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Effective Asset Utilisation Study on Selected Fossil Fuel Operated Power Stations in Nigeria

Kamalu, U. A.,Etebu, O. M. O. And *Agara, M. P
Faculty Of Engineering, University Of Port Harcourt, Rivers State, Nigeria.

Abstract: Infrastructural development of bulk power supply systems in Nigeria began in 1896 when a 60 kilo-watt power plant was commissioned in Lagos.One hundred and eighty years after this historic event, the power industry is still grappling with how to generate and supply reliableelectric energy to Nigeria's teaming population. As at 31st December 2015,fossil fuel operated power stations constitutes 84.02% of the total installed energy generating stations connected to the national electric power grid in Nigeria. This studyhaveselected four representative thermal power plants and analysedtheir performance indices fora period covering from 2002 to 2015. The combined installed capacity of these four power plants is 31.60% of the 10,194MW totalinstalled capacity of the twenty-two thermal power stations on the national grid. Results obtained shows that, the effective utilisation of Afam I-V, Afam VI, Delta and Egbin power stations varies from 0.07% - 13.9%, 31.43% - 67.41%, 4.68% - 29.8% and 18.29% - 65.69% respectively. The fourteen years average effective utilisation of Afam I-V, Delta and Egbin power stations are 4.73%, 16.06% and 37.24% respectively, while the seven years average effectiveutilisation of Afam VI power station is 47.25%. These values are lower than the 58.66% and 60.52% benchmark targets, set as good performance for steam turbines and simple/combined cycle turbines generating stations respectively.

Keywords: Availability factor, Capacity factor, Commercial availability of generated energy, Effective asset utilisation, performance

I. INTRODUCTION

The commissioning of the first electric power generation plant with an installed capacity of 60 kilo-watt (KW) at Lagos in 1896, herald the development of the electric power industry in Nigeria. From that era to the year 2015, infrastructural development of power supply systems in Nigeria have stagnated. As at the 31st December 2015, there are three hydroelectric power plants and twenty-two thermal power generating stations connected to the national power grid in Nigeria. The total installed power generation capacity from the above twenty five power plants was 12,132.40MW but only an average daily generation of 6,401.20MW was achieved [1]. The demand for electricity by domestic, commercial and industrial users in Nigeria is increasing by the day.Electricity generating plants are insufficient in number, and where available, these plants are under utilised and lack appropriate preventive and break down maintenance. The technology upon which some of these plants were built are obsolete and the additional new plants which are expected to be built based on new technology, lacks human capacity with basic expertise to manage their day to day operations. Hence, the diffusion of knowledge on how these plants ought to be managed with the appropriate technical skills cannot be over emphasized.

Power generation, has remained a hydra-headed challenge for successive governments in Nigeria. In fact, public electrical power supply in Nigeria is very epileptic with high voltage drops when available.Most appalling aspect is thelow utilisation of installed capacities of power plants, with unavailability hours stressing over 80% of total hours in a week.The Energy Commission of Nigeria [2] has projected 175,000 – 192,000 MW peak load demand in Nigeria by the year 2030 for the country to keep pace with the United Nations' Millennium Development Goals (MDGs) and the country's aspiration to be among the first twenty strongest economies of the World by the year 2020. An annual average of less than 50% asset utilisation in Nigeria requires that, the nation must have an installed capacity at least, twice the above projections to meet energy demands in the country. This is huge money that the Government and independent power producers cannot afford. This calls for the need to investigate the challenges in Nigeria power industry, with a view to improving reliability and capacity utilisation of the plants, in line with global best practices.

Stable and adequate electric power supply is required to improve the quality of life of the citizens of any country. Power as a major component for effective industrialization and development is grossly inadequate in Nigeria. Presently, Nigeria power sector is confronted with major difficulties in the core areas of power generation which inspired this study. Four representative fossil fuel operated power plant are selected for this study.The age of selected power plants for this study covers old generation fossil fuel power plants in Nigeria (plants in operation for above 50 years), middle generation plants (plants in operation between 11 – 49 years) and new generation plant (plants commissioned 10 years or less). Afam I-V, Afam VI, Delta and Egbin Power

Stations are selected among the twenty-two fossil fuel operated power plants connected to the national power grid 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 with twenty power generator units (GT1 – GT20) but it has beenderated to 351MW. 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), but the first two generator units were decommissioned in 2002 and as such it currently have eighteen generating units. The rated capacity of this power station is now 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. This power plant is still rated 1320 MW.

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 at 650MW. The selection of this power station for study is to represent the new generation power plants.

In this study, effective Utilisation study of selected fossil fuelled power stations, Afam I-V, Afam VI, Delta and Egbin power plants have been investigated to ascertain the effective Utilisation of their existing assets and the major contributory factor mitigating high performance. Effective Asset Utilisation (EAU) is suitable for dissecting losses from single and multiple assets that are badly managed or poorly utilised. EAU measures the gap between the actual and the potential performance of a plant. EAU promotes sustainable improvement culture, and facilitates gaps identification between current performances and the designed maximum or nameplate capacity utilisation [3]. It is a focused business improvement tool and it is determined by three types of technical losses from functional assets namely, Downtime, Speed, and Quality losses [4].

Effective Asset Utilisation is not the only key performance indicator (KPI) to assess systems performance, but it is a very useful tool in setting performance targets, and improving the reliability of functional systems. The three EAU factors of availability, capacity and quantity, work together and the lowest percentage is usually the biggest barrier that requires tackling first for improvement. When the factors of EAU have been obtained, gaps which hinders good performance become very glaring and opportunities that could be harnessed to improve the equipment reliability becomes obvious. Ideally, tackling the greatest opportunities to improve performance is the most logical step to take, however, it is pertinent to ponder and look for the simplest quick wins that will add value to equipment integrity and reliability.

II. MATERIALS AND METHODS

2.1 Case Study – Afam I-V, Afam VI, Delta And Egbin Power Stations

The Generating Availability Data of the National Control Centre (NNC) at Osogbo which is the load management system of the national power grid is obtained for this study. The sample size is fourteen years covering from the year 2002 to 2015, which is seen as a true representation of the thermal power plants population in Nigeria. The operational availability data is capture in days and to the nearest wholenumber.Data presentation tools includes tables, bar charts, line charts, pie charts, histograms, etc.

Generator units' availability data forEgbin power station is used to illustrate the evaluation of the operational availability of each power station. Table 1 is the annual uptime (days) data for the six generator units in Egbinpower station from 2002 to 2015.Similarly, generator units' availability were compiled from NCC annual report for the generator units in the other three power stations.

Other power generation parameters, extracted from the fourteen years NCC annual reports for the evaluation of the effective utilisation of the selected four power generation stations include:

- **i.** Summary on Power Stations' Maximum Capacity and Annual Average Load (MW)
- **ii.** Electric Energy generated (MWH) by the Four Power Stations
- **iii.** Electric Energy (MWH) Sent Out by the Four Power Stations

2.2 Methodology

Analysis of power plant performance indices are carried out for the four power station using the data in Tables 1 – 7 attached below.

Table 1: Generator Availability (days) in Egbin Power Station

UNIT CAPACITY		6x220MW						1320MW		
UNIT TAG		ST1	ST2	ST3	ST4	ST5	ST6	Total	Av.P/S	Plant Ava
	2002	351	351	358	234	327	172	1793	299	0.8187
	2003	345	340	334	347	355	357	2078	346	0.9489
	2004	337	336	347	352	343	352	2067	345	0.9413
	2005	328	335	344	346	343	365	2061	344	0.9411
	2006	358	282	351	337	350	64	1742	290	0.7954
	2007	277	351	28	337	363	0	1356	226	0.6192
YEAR	2008	316	246	94	276	331	0	1263	211	0.5751
	2009	312	354	302	331	310	0	1609	268	0.7347
	2010	24	351	346	358	338	0	1417	236	0.6470
	2011	360	356	313	327	320	0	1676	279	0.7653
	2012	340	363	340	328	355	0	1726	288	0.7860
	2013	307	339	313	343	299	0	1601	267	0.7311
	2014	322	344	347	314	279	0	1606	268	0.7333
	2015	197	355	323	261	225	190	1551	259	0.7082
Total (02-15)		**3977**	**4348**	**3817**	**4230**	**4313**	**1310**			

Table 2: Generator Availability (days) in Afam I-V Power Station

Unit Capacity		Afam-I (4x10.3MW)				Afam-II (4x23.9MW)				Afam-III (2x27.5MW)		Afam-IV (5x75MW)					Afam-V (2x138MW)		Total Run Days					P/S
Unit Tag		GT1	GT2	GT3	GT4	GT5	GT6	GT7	GT8	GT9	GT10	GT14	GT15	GT16	GT17	GT18	GT19	GT20	Afam-II	Afam-III	Afam-IV	Afam-V	Total Days	Av./YR
	2002	0	0	0	0	0	312	151	0	0	49	0	0	0	284	168	339	313	463	49	452	652	1616	162
	2003	0	0	0	0	0	231	0	0	0	0	0	0	0	329	0	337	245	231	0	329	582	1142	114
	2004	0	0	0	0	0	366	0	0	0	0	0	0	0	326	0	16	276	366	0	326	292	984	98
	2005	0	0	0	0	89	319	0	0	0	0	0	0	0	313	0	160	309	408	0	313	469	1190	119
	2006	0	0	0	0	150	226	0	0	0	0	0	0	0	144	0	358	351	376	0	144	709	1229	112
	2007	0	0	0	0	61	0	0	0	0	0	0	0	0	3	112	348	298	61	0	115	646	822	63
YEAR	2008	0	0	0	0	9	0	0	0	0	0	0	0	0	271	0	46	53	9	0	271	99	379	29
	2009	0	0	0	0	3	0	0	0	0	0	0	0	0	182	0	0	0	3	0	182	0	185	14
	2010	0	0	0	0	0	0	0	0	0	0	0	0	0	37	0	0	0	0	0	37	0	37	7
	2011	0	0	0	0	0	0	0	0	0	0	0	0	0	23	286	0	0	0	0	309	0	309	77
	2012	0	0	0	0	0	0	0	0	0	0	0	0	0	200	336	0	0	0	0	536	0	536	134
	2013	0	0	0	0	0	0	0	0	0	0	0	0	0	0	267	0	0	0	0	267	0	267	67
	2014	0	0	0	0	0	0	0	0	0	0	0	0	0	88	316	0	0	0	0	404	0	404	101
	2015	0	0	0	0	0	0	0	0	0	0	0	0	0	107	0	0	0	0	0	107	0	107	27
Ave. Uptime (2002-2015)		0	0	0	0	22	104	11	0	0	4	0	0	0	165	106	115	132						

Table 3: Generator Availability (days) in Afam VI Power Station

Unit Capacity		**3x150MW**			**200MW**	**150 MW**	**200 MW**	**650MW**
UNIT TAG		**GT11**	**GT12**	**GT13**	**ST1**	**Total**	**Total**	**P/S**
	2009	287	214	224	N/A	725	0	242
	2010	310	342	341	N/A	993	0	331
	2011	336	306	298	198	940	198	285
YEAR	**2012**	336	351	360	331	1047	331	345
	2013	334	282	342	286	958	286	311
	2014	335	358	355	317	1048	317	341
	2015	246	320	308	202	874	202	269
AV. AF (02 - 15)		**1938**	**2163**	**1920**	**1132**			

Table 4: Generator Availability (days) in Delta Power Station

Unit Capacity		elta-I (2x6MW		Delta-II (6x25MW)						Delta-III (6x25MW)						Delta-IV (6x100MW)						300MW	600MW	900MW
UNIT TAG		GT1	GT2	GT3	GT4	GT5	GT6	GT7	GT8	GT9	GT10	GT11	GT12	GT13	GT14	GT15	GT16	GT17	GT18	GT19	GT20	Days (25MW)	Total Days (100MW)	P/S
YEAR	2002	0	0	290	320	306	306	306	351	120	179	293	0	0	0	328	365	329	365	0	241	2471	1628	**228**
	2003	0	0	350	343	321	365	358	334	0	0	341	0	0	0	359	265	365	326	0	106	2412	1421	**213**
	2004	0	0	336	345	332	366	366	366	106	0	111	0	0	0	336	366	334	358	0	0	2328	1394	**207**
	2005	0	0	344	265	265	337	339	339	46	272	61	46	42	29	350	225	347	146	0	106	2385	1174	**198**
	2006	0	0	0	0	0	283	289	289	344	344	344	365	365	358	312	0	235	358	0	317	2981	1222	**234**
	2007	0	0	0	0	0	358	311	344	353	348	355	358	351	282	90	0	253	358	0	316	3060	1017	**227**
	2008	0	0	0	0	0	102	79	121	313	213	343	291	0	324	163	0	0	25	0	226	1786	414	**122**
	2009	0	0	0	0	0	102	63	120	215	187	262	236	0	236	0	0	0	295	0	333	1421	628	**114**
	2010	0	0	0	0	0	251	307	78	326	125	324	349	57	269	51	276	49	270	199	148	2086	993	**171**
	2011	0	0	0	0	0	63	42	65	206	103	320	209	135	197	136	302	135	114	237	294	1340	1218	**142**
	2012	0	0	0	349	0	0	0	318	366	0	309	295	0	0	0	0	0	76	300	296	1637	672	**128**
	2013	0	0	0	175	0	0	0	331	0	0	0	246	0	0	0	183	126	0	73	349	752	731	**82**
	2014	0	0	0	365	0	0	365	346	0	323	275	328	92	0	0	336	363	0	0	351	2094	1050	**175**
	2015	0	0	0	365	0	0	365	345	0	323	275	345	92	0	0	343	363	0	361	353	2110	1420	**196**
Av. AF (02-15)		**0**	**0**	**94**	**181**	**87**	**181**	**228**	**268**	**171**	**173**	**258**	**219**	**81**	**121**	**152**	**190**	**207**	**192**	**84**	**245**			

Table 5: 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	2015
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	4.93
	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	351.00
Afam VI	Average Load (MW)	NA	NA	NA	NA	NA	NA	NA	322.82	435.64	486.16	603.70	468.24	554.20	509.13
	Rate Capacity (MW)	NA	NA	NA	NA	NA	NA	NA	497.25	650.00	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	475.45
	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	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	951.63
	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	1320.00

Table 6: Electric Energy generated (GWH) by the Four Power Stations

Year		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	PEG (02-15)
Power Station	Afam I-V	1733.57	2086.30	1247.81	1838.93	1864.11	1274.10	454.61	151.05	56.22	391.28	493.73	336.99	288.56	8.56	12225.81
	Afam VI	NA	NA	NA	NA	NA	NA	142.34	2129.06	2927.28	3291.65	4138.15	3305.25	3408.99	3045.83	22388.55
	Delta	3430.11	3536.42	3933.79	3235.21	3752.05	2696.72	1510.99	1591.57	1957.87	1488.12	1346.68	1692.83	2804.07	2777.56	35753.98
	Egbin	6876.37	6820.11	7962.76	8592.10	4924.48	3636.68	4381.56	3383.99	5385.48	6752.68	6679.70	5559.12	4672.30	5501.66	81128.98
Yearly Total		12040.05	12442.83	13144.36	13666.24	10540.64	7607.50	6489.50	7255.67	10326.85	11923.73	12658.26	10894.19	11173.92	11333.61	151497.32

Table 7: Electric Energy (GWH) Sent Out by the Four Power Stations

Year		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total PEO (02-15)
Power Station	Afam I-V	1713.28	2061.89	1233.21	1817.42	1842.30	1259.20	449.29	148.12	54.85	388.91	490.91	334.11	286.75	8.50	12088.78
	Afam VI	NA	NA	NA	NA	NA	NA	133.41	2062.22	2860.23	3263.85	4089.04	3230.71	3333.15	2991.28	21963.90
	Delta	3290.84	3392.84	3774.07	3103.86	3599.72	2587.23	1449.64	1564.77	1891.44	1392.44	1283.26	1634.62	2671.88	2761.02	34397.64
	Egbin	6458.97	6406.13	7479.42	8070.56	4625.56	3415.93	4115.60	3126.91	5094.70	6397.43	6317.13	5228.45	4356.46	5192.95	76286.22
Yearly Total		11463.09	11860.86	12486.70	12991.84	10067.58	7262.36	6147.94	6902.02	9901.22	11442.63	12180.34	10427.89	10648.24	10953.75	144736.54

III. DATA PRESENTATION

Plant performance indices to be evaluated using the obtained data includes:(i)PlantAvailability Factor (PAF); (ii)Plant Capacity Factor (PCF); (iii)Plant Use factor (PUF); (iv)Commercial Availability Factor of Plant (PCAF) on generated energy; (v)Effective Asset Utilisation of the Plant (PEAU).

3.1 Plant Availability Factor (Paf)

Three frequently used availability terms are; Inherent Availability, Achieved Availability and Operational Availability. Each of these terms has its peculiar definition and method of evaluation. This study focuses on operational availability (A_O) which is the actual measure of availability over a timeframe that captures every downtime incurred in maintenance implementation process such as, planning, scheduling and other administrative duties, logistic downtime, spare parts acquisition downtime if not on site, etc. Operational availability takes into account all downtime losses from skilled manpower needs, spare parts, logistics, and administrative bottlenecks, including the implementation of the maintenance job[5]. Operational availability which is synonymous with availability factor is the ratio of the equipment uptime to the total time of the operating cycle:

$$A_O = \frac{\text{Uptime}}{\text{Operating Cycle}} \qquad (1)$$

Where,Uptime is the total run time of the equipment within the operating cycle, and the Operating Cycle is equal to the overall time of the investigation which in this study is yearly.

Therefore, the Availability Factor of each power generating set is obtained by dividing the Uptime by the total days in the year as in equation (1):

$$AF = \frac{\text{Uptime}}{\text{Operating Cycle}} = \frac{\text{Uptime (Days)}}{\text{(Uptime + Downtime) Days}} = \frac{\text{Uptime (Days)}}{\text{365 or 366 Days}}$$

Using Table 1 which is the fourteen years uptime data for generator units in Egbin power station and equation (1), calculations of the Availability Factors of Egbin generator units ST2 and ST5 in 2002 are illustrated below:

In Table 1, under the year 2002, the Uptime of generator units ST2 and ST5 are 351days and 327days respectively. Therefore, the availability factors of the two generator units are calculated by substituting the operated days and the total days in the operating cycle into equation (1):

$$AF_{ST2} = \frac{351\,(\text{Days})}{365\,(\text{Days})} = 0.9616$$

and

$$AF_{ST5} = \frac{327\,(Days)}{365\,(\text{Days})} = 0.8959$$

Thus the Generator Availability Factor (GAF) for ST2 and ST5 in 2002, is equal to 0.9616 and 0.8959 respectively. Similarly, substituting the yearly Uptime values for the generator units in the Uptime Tables 1 to 4 for four power stations into equation (1), gives the following Generator Availability Factors in Tables 8 – 11 below.

Table 8: Generator Availability Factors in Egbin Power Station

	Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Av. (02-15)
Unit Tag	ST1	0.9616	0.9452	0.9208	0.8986	0.9808	0.7589	0.8634	0.8548	0.0658	0.9863	0.9290	0.8411	0.8822	0.5397	0.8376
	ST2	0.9616	0.9315	0.9180	0.9178	0.7726	0.9616	0.6721	0.9699	0.9616	0.9753	0.9918	0.9288	0.9425	0.9726	0.9158
	ST3	0.9808	0.9151	0.9481	0.9425	0.9616	0.0767	0.2568	0.8274	0.9479	0.8575	0.9290	0.8575	0.9507	0.8849	0.8040
	ST4	0.6411	0.9507	0.9617	0.9479	0.9233	0.9233	0.7541	0.9068	0.9808	0.8959	0.8962	0.9397	0.8603	0.7151	0.8909
	ST5	0.8959	0.9726	0.9372	0.9397	0.9589	0.9945	0.9044	0.8493	0.9260	0.8767	0.9699	0.8192	0.7644	0.6164	0.9084
	ST6	0.4712	0.9781	0.9617	1.0000	0.1753	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.5205	0.2759
P/S	Av.AF	0.8187	0.9489	0.9413	0.9411	0.7954	0.6192	0.5751	0.7347	0.6470	0.7653	0.7860	0.7311	0.7333	0.7082	0.7721

Table 9: Generator Availability Factors in Afam VI Power Station

Unit Capacity		3x150MW			200MW	P/S	
Unit Tag		GT11	GT12	GT13	ST1	Av.AF	P/S
Year	2009	0.7863	0.5863	0.6137	0.0000	0.6621	0.6621
	2010	0.8493	0.9370	0.9342	0.0000	0.9068	0.9068
	2011	0.9205	0.8384	0.8164	0.5425	0.7795	0.7795
	2012	0.9180	0.9590	0.9836	0.9044	0.9413	0.9413
	2013	0.9151	0.7726	0.9370	0.7836	0.8521	0.8521
	2014	0.9178	0.9808	0.9726	0.8685	0.9349	0.9349
	2015	0.6740	0.8767	0.8438	0.5534	0.7370	0.7370
AF (09-15)		0.8544	0.8501	0.8716	0.7305	0.8461	0.8461

Table 10: Generator Availability Factors 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					P/S	P/S
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	Av./YR	AF
YEAR	2002	0	312	151	0	0	49	0	0	0	284	168	339	313	463	49	452	652	1616	162	0.4427
	2003	0	231	0	0	0	0	0	0	0	329	0	337	245	231	0	329	582	1142	114	0.3129
	2004	0	366	0	0	0	0	0	0	0	326	0	16	276	366	0	326	292	984	98	0.2696
	2005	89	319	0	0	0	0	0	0	0	313	0	160	309	408	0	313	469	1190	119	0.3260
	2006	150	226	0	0	0	0	0	0	0	144	0	358	351	376	0	144	709	1229	112	0.3061
	2007	61	0	0	0	0	0	0	0	0	3	112	348	298	61	0	115	646	822	63	0.1732
	2008	9	0	0	0	0	0	0	0	0	271	0	46	53	9	0	271	99	379	29	0.0799
	2009	3	0	0	0	0	0	0	0	0	182	0	0	0	3	0	182	0	185	14	0.0390
	2010	0	0	0	0	0	0	0	0	0	37	0	0	0	0	0	37	0	37	7	0.0203
	2011	0	0	0	0	0	0	0	0	0	23	286	0	0	0	0	309	0	309	77	0.2116
	2012	0	0	0	0	0	0	0	0	0	200	336	0	0	0	0	536	0	536	134	0.3661
	2013	0	0	0	0	0	0	0	0	0	0	267	0	0	0	0	267	0	267	67	0.1829
	2014	0	0	0	0	0	0	0	0	0	88	316	0	0	0	0	404	0	404	101	0.2767
	2015	0	0	0	0	0	0	0	0	0	107	0	0	0	0	0	107	0	107	27	0.0733
Ave. Uptime (2002-2015)		22	104	11	0	0	4	0	0	0	165	106	115	132							

Table 11: Generator Availability Factors 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. AF
YEAR	2002	0.7945	0.8767	0.8384	0.8384	0.8384	0.9616	0.3288	0.4904	0.8027	0.0000	0.0000	0.0000	0.8986	1.0000	0.9014	1.0000	0.0000	0.6603	0.6239
	2003	0.9589	0.9397	0.8795	1.0000	0.9808	0.9151	0.0000	0.0000	0.9342	0.0000	0.0000	0.0000	0.9836	0.7260	1.0000	0.8932	0.0000	0.2904	0.5834
	2004	0.9180	0.9426	0.9071	1.0000	1.0000	1.0000	0.2896	0.0000	0.3033	0.0000	0.0000	0.0000	0.9180	1.0000	0.9126	0.9781	0.0000	0.0000	0.5650
	2005	0.9425	0.7260	0.7260	0.9233	0.9288	0.9288	0.1260	0.7452	0.1671	0.1260	0.1151	0.0795	0.9589	0.6164	0.9507	0.4000	0.0000	0.2904	0.5417
	2006	0.0000	0.0000	0.0000	0.7753	0.7918	0.7918	0.9425	0.9425	0.9425	1.0000	1.0000	0.9808	0.8548	0.0000	0.6438	0.9808	0.0000	0.8685	0.6397
	2007	0.0000	0.0000	0.0000	0.9808	0.8521	0.9425	0.9671	0.9534	0.9726	0.9808	0.9616	0.7726	0.2466	0.0000	0.6932	0.9808	0.0000	0.8658	0.6205
	2008	0.0000	0.0000	0.0000	0.2787	0.2158	0.3306	0.8552	0.5820	0.9372	0.7951	0.0000	0.8852	0.4454	0.0000	0.0000	0.0683	0.0000	0.6175	0.3339
	2009	0.0000	0.0000	0.0000	0.2795	0.1726	0.3288	0.5890	0.5123	0.7178	0.6466	0.0000	0.6466	0.0000	0.0000	0.0000	0.8082	0.0000	0.9123	0.3119
	2010	0.0000	0.0000	0.0000	0.6877	0.8411	0.2137	0.8932	0.3425	0.8877	0.9562	0.1562	0.7370	0.1397	0.7562	0.1342	0.7397	0.5452	0.4055	0.4686
	2011	0.0000	0.0000	0.0000	0.1726	0.1151	0.1781	0.5644	0.2822	0.8767	0.5726	0.3699	0.5397	0.3726	0.8274	0.3699	0.3123	0.6493	0.8055	0.3893
	2012	0.0000	0.9536	0.0000	0.0000	0.0000	0.8689	1.0000	0.0000	0.8443	0.8060	0.0000	0.0000	0.0000	0.0000	0.0000	0.2077	0.8197	0.8087	0.3505
	2013	0.0000	0.4795	0.0000	0.0000	0.0000	0.9068	0.0000	0.0000	0.0000	0.6740	0.0000	0.0000	0.0000	0.5014	0.3452	0.0000	0.2000	0.9562	0.2257
	2014	0.0000	1.0000	0.0000	0.0000	1.0000	0.9479	0.0000	0.8849	0.7534	0.8986	0.2521	0.0000	0.0000	0.9205	0.9945	0.0000	0.0000	0.9616	0.4785
Av. AF(02-14)		0.2780	0.4552	0.2578	0.5336	0.5951	0.7165	0.5043	0.4412	0.7030	0.5735	0.2196	0.3570	0.4476	0.4883	0.5343	0.5669	0.1703	0.6494	0.4718

When the average availability of all the generator units captured under the annual rating of each power plant is computed, the obtained result is the operational availability of the power plant for the given year as shown in Table 12

Table 12: Availability Factors of the four Power Station (%)

	YEAR	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Av. PAF (02-15)
Power Plant	Afam I-V	44.27	31.29	26.89	32.60	30.61	17.32	7.97	3.90	2.90	21.16	36.61	18.29	27.67	7.40	22.06
	Afam VI	NA	NA	NA	NA	NA	NA	NA	66.39	90.68	77.95	94.13	84.97	93.49	73.70	83.04
	Delta	62.39	58.34	56.50	54.17	63.97	62.05	33.39	31.19	46.86	38.93	35.05	22.57	47.85	53.70	47.64
	Egbin	81.87	94.89	94.13	94.11	79.54	61.92	61.92	73.47	64.70	76.53	78.60	73.11	73.33	70.96	77.08

IEEE Standard 762 recommended an average service availability index (ASAI) of 0.999 as global best practice value on availability factor[6]. But this ASAI is based on only 52 minutes system average interruption duration index (SAIDI) in a year. Obviously, 52 minutes is inadequate to carry out preventive maintenance in Nigeria environment where the harmattan and contaminated fossilfuel fouls turbine blades. The study adopts an ASAI of .95 for an SAIDI of 18 days in a year to allow for water washing of turbine blades, cleaning of air inlet filters and carrying out preventive maintenance activities.

3.2 Plant Capacity Factor (Pcf)

PCF is defined in this study as the ratio of actual energy generated by the power plant in a given year to the potential maximum energy that the plant could generate in that year.

$$PCF = \frac{\text{Total Energy Generated by the Plant (MWH)}}{\text{Maximum rated Capacity of the Plant (MWH)}} \quad (2)$$

Using equation (2), Table 5 (Summary on Power Stations' Maximum Capacity and Annual Average Load (MW)) and Table6 (electric energy generated (MWH) by the Four Power Stations), the yearly Plant Capacity Factors of each power station is computed as illustrated below.

In Table 6 under the year 2012, Afam VI power plant generated 4138.15 GWH whereas, Egbin power plant generated 6679.70 GWH in same year. From Table 5, under the year 2012, the maximum rated capacities of Afam VI and Egbin power plants are 650MW and 1,320MW respectively. Therefore, the Plant Capacity Factors of the two plants, using equation (2) in the year 2012 are as follows:

$$PCF_{\text{Afam VI}} = \frac{4138.15 \text{ GWH}}{(650 \times 24 \times 366)/1000 \text{ GWH}} = 0.7248$$

And

$$PCF_{\text{Egbin}} = \frac{6679.70 \text{ GWH}}{(1320 \times 24 \times 366)/1000 \text{ GWH}} = 0.5761$$

Similarly, the Plant Capacity Factors for the fourteen years operations of the four thermal power plants have been evaluated using equation (2). The obtained results for the fourteen years percentage on "Plant Capacity Factor" for the four power plants is arranged in tabular format as shown in Table13 below.

Table 13: Plant Capacity Factor for the four thermal Power Station (%).

YEAR		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Av. PCF (02-15)
Power Plant	Afam I-V	31.76	38.23	22.80	33.70	26.00	15.61	5.56	1.85	1.24	16.06	12.61	10.96	9.38	0.28	16.15
	Afam VI	NA	NA	NA	NA	NA	NA	NA	48.88	51.41	57.81	72.48	58.05	59.87	53.49	57.43
	Delta	42.93	44.27	49.10	40.50	48.56	34.90	19.50	20.60	24.83	18.88	17.03	21.47	35.57	35.23	32.38
	Egbin	59.47	58.98	68.67	74.31	42.59	31.45	37.79	29.27	46.57	58.40	57.61	48.08	40.41	47.58	50.08

Global best practice values ranges from 0.5 to 0.8 and the benchmark for good performance in this study is set at 0.65.

3.3 Commercial Availability Of Generated Energy By The Plant (PCAF)

Consensus on the concept of Commercial Availability as a primary measure on power plant performance index has not been reached. The IEEE Standard 762 Working Group recommended further study and development before including the accepted definition and suitable indicators in future standards [7]. The proposed indicator for this index in this study is defined as the ratio of the energy sent out for sales to consumers in a year, to the total energy generated by the power plant in that year. It is mathematically expressed as:

$$PCAF = \frac{\textbf{Total energy sent out from the plant in a year (PEO) MWH}}{\textbf{Total nergy generated by the plant in a year (PEG) MWH}} \quad (3)$$

This index is aimed at enriching the debate on the use of this terminology and a suitable indicator. Most importantly, this parameter encourages the sending out for sales, as much energy generated as possible, thereby improving cash flow into the organisation. The benchmarks set as good performance on this parameter are 0.95 and 0.98 for steam turbine and simple/combined cycle turbine power stations respectively.

Using equation (3), Table 6 (electric energy generated (MWH) by the Four Power Stations) and Table 7 (Electric Energy (MWH) Sent Out by the Four Power Stations), the computation of the Commercial Availability Factor of each power plant (PCAF) is illustrated below.

In Table 6, under the year 2009, Afam I-V power station generated 151.05 GWH and in Table 7, under the year 2009, Afam I-V sent out 148.12 GWH. In Table 6, under the year 2009 Afam VI generated 2129.06 GWH and in Table 7, under the year 2009 Afam VI sent out 2062.22 GWH.

$$PCAF_{\text{Afam I-V}} = \frac{148.12 \text{ GWH}}{151.05 \text{ GWH}} = 0.9806$$

$$PCAF_{\text{Afam VI}} = \frac{2062.22 \text{ GWH}}{2129.06 \text{ GWH}} = 0.9686$$

Similarly, substituting the data in Tables 6 and into equation (3), gives the annual commercial availability factor for each plant from 2002 to2015. The results are as contained in Table 14 below.

Table 14: Commercial Availability Factor for the four Power Stations

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Av. (02-15)
Afam I-V	98.91	98.91	98.91	98.91	98.91	98.91	98.91	98.06	97.55	99.39	99.43	99.15	99.37	99.41	98.91
Afam VI	NA	NA	NA	NA	NA	NA	NA	96.86	97.71	99.16	98.81	97.74	97.78	98.21	98.04
Delta	96.43	96.43	96.43	96.43	96.43	96.43	96.43	98.32	96.61	93.57	95.29	96.56	95.29	99.40	96.43
Egbin	94.00	94.00	94.00	94.00	94.00	94.00	94.00	92.40	94.60	94.74	94.57	94.05	93.24	94.39	94.00

3.4 Effective Utilisation Of Power Plant (PEAU)

The effective asset utilisation of a power plant (PEAU) is defined as the product of the plant availability factor (PAF), the plant capacity factor (PCF) and the commercial availability factor of generated energy by the power plant (PCAF) and it is mathematically expressed as:

$$\text{PEAU} = \text{PAF x PCF x PCAF} \qquad (4)$$

Substituting equations (1), (2) and (3) into equation (4), the Plant Effective Utilisation (PEAU) is equal to:

$$\text{PEAU}=\frac{\textit{Plant}\ \text{Uptime (days)}}{\text{Total Time (days)}} \text{ x } \frac{\text{Energy Genetated by the Plant (MWH)}}{\text{Maximum capacity of the plant (MWH)}} \text{ x } \frac{\text{Energy Sent Out by the Plant (MWH)}}{\text{Energy generated by the plant (MWH)}}$$

Using Table 12: Availability Factors for the four Power Stations, Table 13: Plant Capacity Factor for the four thermal Power Station and Table 14: Commercial Availability for the four Power Stations, the computation of the Effective Asset Utilisation of the power plants are illustrated as follows:

In 2014, Afam VI power plant achieved 0.9349 availability factor (Table 12), 0.5987 plant capacity factor (Table 13) and 0.9778 commercial Availability factor (Table 14) whereas, Delta recorded 0.4785 availability factor (Table 12), 0.3557 plant capacity factor (Table 13) and 0.9529 commercial Availability factor (Table 14) in the same year. Substituting these data into equation (4) the Effective Asset Utilisation of the two plants are calculated as follows:

$\text{PEAU}_{\text{AfamVI}}$ = 0.9349 x 0.5987 x 0.9778 = 0.5473 = 0.5473 x 100 = 54.73%

And

$\text{PEAU}_{\text{Delta}}$ = 0.4785 x 0.3557 x 0.9529 = 0.1622 = 0.1622 x 100 = 16.22%

Similarly, substituting the performance factors for individual power plant in a given year into equation (4), produces the Effective Asset Utilisation of the four power plant for that year. Achieved Effective Asset Utilisation of the four power plants in the fourteen years period of this study is shown in Table 15 below.

Table 15: Percentage Effectiveness of Asset Utilisation of the four Power Stations

Year		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	PEAU (02-15)
Power Station	Afam I-V	13.91	11.83	6.06	10.87	7.87	2.67	0.44	0.07	0.02	3.38	4.59	1.99	2.58	0.02	3.52
	Afam VI	NA	NA	NA	NA	NA	NA	NA	31.35	45.55	44.68	67.41	48.35	54.73	38.72	46.74
	Delta	25.83	24.91	26.82	21.16	29.95	20.88	6.30	6.32	11.24	6.88	5.70	4.68	16.22	18.82	14.88
	Egbin	45.77	52.61	60.76	65.74	31.84	18.31	20.43	19.87	28.50	42.34	42.82	33.06	27.63	31.81	36.13

IV. RESULTS AND DISCUSSION

4.1 Availability Factors Of The Four Power Station

The yearly availability factors of the four power stations in Table 12 have been used to generate the graph in Fig.1.Four out of the five trends in this graph represents the yearly average availability factorsof the four power plants as indicated in the legend while an Average Service Availability Index (ASAI) of 95.00% accepted as a benchmark for good performance in this study is inserted to compare and contrast the performances of each power station.

The operational availability of the four thermal power plants varies from 2.9% to 44.27%, 66.3% to 94.13%, 22.57% to 63.97% and 57.51% to 94.89% for Afam I-V, Afam VI, Delta and Egbin power stations respectively. The fourteen years average availability of the four power stations are 22.06%, 83.04%, 47.64% and 77.08% for Afam I-V, Afam VI, Delta and Egbin power stations respectively. These availability values are lower than the ASAI value of 95.00%.

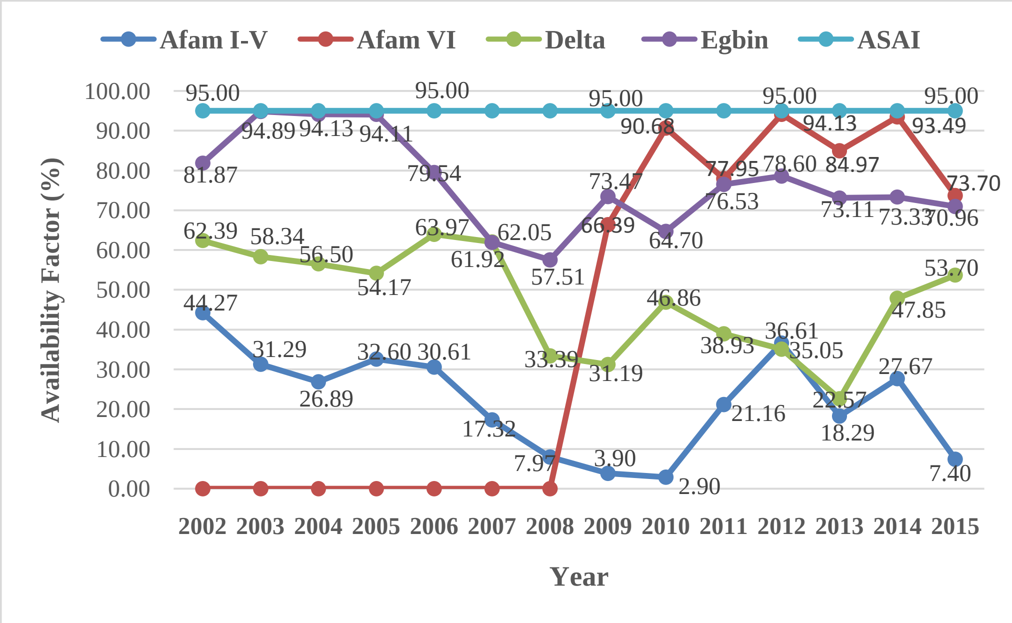

Figure 1: variation of availability factors of the four power stations with year

Afam I-V power station stands out as a poorly managed facility without a clear maintenance policy, nor a clear operational philosophy [8]. Turbine blade failures dominates problem logs on generator units in Afam I-V power station, which is an indication of lack of the skills, competence and technical-know-how of both operations and maintenance personnel of the plant. Solving of operational problems on turbine faults in Afam I-V power plant, are characterised by trial and error approach thus, leading to numerous failures on turbine blades. There is no systematic approach to solving technical problems in Afam I-V power station. Reliability improvement of Afam I-V power station must first and foremost be focused in tackling operational availability of the equipment. As a matter of fact, management of change process is required to capture, review, agree and implementasset integrity improvement programme in Afam I-V power station.

Availability of Afam VI power station hovers closely to the ASAI value of 95% as clearly shown in Fig.1. The plant has a structured maintenance policy and asset integrity management framework in line with Shell Global policy on asset integrity management. There is a well-structured competence and skill development programme for staff, which have also been extended to developingthe youths from the host communities around the power plant. Asset integrity management of Afam VI is structured in line with condition-based maintenance philosophy, infused with performance management palliatives, tailored to encourage total cost of ownership assurance. Consequently, it requires just little efforts to achieve and improve on asset availability in Afam VI power station.

The Delta power station also had similar issuesin Afam I-V power station but the only difference is that, Delta power station had fewer cases on turbine blade failures. Operations and maintenance staff incompetence was also glaring in Delta power plant when one considers the nature of failures, the MTBF and the MTTR of generator units. There is no clear indication that an effective maintenance organization is in place in Delta power station, designed and structured to implement operational excellence. Consequently, improving Utilisation of Delta power station must be focused on staff training and tackling equipment availability problems. There is need for good maintenance policy and preventive maintenance programme in Delta whereby all major failures must be subjected to root-cause-analysis and implementing remedial actions.

Availability of Egbin power station was at the threshold of the ASAI target of 95% in the first four years of this study until the year 2006, when ST6 had catastrophic failure from the boilers. This singular failure, incapacitated the generator unit for the eight and half years of this study. ST6 was rehabilitated and put back on service in January 2015. Boiler failures are very rampant on other generator units in Egbin power station. Consequently, there is need to constitute an interdisciplinary team to carry out root cause analysis in all boiler failures in the power plant with a view to reassessing maintenance requirements and critical opportunities that will enhance improved performance of the power station. Issues of wet gas, foiling turbine blades are also frequent and there is need to put a daily frontline checks and maintenanceof the gas scrubbers in the power plant. Operational challenges is hampered with frequent low gas pressure, and restrictions on the quantity of load synchronization onto the power grid. These are issues outside the control of the plant, but management should continuously engage service providers.

4.2 Performance On Capacity Factor Of The Four Power Stations

Using the fourteen years data on energy generation by the four power stations in Table13 and the annual ratings of the plants, the histograms in Figure 2 is generated. Fig.2 shows the actual quantity versus expected energy generated by each of the four power plants in fourteen years.Therefore the energy shortfall from the expected targets for the four thermal power stations are 61,014.96GWH, 17,173.28GWH, 74,476.43GWH and 81,931.56GWH for Afam I-V, Afam VI, Delta and Egbin power stations respectively. The combine energy generated by the four power plants is 151,497.35GWH out of an expected combined maximum of 386,093.58GWH of electric energy generation in the fourteen years of operations.

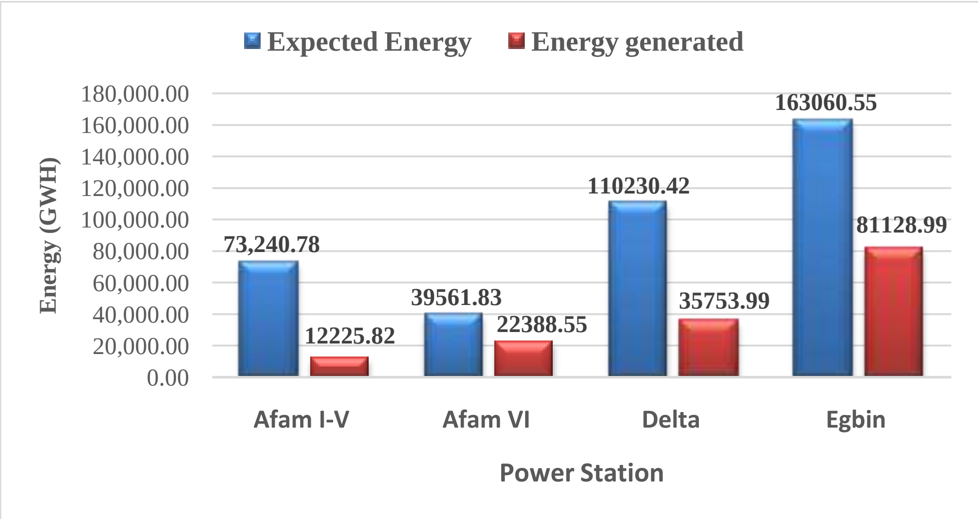

Figure2: expected and actual energy generated by the four power stations (2002-2015)

Using the evaluated data in Table 13 covering from 2002 to 2015, the graph in Fig.4 is generated.This graph captures the performance trends of the capacity factors of the four thermal power stations under study

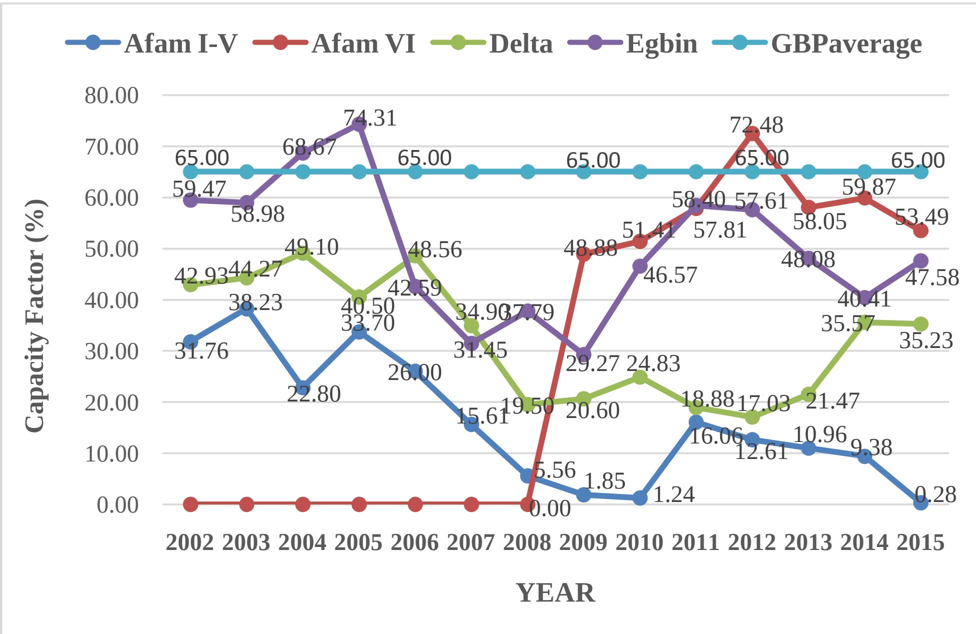

Figure 4: variation of capacity factor for the four power stations with year

The plant capacity factors obtained for the four thermal power plants varies from 0.28% to 38.23%, 13.89% to 72.48, 17.03% to 49.1%, and 29.27% to 74.31% for Afam I-V, Afam VI, Delta and Egbin power stations respectively. The fourteen years average capacity factors attained by Afam I-V, Delta and Egbin power station are 16.15%, 32.38% and 50.08% respectively, while Afam VI power station achieved a seven years average capacity factor of 57.43%.

The average capacity factors obtained by the four powers are all below global best practice average of 65% set as a benchmark for good performance in this study. It could be recalled that Afam VI and Egbin power stations had occasional restrictions on energy evacuation through the national power grid. It is obvious that with upgrade of the power transmission network and extra efforts on asset integrity implementation programs, Afam VI and Egbin power stations can achieve and surpass the target of 65% capacity factor. Low plant capacity factor is an indication of incessant generator failures whereas, high plant capacity factor is an indication of high ratio of power generation to the expected energy generation at the maximum rated capacity of the plant.

Upon analysis of the four power plants use factor, based on their annual ratings and actual hours theplants operated in those years, the shortfall from expected energy generation for Afam I-V, Afam VI, Delta and Egbin power stations are 71.56%, 31.085, 55% and 41.85% respectively. These shortfalls on targeted energy generation, are far higher than the average acceptable value between 5% and 10% [9].The major hindrance mitigating high use factor of the power plants is high unavailability of generation sets.

4.3 Commercial Availability Factor Of Generated Energy In The Four Power Stations (PCAF)

PCAF is defined in this study as the ratio of the total energy sent out in a year to the total energy generated in that year. This is a critical factor in Nigeria operating environment where power generation is grossly inadequate. Thus, this factor encourages diversion of as much energy generated for sales as possible, thereby improving revenue accruable to the power station. Using the evaluated data in Tables 14, the graph in Figure 5 is generated.

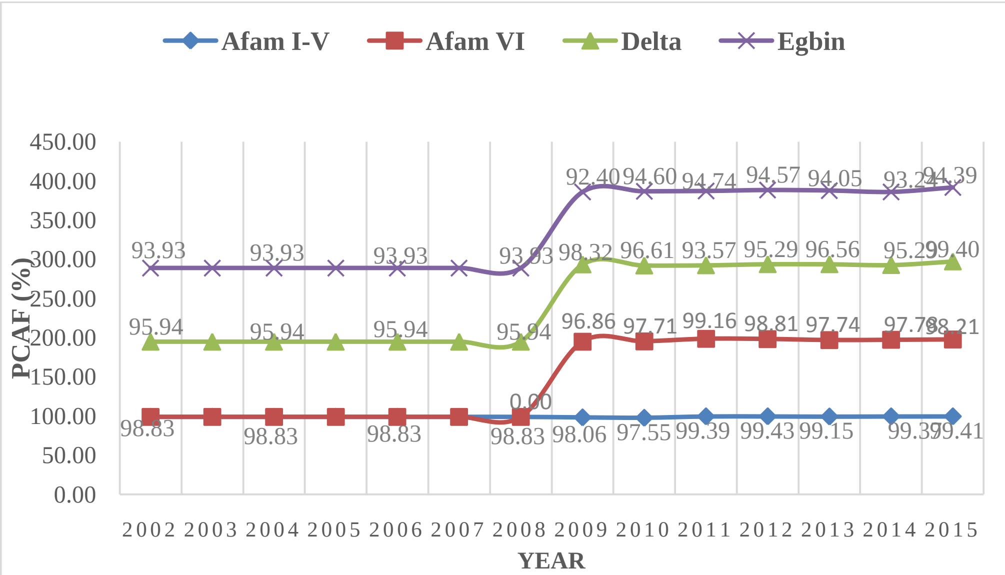

Figure 5: Variation of Commercial Availability Factor of the four Plants with year

Prior to the year 2009, the parameter, "Energy Sent Out" was been reported was been reported as a weighted value contributed by all the thermal power station connected to the national power grid.Reporting of energy sent out from individual power stationsstarted in 2009. Consequently, to estimate the energy sent from 2002 to 2008, the seven years average commercial availability factor of the annual generated energy by each power station have been applied. This is why variations from 2002 to 2008 in fig. 5 are flat. The commercial availability factors of the four power stations varies from 97.55% to 99.43%, 96.86% to 99.16%, 93.57% to 99.40% and 92,40% to 94.74% for Afam I-V, Afam VI, Delta and Egbin power stations respectively. The seven years average commercial availability factor covering from 2009 to 2015 for Afam I-V, Afam VI, Delta and Egbin power stations are 98.91%, 98.08%, 96.43% and 94.00% respectively.

Afam I-V power station came tops as the best performing plant on this parameter, closely followed by Afam VI power. Egbin had the lowest value but as earlier acknowledged, steam turbine power plants are bound to consume more energy within the plant than gas turbine stations. Egbin operated at the threshold of 95% set for steam turbine stations from 2010 to 2013. Delta power station only achieved the target in 2009 and needs extra efforts to improve on commercial availability.

4.6.4 Effective Utilisation Of The Four Power Stations

Effective asset Utilisation metrics is a tool that facilitates the setting of improvements targets for a given facility. It is not intended to be used for comparing the performances of the four power stations, as their equipment and technologies are not similar. Thus the product of the three minimum targets set for the three factors of effective asset utilisation gives a benchmark of 60.52% as the target for good performance for simple/combined cycle gas turbine power stations and 58.66% for steam turbine driven power plants in this study.

Using the evaluated fourteen years data in Table 15, the graph in Fig.6 is generated The trends in this graph reflects the variation ofeffective utilisation of assets in the four thermal power plants from 2002 to 2015.

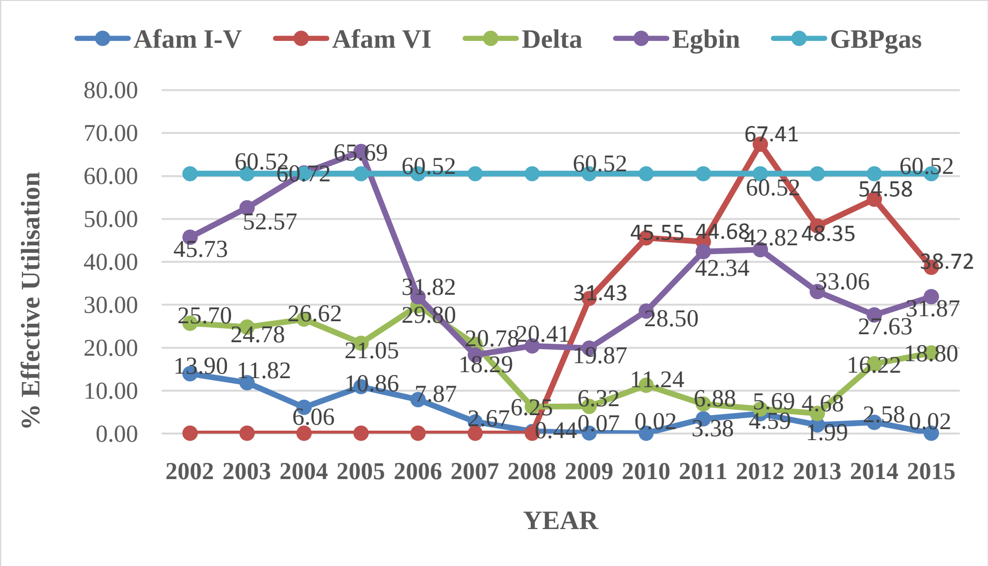

Figure 6: Variation of PEAU of the four Power Stations with year

Effective utilisation of Afam I-V power station in the fourteen years varied from 0.02% to 13.9% with an overall average performance of 3.52%. This is an underperformance that falls far short of the set target of 60.52% for this study. Availability factor is the major impediments against good performance in Afam I-V power station. Lack of strategic maintenance planning, poor organizational leadership, dearth of skilled and competent manpower are responsible for high unavailability of generator units in Afam I-V power station.

The effective utilisation of assets in Afam VI power station ranges from 31.43% to 67.41% with a seven years average value of 46.74%. Afam VI achieved above target in 2012 with 67.41% effective Utilisation. Though generator unavailability was a challenge, capacity factor was the major barrier that militated against effective utilisation of Afam VI power plant. The prominent loss event is the restrictions from NCC, limiting energy upload onto the national power grid, resulting to either retaining spinning reserves or putting generator units on standby in the power plant.

Delta power station achieved a fourteen years average of 14.88% effective utilisation of its facilities with a minimum value of 4.68% in 2013 and a maximum value of 29.80% in 2006. The performance of delta power plant in the fourteen years of this study is abysmal. Downtime losses are the major obstacles that militated against high effective utilisation of the assets in Delta power station. The obvious loss events leading to prolong downtime of generator units includes equipment breakdowns, poor leadership, lack of strategic maintenance planning, long lead time to procure spares and material management, dearth of competent and skilled work force.Special interdisciplinary team is required to rejuvenate asset integrity planning and implementationin Delta power station.

Effective utilisation of Egbin power station varies from 18.29% in 2007 to 65.69% in 2005, with a fourteen years average value of 36.13%. Egbin power station also performed below the 58.66% effective utilisation target set for steam turbine driven power stations. Egbin power station was well on course and even surpassed the target in 2005 before the failure of ST6, which grounded the generator unit for almost nine years. Egbin power station had both downtime and speed losses that contributed to its marginal performance on effective asset utilisation. Glaring downtime loss events that hampered plant availability includes equipment breakdowns, as recorded on ST6, maintenance planning and optimisation, spare parts shortages and fuel gas supply problems. Most prominent speed loss events are occasional restrictions of load synchronization onto the power gridby the NCC, operators' incompetence or inefficiency, equipment wear and tear.

V. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Yearly variations on effective utilisation of Afam I-V, Afam VI, Delta and Egbin power plants ranges from 0.02 to 13.9%, 31.43% to 67.41%, 4.68% to 29.8% and 18.29% to 65.69% respectively. The average effective utilisation of Afam I-V, Afam VI, Delta and Egbin power stations covering the period from 2002 to

2014 are 3.52%, 46.74%, 14.88% and 36.13% respectively. These values are lower than the minimum effective utilisationtarget of 58.66% set for steam turbine plants such as in Egbin power plant and 60.52% for simple/combined cycle turbine power plants, as in the three other power plants.

5.2 Recommendation

5.2.1 *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.*

5.2.2 *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.*

5.2.3 *Negligence or under-maintenance of equipment increases the risk of deterioration and failures and this calls for the need to develop and implement preventive maintenance programme for all the equipment in each power plant. Subsequently, establish condition-based maintenance by deploying diagnostics tools to conduct non-intrusive analysis of running equipment to facilitate timely interventions, so that abnormal conditions of generator units can be rectified promptly. Condition based maintenance (CBM) analysis such as acoustic emission, vibration analysis, ultrasonic sounding, oil fluid analysis, alignment and balancing, etc., helps to measure asset condition with a view to implementing predictive maintenance actions to safeguard asset reliability.*

5.2.4 *Administer autonomous maintenance for aging equipment so that the special care needed by such equipment is met. This is necessary because the condition of many generator units, especially in Afam I-V and Delta power plants have deteriorated due to neglect or improper administration of preventive maintenance.*

5.2.5 *Provide an effective supply chain management that will ensure the availability of essential and critical spare parts in line with service level expectations.*

5.2.6 *Imbibe the culture of Total Cost of Ownership by tracking maintenance costs to facilitate identification of equipment that gives the greatest return on investment over the life circle of the assets. This data is vital for optimising maintenance of the asset.*

REFERENCES

[1]. TCN (Transmission Company of Nigeria), Grid Operations: Annual Technical Report(National Control Centre, Osogbo: 2015).

[2]. Nigeria. ECN (Energy Commission of Nigeria), 60m Nigerians now on power generators. Available from: http://www.energy.gov.ng [Accessed 4th October 2010].

[3]. Taisir, O. and Almeanazel, R., Total Productive Maintenance Review and Overall Equipment Effectiveness Measurement, Jordan Journal of Mechanical and Industrial Engineering, 4(4), 2010, 517 – 522.

[4]. Vorne Industries, Increase Capacity: Measure Overall Equipment Effectiveness, Available at: http://www.vorne.com/inrease-manufacturing-production -capacity.htm#measure oee [Accessed 4thNovember 2016].

[5]. Reliability HotWire, Blueprint for a Comprehensive Reliability Program, Available at:

[6]. http://www.weibull.com/Articles/Relintro/index.htm, [Accessed 30th October 2016].

[7]. Bertling, L. and Erikson, R., A Reliability Centered Maintenance Method for Assessing the Impact of Maintenance in Power Distribution System, IEEE Transactions on Power Systems, 20(1), 2005, 23-46.

[8]. Curley G. M., Power Plant Performance Indices in New Market Environment: IEEE Standard 762 Working Group Activities and GADS Database, GADS Services, (NERC, New Jersey 2006).

[9]. Eti, M. C., Ogaji, S. O. T. and Probert, S. D., Reliability of the Afam Electric Power Generating Station, Nigeria, Applied Energy, Vol. 77(3), 2004, 309-315.

[10]. [9] Infrastructural Consortium for Africa (ICA), Regional power status in Africa power pool report, (Tunisia: Africa Development Bank, 2011), 11-12.