365	308
	2011	365	365	365	365	365	366	365	365	365	49	4	365	365	196
	2012	366	366	366	366	366	366	366	366	366	7	2	366	366	185
	2013	365	365	365	365	365	365	365	365	365	365	7	365	365	275
	2014	365	365	365	365	365	365	365	365	365	40	4	365	365	193
	2015	365	365	365	365	365	365	365	365	365	48	6	365	365	313
	2016	366	366	366	366	366	366	366	366	366	14	366	366	366	339
	2017	365	365	365	365	365	365	365	365	365	16	9	365	365	311
Av. 06-17)	MTTR	332	336	335	335	335	365	365	365	365	70	162	286	263	268

TABLE VII
AFAM VI POWER STATION GENERATOR
UNITS YEARLY TRIPS

Unit Capacity		3x150 MW			200 MW
Unit Tag		GT11	GT12	GT13	ST1
Year	2010	16	8	11	NA
	2011	7	8	10	15
	2012	2	3	3	4
	2013	2	4	6	10
	2014	5	5	5	6
	2015	9	6	5	7
	2016	4	8	7	3
	2017	7	6	8	9

TABLE VIX
AFAM VI POWER STATION GENERATOR MTTR

Unit Capacity		3x150 MW			200MW	P/S
Unit Tag		GT11	GT12	GT13	ST1	Aver. MTTR
Year	2010	3	3	3	0	3
	2011	4	8	7	11	7
	2012	15	5	2	9	8
	2013	16	21	4	8	12
	2014	6	1	2	8	4
	2015	7	9	3	6	6
	2016	6	3	2	3	4
	2017	10	7	3	3	6
Avr. MTTR (10-17)		8	7	3	7	6

Station Plant Equivalent/Energy Availability Factor over one year period – ‘f ’ is the ratio of energy H that the available capacity (h) could have produce during one year to the energy G that the maximum capacity (g) could have produced in that same year:

$$EAF : f = \frac{H}{G} \quad \text{(expressed in percentage of the energy G)} \quad (5)$$

The energies G and H are expressed mathematically as:

$$H = \Sigma h.dt \text{ or } H = \Sigma h.th, \text{ and}$$
$$G = \Sigma g..dt, \text{ or } G = \Sigma g.tg \quad (6)$$

Where: th = duration of available capacity h and tg = duration of maximum capacity g as in (5),

$$PEAF = \frac{Plant\ Average\ Load\ (PAL)\ MW\ in\ agiven\ Year}{Plant\ Maximum Capacity\ of\ the\ Plant\ (PMC)\ MW\ in\ that\ given\ Year} \quad (7)$$

Calculation of PEAF is carried out using Eq. (7). From Table I. Afam I-V PEAF for 2012 is calculated thus

$$PEAF\ for\ Afam\ I - V = \frac{95.32MW}{351.00MW} = 0.272,$$

weighted average Load of Afam I-V in the year 2007 & 2008 are 228.11MW & plant rating of 931.6MW, 82.12MW & plant rate of 931.6MW as shown in the Table. Using Eq. (9), the Average Loads carried by each generator unit are calculated

$$PEAF\ for\ Delta = \frac{246.23MW}{900.00MW} = 0.274,$$

The yearly data in Table I and V have been used to calculate the yearly PEAF for the four chosen power plants. The results of the yearly PEAF of four chosen plants in under review are presented in Table X. Thus, this index gives the true measure of the probability of the power station performing its intended function. Energy Available Factor (EAF) illustrates the reliability of the plant in general, taking in to account all complete and partial outages [1, 8]. Generator Equivalent Availability Factor (GEAF) is expressed as:

$$GEAF = \frac{Generator\ Average\ Load\ (GAL)\ MW\ in\ a\ given\ Year}{Generator\ Maximum Capacity\ \ (GMC)\ MW\ in\ that\ given\ Year} \quad (8)$$

D. Model for Calculation of Generator Average Load (GAL) for the given year

On the generators operational Uptime Table for the given plant, separate and add up the total Uptime for the generators with similar installed capacities within the year as presented at the extreme right of the uptime tables in Tables 2. For Afam I-V plants, summation of the generator units with the same nameplate and capacities that contributed to the annual maximum rating of the plant were carried out. Eq. (9) is the developed model for determining the Generator Average Load (GAL) from the weighted Plant Average Load (PAL) as presented in Table III.

$$GAL = \frac{PAL\ (MW) \times TCSU\ (MW)}{PMC\ (MW)} \times \frac{Uptime\ of\ the\ Unit (Days)}{Total\ Uptime\ of\ \ Similar\ Units\ (Days)} \quad (9)$$

Where: TCSU = Total Capacity of Similar Units (MW) operated in the year & PMC = Plant
Rated (maximum) Capacity of the year.
Total Uptime of similar Units (in days) are shown at the extreme right columns after generators in Table II. The

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thus: For 2007, we have GT5, GT17, GT18, GT19 and GT20 respectively.

$$GAL\ \ for\ \ GT5 = \frac{228.11\,MW \times 47.8\,MW}{931.60\ MW} \times \frac{61\,(Days)}{61\,(Days)} = 11.70 MW$$

$$GAL\ \ for\ \ GT18\ = \frac{228.11\,MW \times 150\ MW}{931.60\ MW} \times \frac{112\ (Days)}{115\ (Days)} = 35.77 MW$$

The Generator Average Load (GAL) for all the generator units in the four power stations are calculated and some are as presented in Tables XI-XII for the four chosen power plants from 2007 to 2017.

TABLE XII
GENERATORS' CAPACITIES AND ANNUAL AVERAGE LOAD SUMMARY IN AFAM VI POWER STATION

Unit Capacity		3x150 MW			200 MW
Unit Tag		GT11	GT12	GT13	ST1
	2010	136.00	150.04	149.60	0.00
	2011	120.31	109.57	106.70	149.59
	2012	134.13	140.11	143.71	185.75
Year	2013	113.02	95.42	115.73	144.07
	2014	122.64	131.07	129.97	170.52
	2015	106.09	108.49	127.61	139.42
	2016	118.30	121.47	102.70	155.29
	2017	99.79	96.58	142.76	131.75

After computing GAL for Afam I-V's GT6, GT10, GT17 and GT20 in the above examples, Values of the Generator Average Load (GAL) obtained from Eq. (9) are substitute into Eq. (8) to get the value of equivalent availability factor of each generator unit. For 2015 & 2016:

$$GEAF_{GT7} = \frac{10.69 MW}{23.9 MW} = 0.45;$$

$$GEAF_{GT16} = \frac{29.50 MW}{75 MW} = 0.39;$$

$$GEAF_{GT17} = (\frac{45.40}{75}) MW = 0.61;$$

Some of these (GAL) are presented in Tables XIII to XIV for the chosen generator units, which is Afam I-V, Afam VI, Delta and Egbin power station accordingly.

TABLE X
ENERGY/EQUIVALENT AVAILABILITY FACTORS FOR THE FOUR POWER STATIONS

Year		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	Avr. (06-17)
	Afam I-V	0.1006	0.2449	0.0881	0.0682	0.0418	0.1847	0.2716	0.1669	0.2299	0.2744	0.1648	0.2309	0.1713
P/	Afam VI	NA	NA	0.1701	0.6492	0.6702	0.7479	0.9288	0.7204	0.8526	0.9303	0.7199	0.8527	0.7857
Stations	Delta	0.5584	0.3841	0.2400	0.2895	0.3811	0.2742	0.2736	0.2742	0.4546	0.2735	0.2735	0.4544	0.3442
	Egbin	0.7617	0.5572	0.5265	0.7431	0.6209	0.7114	0.7747	0.7400	0.7352	0.7747	0.7399	0.7351	0.7017

TABLE XI
GENERATORS 'CAPACITIES AND AVERAGE LOADS (MW) SUMMARY IN AFAM I-V POWER STATION

Unit Capacity		Afam-II (4x23.9MW)				AfamIII (2x27.5MW)		Afam-IV (5x75MW)					Afam-V (2x138MW)	
Unit Tag		GT5	GT6	GT7	GT8	GT9	GT10	GT14	GT15	GT16	GT17	GT18	GT19	GT20
	2006	1.92	2.89	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.55	0.00	14.02	13.75
	2007	5.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.96	35.77	36.41	31.18
	2008	2.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.61	0.00	11.30	13.02
	2009	1.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.11	0.00	0.00	0.00
	2010	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	6.27	0.00	0.00	0.00
Year	2011	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.06	25.65	0.00	0.00
	2012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	15.20	25.54	0.00	0.00
	2013	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.52	0.00	0.00
	2014	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.51	26.97	0.00	0.00
	2015	0.00	0.00	10.69	0.00	0.00	0.00	0.00	0.00	29.50	45.40	0.00	0.00	17.09
	2016	5.96	0.36	6.20	6.20	0.00	0.83	0.00	0.00	14.37	19.93	0.00	0.00	8.08
	2017	0.00	0.00	10.59	10.12	0.00	0.00	0.00	0.00	19.52	0.00	0.00	0.00	52.90

TABLE XIII
GENERATORS EQUIVALENT AVAILABILITY FACTOR OF AFAM I-V POWER STATION

Unit Capacity		Afam-II (4X23.9MW)				Afam-III (2X27.5MW)		Afam-IV (5X75MW)					Afam-V (2X138MW)		P/S
Unit Tag		GT5	GT6	GT7	GT8	GT9	GT10	GT14	GT15	GT16	GT17	GT18	GT19	GT20	Avr.PEAF
	2007	0.2449	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0128	0.4769	0.2638	0.2259	0.094
	2008	0.0882	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0881	0.0000	0.0819	0.0944	0.027
	2009	0.0682	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0836	0.0000	0.0000	0.0000	0.011
	2010	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0836	0.0000	0.0000	0.0000	0.006
	2011	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0275	0.3420	0.0000	0.0000	0.028
	2012	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2027	0.3405	0.0000	0.0000	0.042
Year	2013	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1669	0.0000	0.0000	0.013
	2014	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1001	0.3596	0.0000	0.0000	0.035
	2015	0.0682	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0236	0.0000	0.0000	0.0000	0.007
	2016	0.0000	0.0051	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2451	0.0000	0.0102	0.0035	0.020
	2017	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4217	0.0605	0.0000	0.0000	0.037
Av.GEAF (07-17)		0.043	0.0001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.159	0.117	0.032	0.029	0.029

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TABLE XIV
GENERATORS EQUIVALENT AVAILABILITY FACTOR OF AFAM VI POWER STATION

Unit Capacity		3x150 MW			200MW	P/S
Unit Tag		GT11	GT12	GT13	ST1	Avr. PEAF
	2010	0.8205	0.9052	0.9026	0.0000	0.657
	2011	0.8020	0.7304	0.7113	0.7479	0.748
	2012	0.8942	0.9341	0.9580	0.9288	0.929
Year	2013	0.7535	0.6362	0.7715	0.7204	0.720
	2014	0.8176	0.8738	0.8664	0.8526	0.853
	2015	0.8061	0.9062	0.9721	0.9450	0.857
	2016	0.7652	0.7620	0.8215	0.9317	0.611
	2017	0.8762	0.8542	0.8627	0.8716	0.866
Avr. GEAF (10-17)		0.817	0.825	0.858	0.7259	0.780

IV. RESULTS AND ANALYSIS

The results of the study for some of the chosen stations are presented thus; ccalculated Reliability Indices in Afam I-V Power Station Presented in Fig.1 & 2.

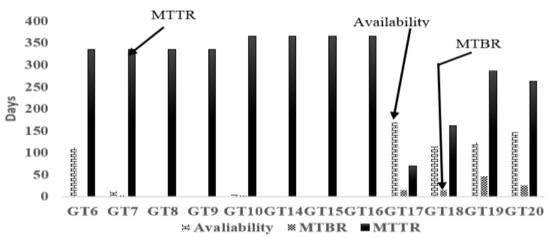

Fig. 1. Average Performance on Reliability Indices by Generators in Afam I-V Power Plant (for 11 years)

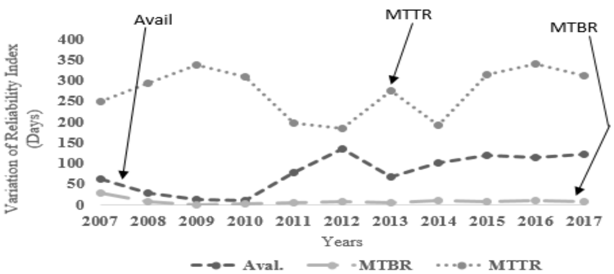

Fig. 2. Reliability Indices Variation of Afam I-V Power Plant with Year.

The yearly average MTBF of Afam I-V generator units varies from 2day in 2010 to 29days in 2007. In contrast with MTTR which varies from185days in 2012 to 339days in the year 2016. The graphs in Fig.2 shows that within the period (12 years) of the study, more time was spent in breakdown maintenance on generator units. Using the evaluated equivalent availability data in Table XIII to access the average availability of generator units in Afam I-V power station as shown in Fig.3.

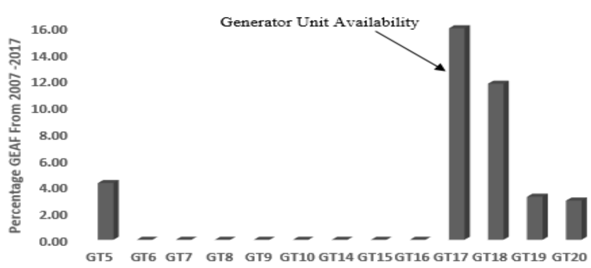

Fig. 3. Average Equivalent Availability of Generator Units in Afam I-V Power Station

From Fig.3, it is shown that GT17 was most reliable in the eleven years operation of the plant. Followed by GT18 with 11.72% reliability.

A. *Reliability Indices Analysis of Afam VI Power Station.*

Using the calculated reliability indices of Afam VI generators presented in Tables III, VII and VIX, Fig.4 is generated.

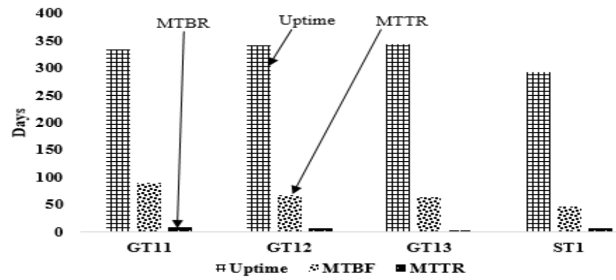

Fig. 4. Average Performance on Reliability Indices by Generators in Afam VI Power Plant (for 8 years)

The chart shows that, an effective preventive maintenance programme of the generator units were in place, and carefully implemented. Fig.4 also reveals abundant availability of all the generator units. The graph on the average annual performance rating for all the generator units of Afam VI plant are calculated and as shown in Fig.5. The performance styles of Afam VI reliability indices in Fig.5, are in harmony with the performance of generator units.

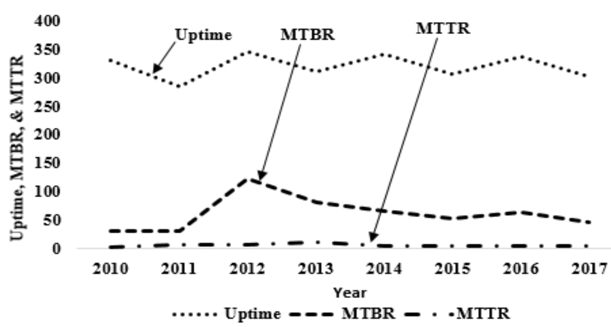

Fig. 5. Reliability Indices Variation of Afam VI Power Plant with Year. It shows that a good condition-based maintenance is being effectively implemented on the system.

Fig.5 also shows a good condition-based maintenance is effectively implemented on the system.

Fig.6 represents the calculated average equivalent available energy graph of generator units in Afam VI power station using the data presented in Table XIV.

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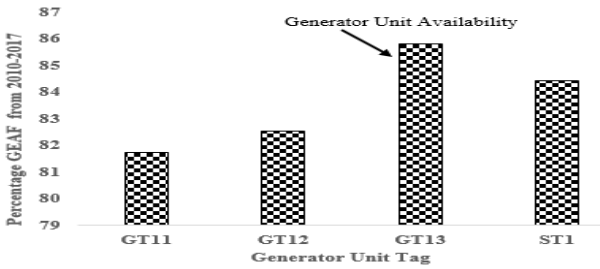

Fig. 6: Average Equivalent Availability of Generator Units in Afam VI Power Station (8 years)

B. *Reliability Indices Analysis of Egbin Power Station*

Furthermore in the analysis, using the calculated reliability indices of Egbin power station the graph shown in Fig. 7 is generated.

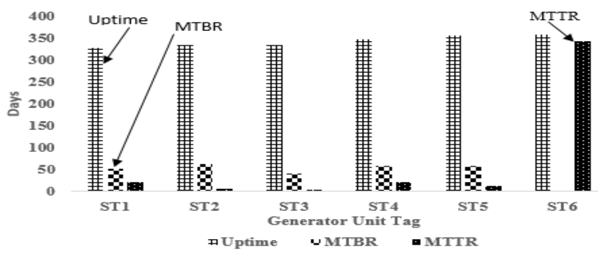

Fig. 7. Average Reliability Indices by Generators in Egbin Power Plant (for 8years).

Reliability indices for generators in Egbin power plant presented in Fig. 7 clearly shows that preventive maintenance programme is being implemented each year. It also shows that the generator units are available most of the time in each year for operations, rather than constant repair. The main time to repair surpassed both the availability and the main time between failures thus, this unit unavailability adversely effected the reliability of Egbin power station during the period.

C. *Reliability Analysis of the Chosen Power Stations*

With the evaluated data information presented in Table X, the graph in Fig. 8 is produced. Fig. 8 presents the percentage equivalent availability of the four power stations for the eleven years period of the study (from 2007 to 2017). Having implemented the Equivalent Availability as the relative index of quality reliability in this study, the reliability of the four thermal power plants varies from (4.18 to 27.44)% for Afam I-V, (17.10 to 93.03)% Afam VI, (24 to 55.84)% Delta and (52.65 to 77.49)% Egbin power plants respectively.

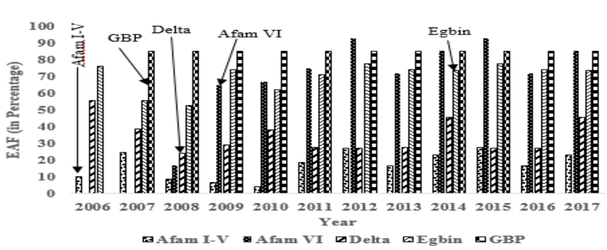

Fig. 8. Plant Energy Availability Factor (PEAF Variation for the four Power Stations with year

Fig. 8 represent the Plant Energy Availability Factor (PEAF) for eleven years period of study of the chosen power stations. Their average reliability factors are (17.13, 78.57, 34.42, & 70.17) percent accordingly. The World Energy Council Availability Factor (WECAF) accepted for used as a benchmark value for good performance in Nigeria is 83.50%. This value is juxtaposed into Fig. 8 to compare the performance of the four power plants. It was observed that each of the four power plants needs some improvement on their daily availability [15]. We noticed short falls from the operational equivalent availability of 66.37 percent by Afam I-VI, 49.08 percent by Delta power station, 4.93 percent by Afam VI and 16.67 percent by Egbin power station respectively. By this analysis, certain basic functions are not fully implemented; i) shortage and obsolete machines/equipment, ii) lack of proficient and trained workers conversant fault location and troubleshooting through the Human-Machine-Interface of the turbine packages. iii) Low operational availability of power plants caused by lack of strategic planning of maintenance activities and poor maintenance practices.

V. CONCLUSION

Average reliability of Afam I-V, AfamVI, Delta and Egbin are (17.13, 78.57, 34.42, & 70.17) percent respectively. These values are lower than the WEC factor recommended average energy availability of fossil energy turbine generators. From the chart, the performance of Afam VI and Egbin Power stations could be rated as fair while the performance of Afam I-V and Delta power stations are so low. Utility companies and operators of power stations have duty to manage electrical assets in a manner that would guarantee uninterrupted electricity supply and the maintenance of the as built technical reliability of the equipment throughout its life span

A. *RECOMMENDATIONS*

1. Root cause failure analysis (RCFA) should be carried out for all major equipment failures to dissect underlying causes of defects thereby helping to implement corrective actions to avoid reoccurrence. RCFA functions are to determine the cause of a problem and implement corrective and curative actions efficiently in cost effective manner, to rectify, identified problem and to provide data that can be used for rectifying similar problems in the future.
2. A positive work environment that encourages the personnel to perform to the best of their abilities should be created. Also periodic performance appraisals and reward to good performance should be motivate personnel and monitored with apt seriousness. [Note: Some tables are not included in this edition because of limited pages]

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