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Reliability Assassment of Selected Fossil Fuel Operated Power Stations in Nigeria

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ABSTRACT
As the gap between supply and demand on electric energy widens in Nigeria, it becomes necessary to assess the performance of fossil fueled generator turbine that dominates the electric power industry. Consequently, this study is to evaluate the historical performance data of four selected powerstations within Nigeria from 2002 to 2014, so as to ascertain if they are supplying electric energy within their installed capacities in line with global best practices. The combined installed capacity of these four selected power plant is 35% of the twenty-one thermal power plants connected to the national power grid. A historical operational data of these selected plants covering a period of thirteen years was obtained and analysed 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 21.89%, 76.15%, 39.14% and 71.75% respectively. The analysis also reveals the Afam VI and Egbin power stations have an effective preventive maintenance programmes that promotes availability of their generatorswhereas, Afam I-V and Delta power stations werealways overwhelmed withcorrective maintenance.
Keywords: *availability factor, equivalent availability factor, performance indices,reliability, reliability indices.*

1. INTRODUCTION

Reliability of electrical power plant is the probability that it will generate electric energy for consumers without interruption and in an acceptable quality in line with designed specifications. Bulk Electric power supply system comprises three functional subunits that could beseparately analysed [1]. These three subunits are the power generation, power transmission and power distribution. The study is mainly focus on the determination of the generation system reliability.

TCN reported in its 2014 annual technical report that the total installed capacity of power generation in Nigeria is 11,165.40 MW and that, an average daily capacity of 6,317.70 MW was generated in that year [2]. Out of the average daily load on the national power grid, the hydroelectric power plants generated an average of 994.66 MW whereas, fossil fueled turbine plants supplied an average of 5,323.04 MW daily load. Gas turbine power generators produces over 80% of energy on the national power grid. This brings into focus the importance and reliance on thermal power plants in Nigeria power sector. Most importantly, the economics of fossil fueled turbine generating plants in Nigeria is very attractive due to the abundance of natural gas reserves.

The most intriguing aspect of the power generation problem in Nigeria is the inability of the power generating companies to operate and maintain the power plants at top quartile of installed capacity. The selected four plants are Afam I-V, Delta, Egbin and Afam VI power plants. The ages of these power plants covers old generation fossil fuel operated power plants (in operation above 50 years), middle generation plants (in operation between 11 – 49 years) and new generation power (plants commissioned between 1- 10 years ago). 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 presentis about 351MWwith twenty power generator units (GT1 – GT20). All the generator drivers are simple cycle gas turbines.

The former Delta power station which is now called Ughelli Power Station had an initial installed capacity of 912MW.This power station also had twenty simple cycle gas turbines generator units (GT1-GT20) initially, but the first two generator units were decommissioned in 2002. The current installed capacity of this power station is 900MW.

Egbin Power Station has six fossil fuel fired steam turbines generator units (ST1 to ST6), with a total installed capacity of 1320 MW. Each generator set is designed to operate on dual fuel (gas and high pour fuel oil) and have a single reheat and six stages of regenerative feed heating steam generators.

Afam VI Power Station is owned and being operated by the Shell Petroleum Development Company of Nigeria Limited (SPDC). The station has three combined cycle gas turbines (GT11 – GT13), each rated 150MW and one 200MW steam turbine generator (ST1). This gives a total installed capacity in Afam VI power plant of 650MW. The selection of this power station for study is to represent the new generation power plants.

2. THE RELIABILITY OF POWER GENERATING PLANT

This study adopts the analytical technique of forced outages in analysing power generation indices in four major thermal power generating plants in the Nigerian power sector. The emphasis on assessing the performance of thermal power plants in this study is due to the fact that, fossil fueled power plants constitute 82.6% of the total installed power generation capacity on the national electrical power grid. Nigeria has been grappling with extreme electricity shortage over the years. In spite of Nigeria's huge resource endowment in energy and enormous investment in the provision of energy infrastructure, the performance of the power sector has remained poor, in comparison with other developing economies [3].

A thermal power generator package consist of several systems, subsystems and auxiliaries that are designed and programed to operate in unison. System components are categorised into different criticality levels such that when failures occur, shutdown or just an alarm is triggered. Consequently, component failure rate affects the reliability, availability and capacity utilisation of the plant. Reliability assessment on power plant are usually tackled from two perspectives; either power plant adequacy or power plant security. Power Plant adequacy 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].

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 implementing remedial actions to improve 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 assessments have been dominated by deterministic and probabilistic methods of modeling. Though deterministic and probabilistic methods of reliability evaluation are different but they complement each other [5].

Deterministic reliability evaluations are aimed at testing the robustness of delivering stable electric energy in line with standardised parameters to consumers under various contingency measures. The deterministic approach requires testing of contingencies by simulating failure of critical components and incorporating sufficient redundancies to prevent those scenarios that could lead to system total collapse [6]. The probabilistic approach queries the operational data accumulated over the years on the facility, to tackle system failures.

The probabilistic modelling method relies on either statistical analysis of data gathered to identify events and the performance of power system components [7]. Probabilistic indices such as, Loss-of-Load Probabilistic (LOLP), Loss-of-Load Expectation (LOLE), Forced Outage Rates, Mean Time between Failure, and Frequency of Failure/Failure Rate, etc., are now very popular for assessing equipment reliability indices. However, the use of probabilistic indices aloneis insufficient for determining the reliability of hydrothermal power mix due to sectorial constrains on modelling of hydroelectric and thermal power generation systems. Consequently, 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).

Power system reliability is a qualitative measure of stability and its availability. Reliability in this context is synonymous with dependability, responsibility or trustworthiness of the power station to generate electricity. Utility companies and operators of power stations have obligation to manage electrical assets in a manner that would guarantee uninterrupted electricity supply and the maintenance of the as built technical integrity of the equipment throughout its lifecycle.

3. MATERIALS AND METHODS

Within the period of this study the number of generator units were one time or the other, included in the annual rating of their respective plant: (i) Afam I-V had scrapped seven out of its' twenty generator units; (ii) Afam VI had four generator units; (iii) Delta had scrapped two out of its' twenty generator units; (iv) Egbin hand six generator units.

3.1 Data Presentation

The parameters extracted from the GADS-NCC for the evaluation of performance indices in the selected power plants are: (i) generator availability; (ii) number of generator trips per year (iii) summaries of the maximum capacities and the average loads of the four power stations.The summaries of the maximum capacities of the four selected power plants and the average load each carried are shown in Table 1. Table 2-5 are the Uptime data for Afam I-V, Afam VI, Delta and Egbin power plants from 2002 to 2014.

Table 1: Summary on Power Stations' Maximum Capacity and Annual Average Load (MW)

YEAR		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Afam I-V	**Average Load (MW)**	**258.74**	267.84	152.70	221.20	80.28	228.11	82.12	63.52	21.56	64.84	95.32	58.57	80.68
	Rate Capacity MW	**623.00**	623.00	623.00	623.00	797.80	931.60	931.60	931.60	516.00	351.00	351.00	351.00	351.00
Afam VI	**Average Load (MW)**	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	56.38	322.82	435.64	486.16	603.70	468.24	554.20
	Rate Capacity MW	**NA**	**NA**	**NA**	**NA**	**NA**	**NA**	331.50	497.25	650.00	650.00	650.00	650.00	650.00
Delta	**Average Load (MW)**	**472.84**	456.67	463.38	393.45	492.49	338.80	211.67	255.33	342.95	246.78	246.23	246.78	409.10
	Rate Capacity MW	**912.00**	912.00	912.00	912.00	882.00	882.00	882.00	882.00	900.00	900.00	900.00	900.00	900.00
Egbin	**Average Load (MW)**	**935.61**	1031.00	1053.48	1147.78	1005.48	735.53	694.97	980.89	819.55	939.11	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	1320.00

Table 2: Generator Uptime (Days) in Afam I-V Power Station

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	otal Day	P/S Avai
YEAR	2002	0	312	151	0	0	49	0	0	0	284	168	339	313	463	49	452	652	1616	231
	2003	0	231	0	0	0	0	0	0	0	329	0	337	245	231	0	329	582	1142	286
	2004	0	366	0	0	0	0	0	0	0	326	0	16	276	366	0	326	292	984	246
	2005	89	319	0	0	0	0	0	0	0	313	0	160	309	408	0	313	469	1190	238
	2006	150	226	0	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

Table 3: Generator Uptime (Days) in Afam VI Power Station

Unit Capacity		3x150MW			200MW			
UNIT TAG		GT11	GT12	GT13	ST1	P/S Uptime	Total days (150 MW)	Total days (200 MW)
YEAR	2009	287	214	224	N/A	242	725	0
	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

Table 4: Generator Uptime (Days) in Delta Power Station

Unit Capacity		Delta-II (6x25MW)						Delta-III (6x25MW)						Delta-IV (6x100MW)								
UNIT TAG		GT3	GT4	GT5	GT6	GT7	GT8	GT9	GT10	GT11	GT12	GT13	GT14	GT15	GT16	GT17	GT18	GT19	GT20	Days (25MW	Days (100MW)	P/S Avai
YEAR	2002	290	320	306	306	306	351	120	179	293	0	0	0	328	365	329	365	0	241	2471	1628	293
	2003	350	343	321	365	358	334	0	0	341	0	0	0	359	265	365	326	0	106	2412	1421	319
	2004	336	345	332	366	366	366	106	0	111	0	0	0	336	366	334	358	0	0	2328	1394	310
	2005	344	265	265	337	339	339	46	272	61	46	42	29	350	225	347	146	0	106	2385	1174	209
	2006	0	0	0	283	289	289	344	344	344	365	365	358	312	0	235	358	0	317	2981	1222	323
	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	120	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

Table 5: Generator Uptime (Days) in Egbin Power Station

Unit Capacity		6x220MW							
UNIT TAG		ST1	ST2	ST3	ST4	ST5	ST6	Total	P/S Avail
YEAR	2002	351	351	358	234	327	172	1793	299
	2003	345	340	334	347	355	357	2078	346
	2004	337	336	347	352	343	352	2067	345
	2005	328	335	344	346	343	365	2061	344
	2006	358	282	351	337	350	64	1742	290
	2007	277	351	28	337	363	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
	2011	360	356	313	327	320	0	1676	335
	2012	340	363	340	328	355	0	1726	345
	2013	307	339	313	343	299	0	1601	320
	2014	322	344	347	314	279	0	1606	321

3.2 Plant Reliability Indices

Evaluation of the availability and reliability of generator units in the selected power stations are carried out using the GADS of NCC from 2002 to 2014. The performance of individual generator units in each power plant were obtained and the average performance of all the generator units included in the annual rating of each power plant gives the plant performance for the given year.Availability is a measure of an operable and committable state of an equipment when it is needed. Every equipment has designed inherent availability (A_I)defined s:

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

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

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

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

Unavailability which is synonymous with downtime, complements availability or uptime. Consequently, the total time is equal to uptime plus downtime.

Total Time (1 year) = Uptime + Downtime

= Uptime + Downtime (Unplanned +Planned)

Therefore: Uptime = Total Time - Downtime (Unplanned +Planned) (4)

Total time in this study is either 365days or 366days if it's a leap year.Tables 6-9 are the annual trip data for the four power stations.

Table 6: Yearly trips of generator units in Afam I-V power station

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
	2002	NA	3	2	NA	NA	2	NA	NA	NA	5	3	3	3
Year	2003	NA	7	NA	NA	NA	NA	NA	NA	NA	3	NA	2	1
	2004	NA	1	NA	NA	NA	NA	NA	NA	NA	3	NA	1	2
	2005	8	3	NA	NA	NA	NA	NA	NA	NA	5	NA	1	2
	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	4	NA	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

Table 7: Yearly trips of generator units in Afam VI power station

Unit Capacity		3x150 MW			200MW
Unit Tag		**GT11**	**GT12**	**GT13**	**ST1**
Year	2008	1	1	NA	NA
	2009	16	14	11	NA
	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

Table 8: Yearly trips of generator units in Delta power station

Unit Capacity		Delta-II (6x25MW)						Delta-III (6x25MW)						Delta-IV (6x100MW)					
Unit Tag		GT3	GT4	GT5	GT6	GT7	GT8	GT9	GT10	GT11	GT12	GT13	GT14	GT15	GT16	GT17	GT18	GT19	GT20
Year	2002	3	1	1	1	1	1	1	2	1	NA	NA	NA	2	NA	1	1	NA	2
	2003	2	3	2	1	1	2	NA	NA	2	NA	NA	NA	1	4	1	2	NA	4
	2004	1	2	1	1	NA	NA	1	NA	3	NA	NA	NA	2	1	2	1	NA	NA
	2005	2	2	5	2	2	2	1	1	1	1	1	1	1	2	1	1	NA	1
	2006	NA	NA	NA	2	2	2	2	2	2	1	1	1	3	NA	4	1	NA	2
	2007	NA	NA	NA	1	3	3	1	2	1	1	2	2	1	NA	2	1	NA	3
	2008	NA	NA	NA	1	NA	3	3	5	2	1	NA	2	4	NA	NA	2	NA	3
	2009	NA	NA	NA	6	4	1	6	9	7	6	NA	4	NA	NA	NA	6	NA	3
	2010	NA	NA	NA	19	14	9	7	11	11	6	5	11	6	10	5	18	12	17
	2011	NA	NA	NA	3	8	9	7	8	4	11	7	8	6	6	7	8	10	12
	2012	NA	6	NA	NA	NA	5	1	NA	2	9	NA	NA	NA	NA	NA	2	19	12
	2013	NA	7	NA	NA	NA	15	NA	NA	NA	15	NA	NA	NA	5	11	NA	3	9
	2014	NA	1	NA	NA	1	1	NA	3	1	5	1	NA	NA	3	2	NA	NA	3

Table 9: Yearly trips of generator units in Egbin power station

Unit Capacity		6 x 220MW					
Unit Tag		ST1	ST2	ST3	ST4	ST5	ST6
Year	2002	2	2	1	1	1	1
	2003	1	1	1	2	1	1
	2004	2	2	2	1	2	1
	2005	3	2	1	1	2	1
	2006	1	5	3	4	3	3
	2007	4	2	1	2	1	NA
	2008	3	2	2	6	1	NA
	2009	6	5	13	6	5	NA
	2010	3	9	6	4	6	NA
	2011	4	9	16	12	12	NA
	2012	6	3	13	10	3	NA
	2013	10	6	9	6	9	NA
	2014	5	4	7	6	10	NA

Using Afam I-V to illustrate the evaluation of generator units' MTBF and MTTR as follows: In Table 2, GT6 and GT7 operated for 312 and 151days in 2002 respectively. In Table 6, GT6 had 3trips in 2002 while, GT7 had 2 trips. Therefore, the MTBF and the MTTR of GT6 and GT7 in 2002 are determined as follows:

$GT6_{MTBF} = \frac{312\ \text{Days})}{3} = 104$day and$GT6_{MTTR} = \frac{(365-312)\ \text{Days})}{3} = 18$days (to the nearest whole number)

$GT7_{MTBF} = \frac{151\ \text{Days})}{2} = 76$days and $GT7_{MTtr} = \frac{365-151\ \text{Days})}{2} = 107$days.

Similarly, the MTBF and MTTR of all generator units in all the four plants have been evaluated for the thirteen years period of this study. Tables 10-13 are the computed MTBFs and Tables 14-17 are the generators' MTTRs for Afam I-V, Afam VI, Delta and Egbin power stations respectively.

Table 10: Generator MTBF in Afam I-V Power Station

Unit Capacity		Afam-II (4x23.9MW)				Afam-III		Afam-IV (5x75MW)					Afam-V		P/S
Unit Tag		GT5	GT6	GT7	GT8	GT9	GT10	GT14	GT15	GT16	GT17	GT18	GT19	GT20	Av.
Year	2002	0	104	76	0	0	25	0	0	0	57	56	113	104	53
	2003	0	33	0	0	0	0	0	0	0	110	0	169	245	56
	2004	0	366	0	0	0	0	0	0	0	109	0	16	138	63
	2005	11	106	0	0	0	0	0	0	0	63	0	160	155	49
	2006	38	28	0	0	0	0	0	0	0	48	0	358	117	54
	2007	12	0	0	0	0	0	0	0	0	1	37	174	149	29
	2008	5	0	0	0	0	0	0	0	0	39	0	23	27	7
	2009	0	0	0	0	0	0	0	0	0	10	0	0	0	1
	2010	0	0	0	0	0	0	0	0	0	9	0	0	0	2
	2011	0	0	0	0	0	0	0	0	0	3	16	0	0	5
	2012	0	0	0	0	0	0	0	0	0	9	22	0	0	8
	2013	0	0	0	0	0	0	0	0	0	0	18	0	0	4
	2014	0	0	0	0	0	0	0	0	0	13	26	0	0	10
Av. MTBF (2002-2014)		5	49	6	0	0	2	0	0	0	36	14	78	72	26

Table 11: Generator MTBF in Afam VI Power Station

Unit Capacity		3x150 MW			200MW	P/S
Unit Tag		GT11	GT12	GT13	ST1	Av.
Year	2009	18	15	20	0.00	18
	2010	19	43	31	0.00	31
	2011	48	38	30	13	32
	2012	168	117	120	83	122
	2013	167	71	57	29	81
	2014	67	72	71	53	66
Av. MTBF (02-14)		81	59	55	44	60

Table 12: Generator MTBF in Delta Power Station

Unit Capacity		Delta-II (6x25MW)						Delta-III (6x25MW)						Delta-IV (6x100MW)						P/S
Unit Tag		GT3	GT4	GT5	GT6	GT7	GT8	GT9	GT10	GT11	GT12	GT13	GT14	GT15	GT16	GT17	GT18	GT19	GT20	Av.
Year	2002	97	320	306	306	306	351	120	90	293	0	0	0	164	0	329	365	0	121	176
	2003	175	114	161	365	358	167	0	0	171	0	0	0	359	66	365	163	0	27	138
	2004	336	173	332	366	0	0	106	0	37	0	0	0	168	366	167	358	0	0	134
	2005	172	133	53	169	170	170	46	272	61	46	42	29	350	113	347	146	0	106	135
	2006	0	0	0	142	145	145	172	172	172	365	365	358	104	0	59	358	0	159	151
	2007	0	0	0	358	104	115	353	174	355	358	176	141	90	0	127	358	0	105	156
	2008	0	0	0	102	0	40	104	43	172	291	0	162	41	0	0	13	0	75	58
	2009	0	0	0	17	16	120	36	21	37	39	0	59	0	0	0	49	0	111	28
	2010	0	0	0	13	22	9	47	11	29	58	11	24	9	28	10	15	17	9	17
	2011	0	0	0	21	5	7	29	13	80	19	19	25	23	50	19	14	24	25	21
	2012	0	58	0	0	0	64	366	0	155	33	0	0	0	0	0	38	16	25	42
	2013	0	25	0	0	0	22	0	0	0	16	0	0	0	37	11	0	24	39	10
	2014	0	365	0	0	365	346	0	108	275	66	92	0	0	112	182	0	0	117	113
Av. MTBF (02-14)		60	91	66	143	115	120	106	69	141	99	54	61	101	59	124	144	6	71	91

Table 13: Generator MTBF in Egbin Power Station

Unit Capacity		6 x 220 MW						P/S
Unit Tag		ST1	ST2	ST3	ST4	ST5	ST6	Ave.
Year	2002	176	176	358	234	327	172	240
	2003	345	340	334	174	355	357	317
	2004	169	168	174	352	172	352	231
	2005	109	168	344	346	172	365	251
	2006	358	56	117	84	117	21	126
	2007	69	176	28	169	363	0.00	134
	2008	105	123	47	46	331	0.00	130
	2009	52	71	23	55	62	0.00	53
	2010	8	39	58	90	56	0.00	50
	2011	90	40	20	27	27	0.00	41
	2012	57	121	26	33	118	0.00	71
	2013	31	57	35	57	33	0.00	42
	2014	64	86	50	52	28	0.00	56
MTBF (02-14)		126	125	124	132	166	97	134

Table 14: Generator MTTR in Afam I-V Power Station

Unit Capacity		Afam-II (4x23.9MW)				(2x27.5MW)		Afam-IV (5x75MW)					(2x138MW)		P/S
Unit Tag		GT5	GT6	GT7	GT8	GT9	GT10	GT14	GT15	GT16	GT17	GT18	GT19	GT20	v. MTTI
Year	2002	365	18	107	365	365	158	365	365	365	16	66	9	17	149
	2003	365	19	365	365	365	365	365	365	365	12	365	14	120	236
	2004	366	0	366	366	366	366	366	366	366	13	365	350	45	260
	2005	35	15	365	365	365	365	365	365	365	10	365	205	28	212
	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	365	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
Av. MTTR (02-14)		281	230	345	365	365	349	365	365	365	62	209	226	200	239

Table 15: Generator MTTR in Afam VI Power Station

Unit Capacity		3x150 MW			200MW	P/S
Unit Tag		GT11	GT12	GT13	ST1	Av. MTTR
Year	2009	5	11	13	0.00	9
	2010	3	3	2	0.00	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
Av. MTTR (02-14)		8	8	5	9	8

Table 16: Generator MTTR in Delta Power Station

Unit Capacity		Delta-II (6x25MW)						Delta-III (6x25MW)						Delta-IV (6x100MW)						P/S
Unit Tag		GT3	GT4	GT5	GT6	GT7	GT8	GT9	GT10	GT11	GT12	GT13	GT14	GT15	GT16	GT17	GT18	GT19	GT20	Av.
Year	2002	25	45	59	59	59	14	245	93	72	365	365	365	19	0	36	0	365	62	125
	2003	8	7	22	0	7	16	0	0	12	365	365	365	6	25	0	20	365	65	91
	2004	30	11	34	0	0	0	260	0	85	366	366	366	15	0	16	8	366	366	127
	2005	11	50	20	14	13	13	319	93	304	319	323	336	15	70	18	219	365	259	153
	2006	365	365	365	41	38	38	11	11	11	0	0	7	18	365	33	7	365	24	115
	2007	365	365	365	7	18	7	12	9	10	7	7	42	275	365	56	7	365	16	128
	2008	366	366	366	264	0	82	18	31	12	75	366	21	51	366	366	171	366	47	185
	2009	365	365	365	44	76	245	25	20	15	22	365	32	365	365	365	12	365	11	190
	2010	365	365	365	6	4	32	6	22	4	3	62	9	52	9	63	5	14	13	78
	2011	365	365	365	101	40	33	23	33	11	14	33	21	38	11	33	31	13	6	85
	2012	366	3	366	366	366	10	0	366	29	8	366	366	366	366	366	145	3	6	215
	2013	365	27	365	365	365	2	365	365	365	8	365	365	365	36	22	365	97	2	234
	2014	365	0	365	365	0	19	365	14	90	7	273	365	365	10	1	365	365	5	185
Av. MTTR (02-14)		258	180	263	126	76	39	127	81	78	120	250	205	150	153	106	104	263	68	147

Table 17: Generator MTTR in Egbin Power Station

Unit Capacity		6 x 220 MW						P/S
Unit Tag		ST1	ST2	ST3	ST4	ST5	ST6	Av.
Year	**2002**	7	7	7	131	38	193	64
	2003	20	25	31	9	10	8	17
	2004	15	15	10	14	12	14	13
	2005	12	15	21	19	11	0	13
	2006	7	17	5	7	5	100	23
	2007	22	7	337	14	2	365	125
	2008	17	60	136	15	35	366	105
	2009	9	2	5	6	11	365	66
	2010	114	2	3	2	5	365	82
	2011	1	1	3	3	4	365	63
	2012	4	1	2	4	4	366	63
	2013	6	4	6	4	7	365	65
	2014	9	5	3	9	9	365	66
Av. MTTR (02-14)		19	12	44	18	12	249	59

3.3 Equivalent Availability Factor of a Plant (PEAF)

The Equivalent or 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 one year:

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

The energies H and G are mathematically expressed as:

$H = \Sigma h.dt$ or $H = \Sigma h.t_{h;}$ and $G = \Sigma g.dt$ or $G = \Sigma g.t_g$

Where: t_h = duration of available capacity h and t_g = duration of maximum capacity g

Therefore, as in (5), PEAF =

$$\frac{\text{Plant Average Load (PAL) MW in a given year}}{\text{Plant Maximum capacity of the plant (PMC) MW in that given year}}$$

Evaluation of PEAF is illustrated as follows:

In Table 1, under the year 2009, the average loads carried by Afam I-V and Delta power plants are 63.52MW and 255.33MW respectively, whereas, Afam I-V and Delta plants were rated 931.60MW and 882.00MW respectively. Therefore, in 2009

$PEAF_{Afam\ \ I\text{-}V} = \frac{63.52\text{ MW}}{931.60\text{ MW}} = 0.0682$and $PEAF_{Delta} = \frac{255.33\text{ MW}}{882.00\text{ MW}} = 0.2895$

Similarly, the yearly data in Table 1 and (5) have been used to evaluate the yearly PEAF for the fourpower plants. Table 6 carries results ofthe yearly PEAF of four plants in the period under review.

Table 18: Equivalent Availability Factors for the four Power Stations

YEAR		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Av.(02-14)
Power Plant	Afam I-V	0.4153	0.4299	0.2451	0.3551	0.1006	0.2449	0.0881	0.0682	0.0418	0.1847	0.2716	0.1669	0.2299	0.2186
	Afam VI	NA	NA	NA	NA	NA	NA	NA	0.6492	0.6702	0.7479	0.9288	0.7204	0.8526	0.7615
	Delta	0.5185	0.5007	0.5081	0.4314	0.5584	0.3841	0.2400	0.2895	0.3811	0.2742	0.2736	0.2742	0.4546	0.3914
	Egbin	0.7088	0.7811	0.7981	0.8695	0.7617	0.5572	0.5265	0.7431	0.6209	0.7114	0.7747	0.7400	0.7352	0.7175

PEAF takes into account, the health of the generators or de-rated generator units of the plant and therefore, it models both the partial and full outages of the generators in the plant. Consequently, this index gives the true measure of the probability of the power station performing its intended function. EAF characterises the reliability of the plant in general, considering all complete and partial outages [8] (ENS, 2015).

Similarly, the Equivalent Availability Factor of a Generator Unit (GEAF) is expressed as:

$$\text{GEAF} = \frac{\text{Generator Average Load (GAL)MW in a given year}}{\text{Generator maximum capacity (GMC) MW in that year}} \qquad (6)$$

3.2.1 Developed model for the evaluation of Generator Average Load (GAL) in a given year

From the generators operational availability (Uptime Table for the given plant), segregate and sum up the total Uptime for the generators with similar installed capacities within the year as shown at the extreme right end of the uptime tables: Tables 3.2, for Afam I-V. Sum up generator units with the same nameplate capacities that contributed to the annual maximum rating of the plant. The developed model for determining the Generator Average Load (GAL) from the weighted Plant Average Load (PAL) as in Table 3.1 is given as:

$$\text{GAL} = \frac{\text{PAL (MW)x TCSU (MW)}}{\text{PMC (MW)}} \text{ x } \frac{\text{Uptime of the Unit (days)}}{\text{Total Uptime of similar Units (days)}} \qquad (7)$$

Where: TCSU = Total Capacity of Similar Units (MW) operated in the year and PMC = Plant Rated (maximum) Capacity of the year. Evaluation of generators yearly average load are illustrated below.

In Table 2, under the year 2002, the Uptime for Afam I-V GT6, GT10, GT17 and GT20 are 312 days (d), 49d, 284d and 313d respectively. Two similar sizes of GT6 operated in the year, only one for GT10, two similar sizes of GT17 and two similar sizes of GT20. Total Uptime of similar Units (days) are as in the extreme right columns after generators in Table 2. In Table 1, the weighted average Load of Afam I-V in the year 2002 is 258.74MW and plant was rated 623MW. Using (7), the Average Load carried by each generator unitis calculated thus:

$$\text{GAL}_{\text{GT6}} = \frac{\textbf{258.74MW x 47.8MW}}{\textbf{623 (MW)}} \text{ x } \frac{\textbf{312(days)}}{\textbf{463 (days)}} = 13.38\text{MW}$$

$$\text{GAL}_{\text{GT10}} = \frac{\textbf{(258.74 x 27.5)MW}}{\textbf{623 (MW)}} \text{ x } \frac{\textbf{49(days)}}{\textbf{49 (days)}} = 11.42\text{MW}$$

$$\text{GAL}_{\text{GT17}} = \frac{\textbf{(258.74 x 150)MW}}{\textbf{623 (MW)}} \text{ x } \frac{\textbf{284(days)}}{\textbf{452 (days)}} = 39.14\text{MW}$$

$$\text{GAL}_{\text{GT20}} = \frac{\textbf{(258.74 x 276)MW}}{\textbf{623 (MW)}} \text{ x } \frac{\textbf{313(days)}}{\textbf{652 (days)}} = 55.03\text{MW}$$

Similarly, the GAL for all the generator units in the four power stationsare computed. Tables19-22 are the average load carried by each generator unit in the four power plants from 2002 to 2014.

Table 19: Summary of Generators'capacities and Average loads (MW) in Afam I-V Power Station

Unit Capacity		Afam-II (4x23.9MW)				Afam-III (2x27.5MW)		Afam-IV (5x75MW)					Afam-V (2x138MW)	
UNIT TAG		GT5	GT6	GT7	GT8	GT9	GT10	GT14	GT15	GT16	GT17	GT18	GT19	GT20
YEAR	2002	0.00	13.38	6.47	0.00	0.00	11.42	0.00	0.00	0.00	39.14	23.15	59.60	55.03
	2003	0.00	10.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	32.24	0.00	68.71	49.95
	2004	0.00	5.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.38	0.00	3.71	63.94
	2005	3.70	13.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	26.63	0.00	33.43	64.56
	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
	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

Table 20: Summary on Generators'capacities and annual average loads (MW) in Afam VI Power Station

Unit Capacity		3x150MW			200MW
Unit Tag		GT11	GT12	GT13	ST1
Year	2009	127.79	95.29	99.74	0.00
	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
	2013	113.02	95.42	115.73	144.07
	2014	122.64	131.07	129.97	170.52

Table 21: Summary on Generators'capacities and annual average loads (MW) in Delta Power Station

Unit Capacity		Delt-II (6x25MW)						Delta-III (6x25MW)						Delta-IV (6x100MW)					
Unit Tag		GT3	GT4	GT5	GT6	GT7	GT8	GT9	GT10	GT11	GT12	GT13	GT14	GT15	GT16	GT17	GT18	GT19	GT20
YEAR	2002	18.25	20.14	19.26	19.26	19.26	22.09	7.55	11.27	18.44	0.00	0.00	0.00	62.67	69.74	62.87	69.74	0.00	46.05
	2003	21.80	21.36	19.99	22.73	22.30	20.80	0.00	0.00	21.24	0.00	0.00	0.00	75.90	56.03	77.17	68.93	0.00	22.41
	2004	22.00	22.59	21.74	23.96	23.96	23.96	6.94	0.00	7.27	0.00	0.00	0.00	73.48	80.04	73.04	78.29	0.00	0.00
	2005	18.67	14.38	14.38	18.29	18.40	18.40	2.50	14.76	3.31	2.50	2.28	1.57	77.17	49.61	76.51	32.19	0.00	23.37
	2006	0.00	0.00	0.00	15.90	16.24	16.24	19.33	19.33	19.33	20.51	20.51	20.12	85.54	0.00	64.43	98.15	0.00	86.91
	2007	0.00	0.00	0.00	13.48	11.71	12.95	13.29	13.11	13.37	13.48	13.22	10.62	20.40	0.00	57.34	81.13	0.00	71.61
	2008	0.00	0.00	0.00	4.11	3.18	4.88	12.62	8.59	13.83	11.73	0.00	13.06	56.69	0.00	0.00	8.70	0.00	78.60
	2009	0.00	0.00	0.00	6.23	3.85	7.33	13.14	11.43	16.01	14.42	0.00	14.42	0.00	0.00	0.00	81.59	0.00	92.10
	2010	0.00	0.00	0.00	13.76	16.82	4.27	17.87	6.85	17.76	19.13	3.12	14.74	11.74	63.55	11.28	62.17	45.82	34.08
	2011	0.00	0.00	0.00	3.87	2.58	3.99	12.65	6.32	19.64	12.83	8.29	12.09	18.37	40.79	18.23	15.40	32.01	39.71
	2012	0.00	17.50	0.00	0.00	0.00	15.94	18.35	0.00	15.49	14.79	0.00	0.00	0.00	0.00	0.00	18.56	73.28	72.31
	2013	0.00	19.14	0.00	0.00	0.00	36.21	0.00	0.00	0.00	26.91	0.00	0.00	0.00	41.19	28.36	0.00	16.43	78.55
	2014	0.00	23.77	0.00	0.00	23.77	22.53	0.00	21.03	17.91	21.36	5.99	0.00	0.00	87.27	94.29	0.00	0.00	91.17

Table 22: Summary on Generators' capacity and annual average load (MW) in Egbin Power Station

Unit Capacity		Egbin PS (6x220MW)					
UNIT TAG		**ST1**	**ST2**	**ST3**	**ST4**	**ST5**	**ST6**
YEAR	2002	183.16	183.16	186.81	122.10	170.63	89.75
	2003	171.17	168.69	165.71	172.16	176.13	177.13
	2004	171.76	171.25	176.85	179.40	174.82	179.40
	2005	182.66	186.56	191.58	192.69	191.02	203.27
	2006	206.64	162.77	202.60	194.52	202.02	36.94
	2007	150.25	190.39	15.19	182.80	196.90	0.00
	2008	173.88	135.36	51.72	151.87	182.13	0.00
	2009	190.20	215.81	184.11	201.79	188.98	0.00
	2010	13.88	203.01	200.12	207.06	195.49	0.00
	2011	201.72	199.48	175.38	183.23	179.31	0.00
	2012	201.43	215.06	201.43	194.32	210.32	0.00
	2013	187.30	206.82	190.96	209.26	182.42	0.00
	2014	194.57	207.86	209.67	189.73	168.58	0.00

Haven obtained GAL Afam I-V's GT6, GT10, GT17 and GT20 in the examples above, we simply substitute the data into (6) to calculate the equivalent availability factor of each generator unit as illustrated below.

$GEAF_{GT6} = \frac{13.38\ MW}{23.9\ MW} = 0.5598$; $GEAF_{GT10} = \frac{11.42\ MW}{27.5\ MW} = 0.4153$;

$GEAF_{GT17} = \frac{39.14\ MW}{75\ MW} = 0.5219$; $GEAF_{GT20} = \frac{55.03\ MW}{138\ MW} = 0.3988$

Similarly, the Equivalent Availability Factor for all the generator units in the four power generating plants are computed. Tables23-26 contains the evaluated equivalent availability factors for generator units in Afam I-V, Afam VI, Delta and Egbin power station respectively.

Table 23: Equivalent Availability Factor of Generators in 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	Ave. PEAF
YEAR	2002	0.0000	0.5597	0.2709	0.0000	0.0000	0.4153	0.0000	0.0000	0.0000	0.5219	0.3087	0.4319	0.3988	0.4153
	2003	0.0000	0.4299	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4299	0.0000	0.4979	0.3620	0.4299
	2004	0.0000	0.2451	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2451	0.0000	0.0269	0.4633	0.2451
	2005	0.1549	0.5552	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3551	0.0000	0.2423	0.4679	0.3551
	2006	0.0803	0.1210	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1006	0.0000	0.1016	0.0996	0.1006
	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	0.2449
	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	0.0882
	2009	0.0682	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0682	0.0000	0.0000	0.0000	0.0682
	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	0.0418
	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	0.1847
	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	0.2716
	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	0.1669
	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	0.2299
Ave. GEAF (02-14)		**0.05**	**0.15**	**0.02**	**0.00**	**0.00**	**0.03**	**0.00**	**0.00**	**0.00**	**0.17**	**0.15**	**0.13**	**0.16**	**0.2186**

Table 24: Equivalent Availability Factor of Generators in Afam VI Power Station

Unit Capacity		**3x150MW**			**200MW**	**P/S**
Unit Tag		**GT11**	**GT12**	**GT13**	**ST1**	**Av. PEAF**
YEAR	2009	0.7710	0.5749	0.6018	0.0000	0.6492
	2010	0.8205	0.9052	0.9026	0.0000	0.6571
	2011	0.8020	0.7304	0.7113	0.7479	0.7479
	2012	0.8942	0.9341	0.9580	0.9288	0.9288
	2013	0.7535	0.6362	0.7715	0.7204	0.7204
	2014	0.8176	0.8738	0.8664	0.8526	0.8526
Ave. GEAF (02-14)		**0.8098**	**0.7758**	**0.8019**	**0.8124**	**0.7593**

Table 25: Equivalent Availability Factor of Generators in Delta Power Station

Unit Capacity		Delt-II (6x25MW)						Delta-III (6x25MW)						Delta-IV (6x100MW)						P/S
Unit Tag		GT3	GT4	GT5	GT6	GT7	GT8	GT9	GT10	GT11	GT12	GT13	GT14	GT15	GT16	GT17	GT18	GT19	GT20	PEAF
YEAR	2002	0.73	0.81	0.77	0.77	0.77	0.88	0.30	0.45	0.74	0.00	0.00	0.00	0.63	0.70	0.63	0.70	0.00	0.46	**0.5185**
	2003	0.87	0.85	0.80	0.91	0.89	0.83	0.00	0.00	0.85	0.00	0.00	0.00	0.76	0.56	0.77	0.69	0.00	0.22	**0.5007**
	2004	0.88	0.90	0.87	0.96	0.96	0.96	0.28	0.00	0.29	0.00	0.00	0.00	0.73	0.80	0.73	0.78	0.00	0.00	**0.5081**
	2005	0.75	0.58	0.58	0.73	0.74	0.74	0.10	0.59	0.13	0.10	0.09	0.06	0.77	0.50	0.77	0.32	0.00	0.23	**0.4314**
	2006	0.00	0.00	0.00	0.64	0.65	0.65	0.77	0.77	0.77	0.82	0.82	0.80	0.86	0.00	0.64	0.98	0.00	0.87	**0.5584**
	2007	0.00	0.00	0.00	0.54	0.47	0.52	0.53	0.52	0.53	0.54	0.53	0.42	0.20	0.00	0.57	0.81	0.00	0.72	**0.3841**
	2008	0.00	0.00	0.00	0.16	0.13	0.20	0.50	0.34	0.55	0.47	0.00	0.52	0.57	0.00	0.00	0.09	0.00	0.79	**0.2400**
	2009	0.00	0.00	0.00	0.25	0.15	0.29	0.53	0.46	0.64	0.58	0.00	0.58	0.00	0.00	0.00	0.82	0.00	0.92	**0.2895**
	2010	0.00	0.00	0.00	0.55	0.67	0.17	0.71	0.27	0.71	0.77	0.12	0.59	0.12	0.64	0.11	0.62	0.46	0.34	**0.3811**
	2011	0.00	0.00	0.00	0.15	0.10	0.16	0.51	0.25	0.79	0.51	0.33	0.48	0.18	0.41	0.18	0.15	0.32	0.40	**0.2742**
	2012	0.00	0.70	0.00	0.00	0.00	0.64	0.73	0.00	0.62	0.59	0.00	0.00	0.00	0.00	0.00	0.19	0.73	0.72	**0.2736**
	2013	0.00	0.77	0.00	0.00	0.00	1.45	0.00	0.00	0.00	1.08	0.00	0.00	0.00	0.41	0.28	0.00	0.16	0.79	**0.2742**
	2014	0.00	0.95	0.00	0.00	0.95	0.90	0.00	0.84	0.72	0.85	0.24	0.00	0.00	0.87	0.94	0.00	0.00	0.91	**0.4546**
Ave. GEAF (02-14)		0.27	0.38	0.25	0.47	0.46	0.62	0.41	0.31	0.55	0.45	0.16	0.29	0.40	0.33	0.39	0.51	0.14	0.54	**0.3861**

Table 26: Equivalent Availability Factor of Generators in Egbin Power Station

Unit Capacity		6 x 220MW						P/S
Unit Tag		ST1	ST2	ST3	ST4	ST5	ST6	PEAF
Year	2002	0.8325	0.8325	0.8491	0.5550	0.7756	0.4080	0.7088
	2003	0.7781	0.7668	0.7532	0.7826	0.8006	0.8051	0.7811
	2004	0.7807	0.7784	0.8039	0.8155	0.7946	0.8155	0.7981
	2005	0.8303	0.8480	0.8708	0.8759	0.8683	0.9240	0.8695
	2006	0.9393	0.7399	0.9209	0.8842	0.9183	0.1679	0.7617
	2007	0.6830	0.8654	0.0690	0.8309	0.8950	0.0000	0.5572
	2008	0.7904	0.6153	0.2351	0.6903	0.8279	0.0000	0.5265
	2009	0.8646	0.9809	0.8369	0.9172	0.8590	0.0000	0.7431
	2010	0.0631	0.9228	0.9096	0.9412	0.8886	0.0000	0.6209
	2011	0.9169	0.9067	0.7972	0.8329	0.8150	0.0000	0.7114
	2012	0.9156	0.9775	0.9156	0.8833	0.9560	0.0000	0.7747
	2013	0.8514	0.9401	0.8680	0.9512	0.8292	0.0000	0.7400
	2014	0.8844	0.9448	0.9531	0.8624	0.7663	0.0000	0.7352
Ave. GEAF (02-14)		0.7792	0.8553	0.7525	0.8325	0.8457	0.2400	0.7175

4. RESULTS AND DISCUSSIONS

Key reliability indices studied are operational availability, the main time between failures, the main time to repair and the equivalent (energy) availability of the power stations.

4.1 Analysis of reliability indices in Afam I-V Power Station

Using the evaluated reliability indices from the data in Tables 2,10 and14, the graph in Fig. 1 is generated.

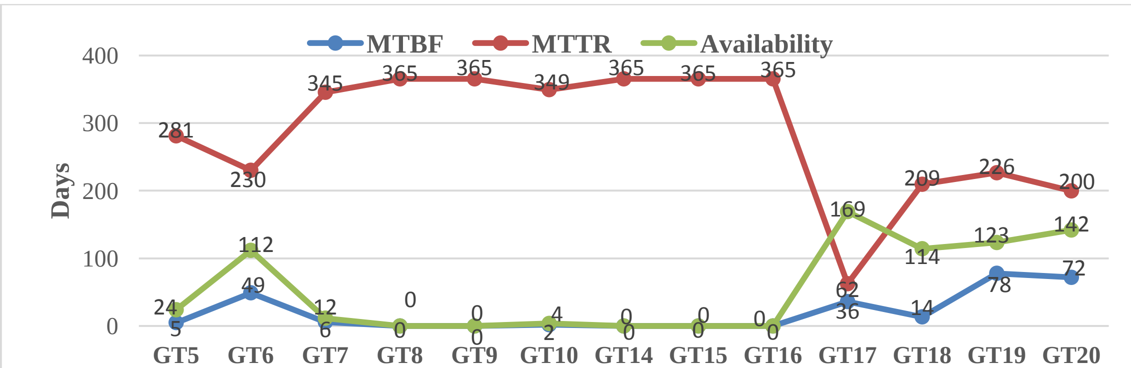

figure 1: thirteen years average performance on reliability indices by generators in Afam I-V power plant

The trends in Fig.1 clearly shows that on the average, much time was devoted to generator repairs or units' unavailability in the thirteen years period of this study, as against running the units. GT17 had the lowest thirteen years average turn-around maintenance period of 62days with thirteen years average MTBF of 36days. Though GT17 came out as the unit with the highest availability, the characteristics of its reliability indices in Fig.1 are poor.

Using the evaluated reliability indices for Afam I-V in Tables 2, 10 and 14, the average yearly performance of power station is generated as shown in Fig.2.

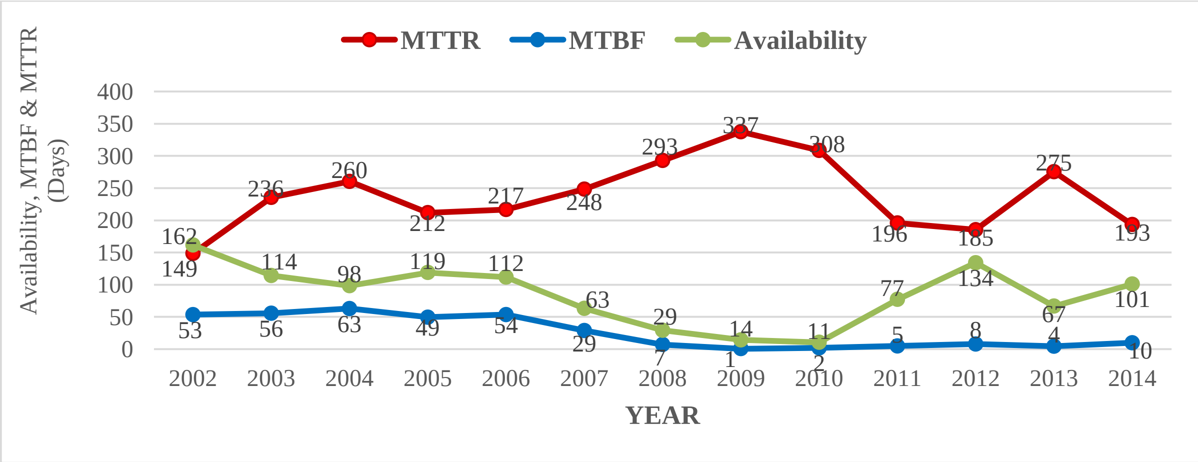

figure 2: variation of reliability indices of Afam I-V power plant with year

The annual average MTBF of Afam I-V generator units varies from 1day in 2009 to 63days in 2004. In sharp contrast, the MTTR varies from185days in 2012 to 337days in the year 2009. The trends in Fig.2 shows that within the thirteen years period, more time was spent in breakdown maintenance on generator units instead of running the units. The trends also shows that availability of the plant have inverse relationship with MTTR. Most importantly, the trends also confirmed that Afam I-V was bedeviled with incessant turbine failures with prolong downtime of generator units and that there is no evidence of any preventive maintenance activities in the power station. Operational availability of the plant adversely affected energy availability of the plant.

Using the evaluated equivalent availability data in Table 23, the histogram in Fig.3 is generated. This is the graph of equivalent availability of generator units in Afam I-V power station.

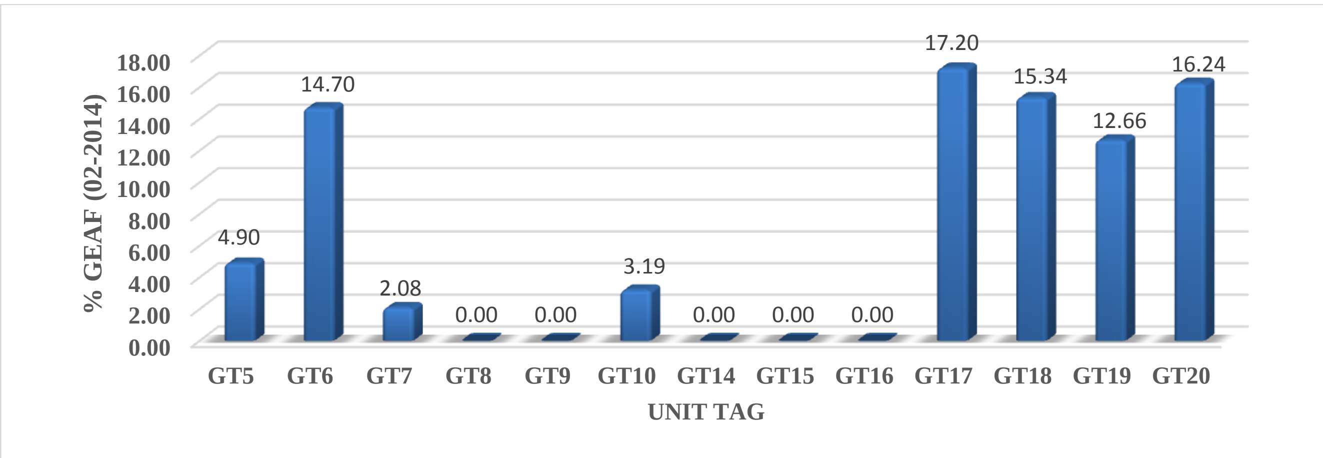

Figure 3: thirteen years average equivalent availability of generator units in Afam I-V power station

Fig.3 clearly shows that GT17 was most reliable in the thirteen years operation of the plant. GT20 came with 16.24% reliability while GT18 came third.

4.2Analysis of reliability indices in Afam VI Power Station

Using the evaluated reliability indices of Afam VI generators in Tables 3,11 and 15, the graph in Fig.4 is generated.

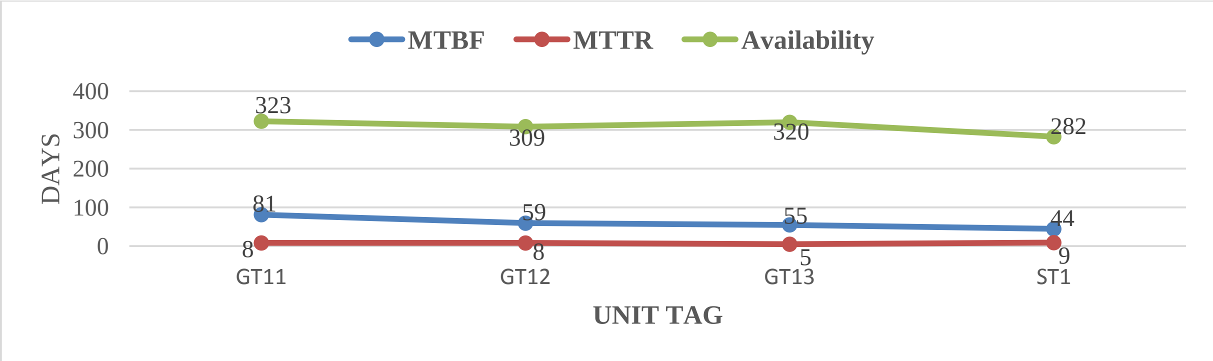

figure 4: six years average performance on reliability indices by generators in Afam VI power plant

Fig.4 shows the six years average performance on reliability indices for the generator units in Afam VI power station. The pattern trends clearly shows that, an effective preventive maintenance programme of generator units is in place, and being judiciously implemented. Fig.4 also reveals highavailability of all the generator units and that between 5 and 8 days are spent annually to sort out maintenance problems of each generator unit. Most importantly, much of the time within each year is devoted to the running of generator units, as against battling with maintainability issues.

Using the evaluated data on the average yearly performance of all the generator units captured under the annual rating of Afam VI plant in Tables 3, 11and 15, the graph in Fig.5 is generated.

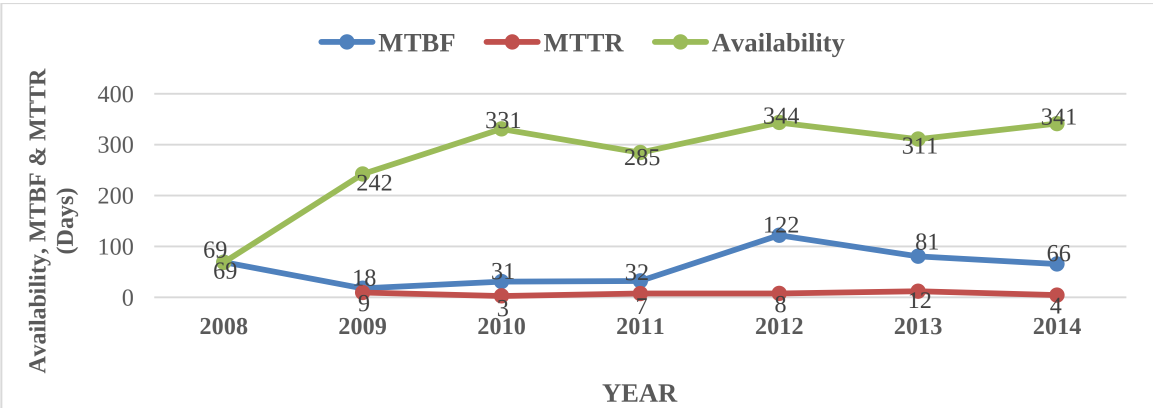

figure 5: variation of reliability indices of Afam VI power plant with year

The performance trends of Afam VI reliability indices in Fig.5,are in sync with the performance of generator units. It also shows that a well-structured condition-based maintenance is being effectively implemented on the assets. The lower MTBF from 2009 to 2011 clearly amplified the commissioning hiccups experienced on the new power plant.

Using the evaluated equivalent availability data in Table 24, the histogram in Fig.6 is generated. This is equivalent or energy availability graph for the generator units in Afam VI power station.

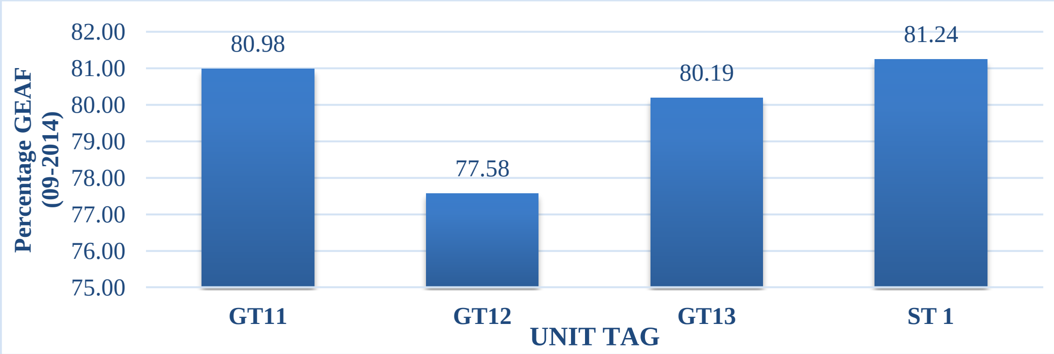

figure 6: Six years average equivalent availability of generator units in Afam I-V power station

Generator ST1 in Afam VI came tops as the most reliable unit, closely followed by GT11. GT12 was the least reliable among the four generator units in Afam VI power station.

4.3 Analysis of reliability indices in Delta Power Station

Using the evaluated reliability indices of Delta generator units in Tables 4,12 and 16, the graph in Fig.7 is generated.

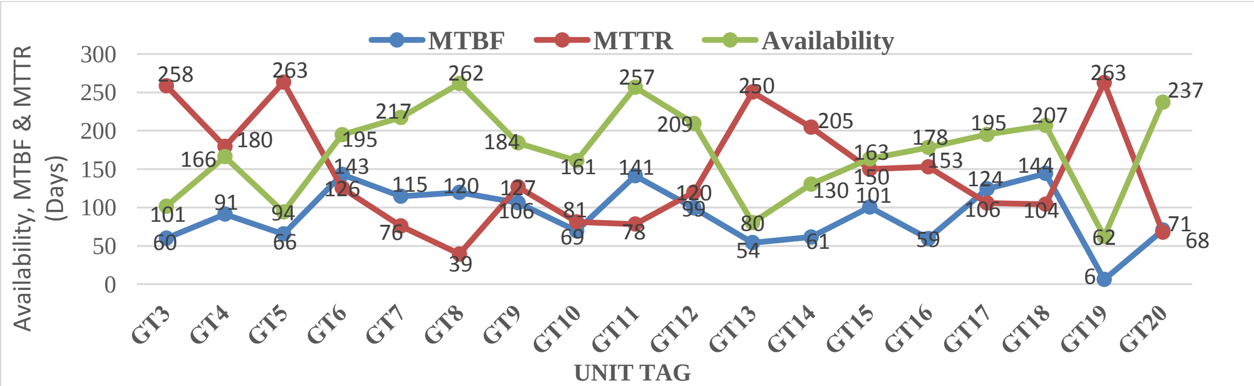

figure 7: thirteen years average performance on reliability indices by generators in Delta power plant

Fig.7 shows the thirteen years average availability, MTTR and MTBF performances of each power generator set in Delta power plant. The performance trends of the reliability indices clearly shows that GT8 presents the best average corrective maintenance turn-around of 39days and the best characteristics of the trends whereby, more time is spent on running the unit rather than carrying out repairs.Other generator units that have favourable characteristics of reliability indices are GT11, GT7, GT6, GT20, GT18 and GT17 in this order. In all these units, much time is spent in running the units as against carrying out repairs.

The worst performed generator units includes GT5, GT19, GT3, GT13 and GT4 in same order. These are units that on yearly average, much time is spent on repairs rather than operations. Higher MTBF and lower MTTR on any of the unit can be achieved through target setting and formulating good maintenance policy, training of personnel and better spare parts management process. The performance of generator units affected the yearly scores on reliability indices of the Delta power plant.

Using the evaluated data on the average yearly performance of all the generator units captured under the annual rating of Delta power in Tables 4, 12and 16, the graph in Fig.8 is generated. This graph shows the annual average performance trends of reliability indices of the entire Delta power plant from 2002 to 2014.

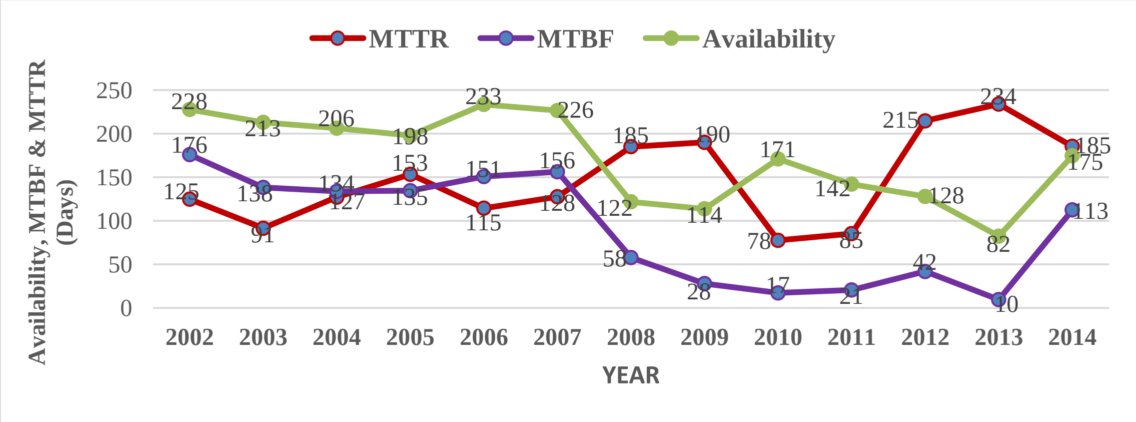

figure 8: variation of reliability indices of Delta power station with year

With the exception from 2002 to 2004 and 2006 to 2007, the maintenance team in Delta power station used much of time to carry out repairs rather than running the generator units. The year with the best reliability characteristics is in 2006 during which, an average of 115days are spent in addressing maintainability issues on each of the generators in the power plant while, it takes an average of 151days operations before failures of each generator unit, with 233days average availability of the power plant.

Using the evaluated equivalent availability data in Table 25, the histogram in Fig.9 is generated. This is equivalent or energy availability graph for the generator units in Delta power station.

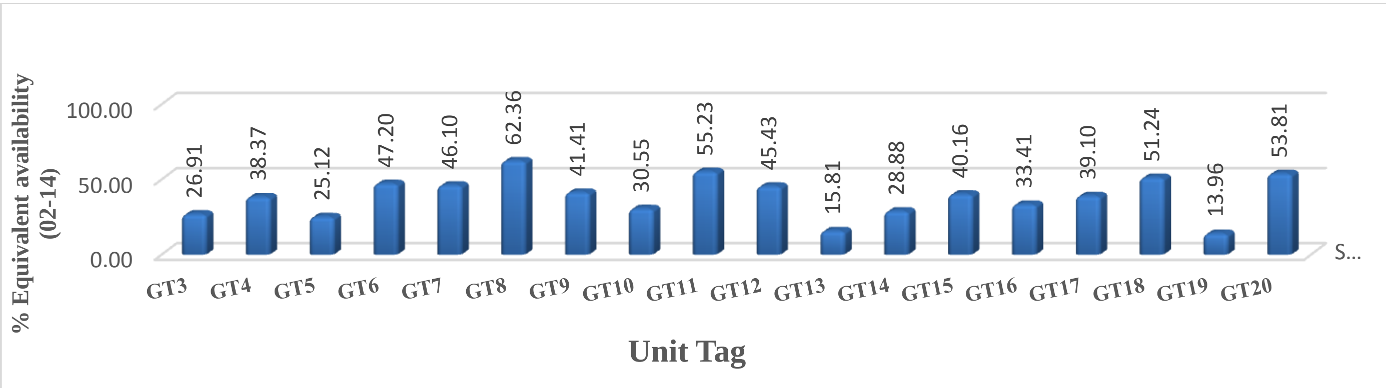

figure 9:thirteen years average equivalent availability of generator units in Delta power station

Generator unit 8 (GT8) was the best performing unit with thirteen years average reliability of 62.36%. Performance of other generator units are appeared in Fig.9. GT19 was the least reliable unit during the period under review.

4.4 Analysis of Reliability Indices in Egbin Power Station

Using the evaluated reliability indices of Egbin generator units in Tables 5,13 and 17 above, the graph in Fig.10 is generated.

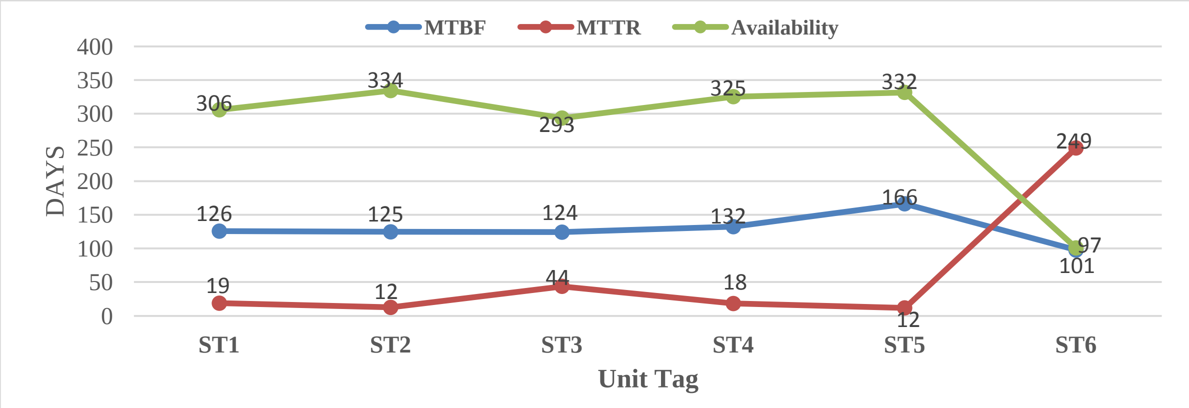

figure10: thirteen years average reliability indices for generators in Egbin power plant

The trends of reliability indices for generators in Egbin power plant clearly shows that there is an existing preventive maintenance programme being implemented each year. It also points to the fact that the generator units are available most of the time in each year for operations, as against carrying out repairs.ST3 was down for 337days in 2007 on damaged boilers and this singular problem negatively impacted on the availability of the power plant during the study period. Though, there is room for performance improvement for units ST1-ST5, the trends of their reliability indices are good.

ST6 was bedeviled with maintainability issues and was down for eight out of the thirteen years operations. As clearly reflected by the reliability trends, the main time to repair surpassed both the availability and the main time between failures trends. This unit unavailability adversely effected the reliability of Egbin power station from 2006 to 2014.

Using the evaluated data on the average yearly performance of all the generator units captured under the annual rating of Delta power in Tables 5, 13 and 17, the graph in Fig.11 is generated.

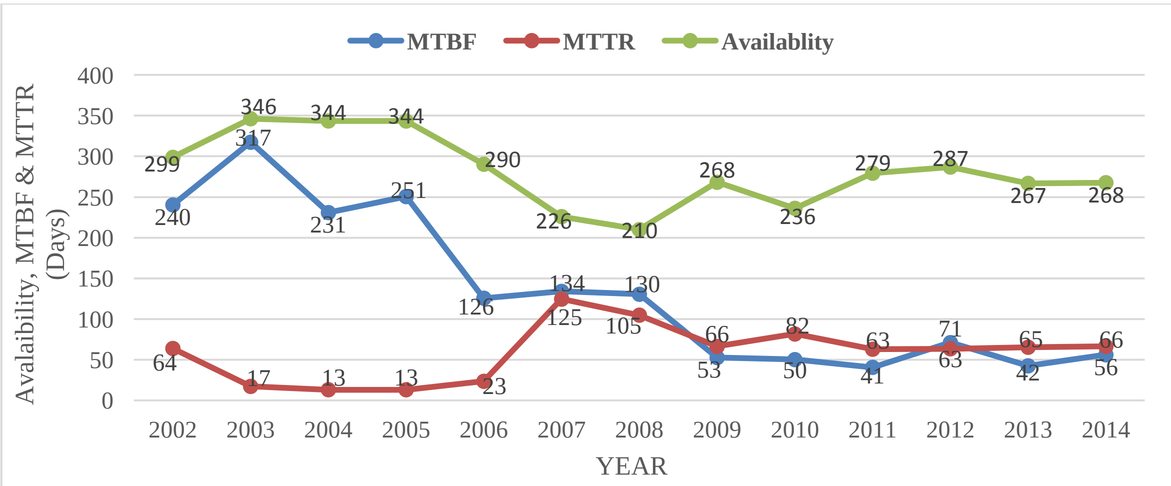

figure 11: Variation of Reliability Indices of Egbin Power Station with year

Fig.11 presents the yearly trends of reliability indices of Egbin power station. The trends pattern shows that performance on reliability indices from the 2002 to 2005 was satisfactory but when ST6 failed in 2006, equipment maintainability questions in the power plant started begging for answers. The prolonged downtime of ST6 affected the average MTTR of the plant and it could be seen from the trends that from the year 2009 to 2011 and 2013 to 2014, much time was spent in tackling maintenance problems in the plant. It is obvious that the forced outage of ST6 in 2006 adversely affected the availability of the plant. Using the evaluated equivalent availability data in Table 26, the histogram in Fig.12 is generated. This is equivalent or energy availability graph for the generator units in Egbin power station.

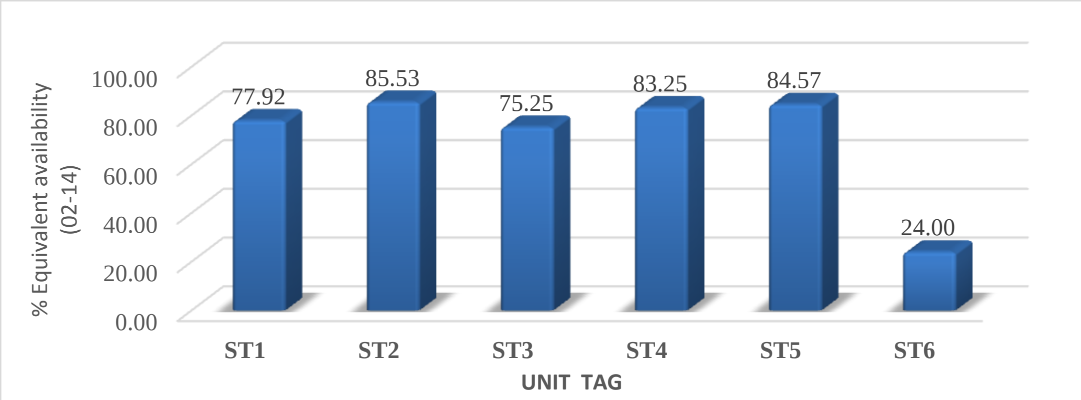

figure 12:thirteen years average equivalent availability of generator units in Afam I-V power station

Generator unit, ST2 in Egbin power station recorded the highest, thirteen years average equivalent availability of 85.53%, closely followed by ST5 which scored 85.57% reliability. ST6 recorded the lowest reliability of 24% during the period under review because, the unit had catastrophic failure in 2006 and remained grounded for the rest of the study period.

4.5 Data Analysis on Reliability of the four Power Stations

Using the evaluated information in Table 18 which covers a period of thirteen years, the graph in Fig.13 is generated. Fig.13presents the percentage equivalent availability of the four power stations for the study period from the year 2002 to 2014. Haven adopted the Equivalent Availability as the relative index of asset reliability in this study, these two terms, reliability and equivalent availability are used interchangeably. Consequently, the reliability of the four thermal power plants varies from 4.18% to 42.99%, 64.92% to 92.88%, 24% to 55.84% and 52.65% to 86.95% for Afam I-V, Afam VI, Delta and Egbin power plants respectively.

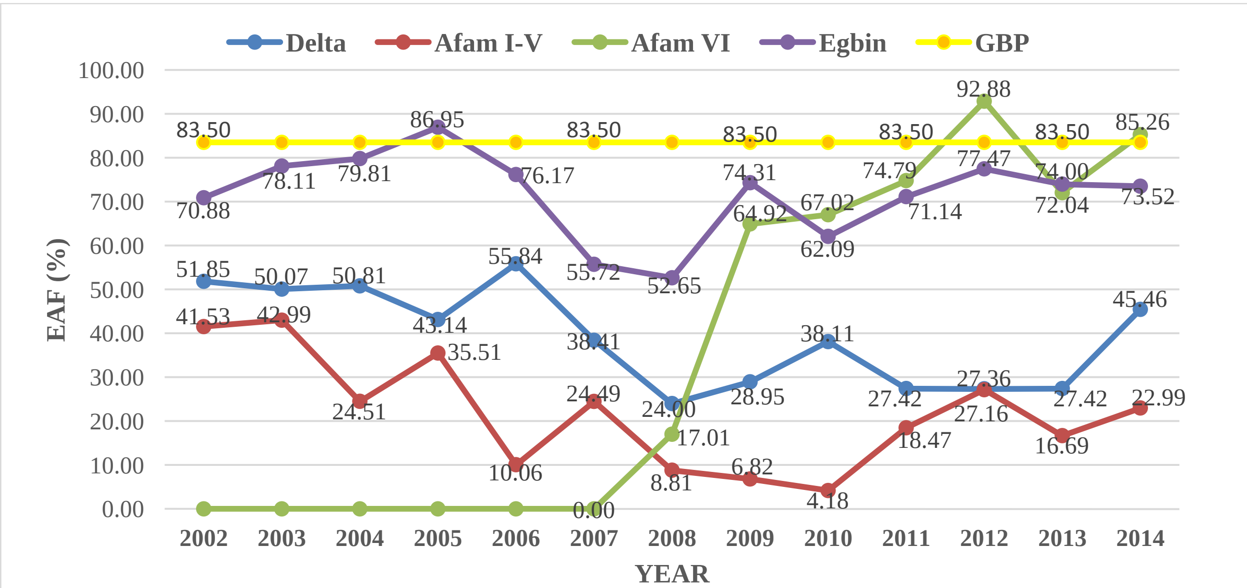

figure 13: Variation of PEAF of the four Power Stations with year

The thirteen years average reliability of Afam I-V, Afam VI, Delta and Egbin power stations covering from 2002 to 2014 are 21.89%, 76.15%, 39.14% and 71.75% respectively. When the World Energy Council's Energy Availability Factor value of 83.50% accepted as a benchmark for good performance in Nigeria is juxtaposed into in figure Fig.13 for the purpose of comparing the performance of the four power plants, it becomes obvious that, each of the four power plants needs some degree of improvement on their daily availability [9].

The operational short fall from the equivalent availability target of 83.5% set as good performance in this study by Afam VI and Egbin power plants are 7.35% and 11.75% respectively. In a sharp contrast, the reliability short fall of Afam I-V and Delta power stations from the set target are 61.61% and 44.36% respectively. From the data analysis, two fundamental deficiencies becomes very glaring in the operations and maintenance of three out of the four power plants and these are:

i. Low operational availability of power the plants occasioned by lack of strategic planning of maintenance activities and poor maintenance practices.
ii. Dearth of competent and skilled personnel who are knowledgeable in troubleshooting faults via the Human-Machine-Interface (HMI) of the turbine packages.

5. Conclusion and recommendations

5.1 Conclusion

The thirteen years average reliability of Afam I-V, AfamVI, Delta and Egbin are 21.89%, 76.15%, 39.14% and 71.75% respectively. These values are lower than the WEC reported average energy availability of fossil fuelled turbine generators. The performance of Afam VI and Egbin Power stations could be categorized as fair whereas the performance of Afam I-V and Delta power stations are poor.

5.2 Recommendations

5.2. Improve the reliability and efficiency of aged equipment by engaging the original equipment manufacturers' in line with terms and conditions of the purchase, care and improvement agreements.

5.2.2 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. The objectives of RCFA are to determine the cause of a problem and implement remedial 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.

5.2.3 Create a positive work environment that encourages the personnel to perform to the best of their abilities. Deploy periodic performance appraisals and reward good performance to motivate personnel.

5.2.4 Create and maintain long-term and short-term work preparation and scheduling with a view to implementing an Integrated Activity Plan for all the assets in the power plant.

5.2.5 Technically strong leadership team is required in these power plants to demonstrate the need for positive change and as such, it is necessary to create and maintain an effective leadership that is capable of developing and implementing preventive maintenance strategy and organizational objectives to achieve organisational tasks and targets.

5.2.6 Technical effectiveness of employees depends on the technical skills they acquires, consequently, there is need to inidentify the required skills and competence to master the technology of the turbo machineries in place, particularly, the control and protection systems software and hardware respectively, including the electrical schematic drawings of the power plant and training both operations and maintenance personnel to acquire those multi-skills.

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