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ORIGINAL RESEARCH ARTICLE

PERFORMANCE AND ECONOMIC ANALYSIS OF KAINJI HYDROPOWER PLANT IN NIGERIA

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ABSTRACT

In this study, performance and economic evaluation of Kainji Hydropower Station in Nigeria from 2008 to 2017 was carried out. Data including total energy generated (MWh), station service consumption (MWh), total energy sent out to the grid (MWh), average inflow rate (m^3/s) and average gross operating head (m) were obtained from the efficiency department of the Hydropower station from the year 2008 to 2017. Mathematical models were used based on some key parameters which include: Capacity Factor, Plant Use Factor, Availability, Power Generated and Economic Cost of Outages and Operations. The result reveals that the average power generated within the period under review was 363.53MW, with a maximum of 476.95MW in 2010 and 292.44MW in 2014 as against the installed capacity of 760MW. The Capacity Factor of the plant was between 11.04% (2014) and 40.51% (2008) as against industry best practice of between 50% to 80%. The Plant Use Factor ranged between 38.48% in 2014 to 62.76% in 2010 as against acceptable value of 95% and above, while the plant availability hovers between 28.69% in 2015 and 91.26% in 2009 as against the recommended standard of 99.99%. The study further reveals that the revenue loss due to system downtime was ₦169,134,293,297. This revenue loss is about 66.82% of the revenue generated which is by no means a huge amount. The above values call for the need of a total overhaul of the generating plant in order to salvage the terrible state of these plants.

1.0 Introduction

In the Nigerian scenario of today, access to reliable and stable power supply has become a major source of concern for both urban and rural dwellers (Franco et al., 2017). This epileptic power supply in Nigeria has hindered both economic and industrial development. Enhancing the power generation capacity of the country has been the topmost priority of successive governments since 1999, even to the extent of declaring a state of emergency in the power sector in 2007 (Gbadamosi et al., 2015). In spite of all these rhetorics, the power generation is still very far from the country's energy demand (Sambo, 2008). This huge shortfall in energy supply is marginally being addressed with an inefficient and comparatively expensive means like using gasoline and diesel generating sets (Obodeh and Isaac, 2011). Electricity production in

Nigeria entails two major methods, namely hydro and thermal, these two methods are meant to complement each other in time of difficulties (Akorede et al., 2017). The hydropower is cheaper to run than the thermal and is expected to perform optimally during favorable season, while the thermal performs better at the other season when the water in the dams run down (Liao et al., 2015).

Successive Government Policies in Nigeria are geared towards building more thermal generating stations due to inadequate generation, without considering exploiting the hydropower potential source of the country, which is the oldest source of electric energy in commercial quantity (Osakwe, 2017), or even considering revamping the existing generating plant which are in a declining state. The performance analysis of Olorunsogo Thermal Power Plant using data covering 2013-2017 was done by (Okoye et al., 2017). The study showed that the performance of the plant fell short of international standard. Also, (Adegboyega and Famoriji, 2013) did a performance study on Edgeba Gas Turbine Power Plant. The outcome of their study is also not too far-fetched from other results obtained from previous studies. The performance evaluation of Egbin Thermal Power Plant for a period from 2000-2010 was studied by (Adegboyega and Odeyemi, 2011). Their result also reveals a short fall in performance of the plant. Performance analysis of some selected gas turbine plants which include Afam Power Plant, Ughelli Power Plant and AES Power Plant was again reviewed (Oyedepo et al., 2015). Their result revealed that the starting reliability of the plants are low compared to international standard. Evaluating the outage cost due to system downtime of Egbin Thermal Power Station was also investigated by (Emovon et al., 2011). In this study, performance and economic evaluation of Kainji Hydropower station, which is the first hydropower station with the highest installed capacity in Nigeria is presented.

1.1 Overview of Kainji Hydropower Station

Kainji Hydropower Station is the oldest Hydropower plant in Nigeria. Figure 1 shows the side view of the Hydropower dam. Kainji Dam is a dam across the Niger River in Niger state of Northern Nigeria (Madu, 2018). Construction of the dam was carried out by an Italian Civil Engineering Company in 1964 and was completed in 1968. The cost of the dam was estimated at $209 million, with one-quarter of this amount used to resettle the displaced people by the construction of the dam (Madu, 2018).The dam was designed to have a generating capacity of 960MW, however, only 8 of its 12 turbines have been installed, making the installed capacity to 760MW (Ajeigbe et al., 2013).

Figure 1: Side View of Kainji Hydropower Dam (Adegboyega and Famoriji, 2013)

2.0 Materials and Methods

2.1 Data Collection

Data for this study were obtained from the power station logbook and inventory records. Data collected include installed capacity of plant, total energy generated (MWh), station service consumption (MWh), total energy sent to the grid (MWh), average inflow rate (m^3/s) and average gross operating head (m) for the period between 2008-2017. Based on the data obtained, the plant installed capacity was found to be 760 MW, the total energy generated in MWh depreciated appreciably from 2008 to 2014, thereafter it appreciated significantly from 2016 to 2017; several factors could be held responsible for this significant improvement in power generated between 2016 and 2017, prominent factors among others could be as a result of well planned maintenance of equipment, replacement of ageing parts and management decision. The station service consumption showed a slight difference in the amount of energy consumed within the reviewed years. Also, similar trend was observed with amount of energy sent as compared to the amount of energy generated. A cursory look at the average inflow rate of water showed that the flow rate undulated within the reviewed years while the average gross operating head was observed to exhibit fairly constant values from 2008 to 2017.

Table 1: Data Obtained For Energy Profile of Kainji Hydropower Plant

Year	Installed Capacity of Plant (MW)	Total Energy Generated (MWh)	Station Service Consumption (MWh)	Total Energy Sent Out to Grid (MWh)	Ave. inflow rate (m^3/s)	Ave. Gross Operating Head (m)
2008	760	2,695,223	6,334	2,688,889	1,238	33.84
2009	760	2,505,663	6,819	2,498,844	1,182	31.80
2010	760	2,300,991	4,960	2,296,031	1,451	39.42
2011	760	1,769,060	6,144	1,762,916	1,118	34.46
2012	760	1,391,853	6,473	1,385,380	1,326	32.96
2013	760	935,868	5,602	930,266	1,256	34.48
2014	760	735,062	4,268	730,794	1,021	34.35
2015	760	1,602,378	6,511	1,595,867	1,233	34.55
2016	760	2,425,464	5,887	2,419,577	1,405	34.68
2017	760	2,697,307	6,235	2,691,072	1,376	

Source: (Kainji Power Station Logbook and Inventory Records, 2017)

2.2 Plant Performance Indices

In order to access the performance of the power station, some performance indices equations were used as follows:

Capacity Factor (CF): The CF of a plant is a measure of the usage of the generating plant. The plant's CF was determined using Equation (1) (Adegboyega and Famoriji, 2013).

$$\mathrm{CF} = \frac{\text{Energy generated in a given period}}{\text{Installed capacity of Plant} \times \text{number of hours in the given period}} \times 100\% \quad (1)$$

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Plant Use Factor (PUF): This is the ratio of the total energy generated during a given period to the product of plant rated capacity and number of operating hours of plant during a given period. The PUF was determined using Equation (2) (Adegboyega and Famoriji, 2013).

$$\mathrm{PUF} = \frac{\text{Total energy generated (MWh)}}{\text{Plant rated capacity}\times\text{number of operating hours}} \times 100\% \quad (2)$$

Availability (A): Availability is the probability that a power plant will be available as required or that it will be in a state of operational effectiveness within a given period. Availability is very important in achieving high performance. The availability of a plant was determined using Equation (3).

$$\mathrm{A} = \frac{\text{Operating hour}}{\text{expected running hours}} \times 100\% \quad (3)$$

Outage Cost: This is the amount lost as revenue due to system downtime. System outages could be either forced outage or planned outages which are both inevitable. The cost of outage was determined using Equation (4) (Emovon et al., 2011).

If;

$$\mathrm{P_f} = \frac{\text{Annual power generated (MW)}}{\text{Installed capacity of Plant (MW)}} \quad (4)$$

$$\mathrm{T_d} = \text{Expected operating hour} - \text{actual operating hour} \quad (5)$$

$$\text{Actual operating hours} = \frac{\text{Total energy generated (MWh)}}{\text{Annual Power generated (MW)}} \quad (6)$$

The annual expected operating hour was assumed to be 8760 hours, then the annual power outage was obtained by combining equations (4), (5) and (6);

$$\mathrm{C_C} = \mathrm{P_g} \times \mathrm{T_d} \times \mathrm{P_f} \times \mathrm{U_c} \quad (7)$$

Where: C_c=annual power outage cost, P_g=annual power generation (MW), P_f =annual power factor of plant and U_c=unit cost of energy (kWh). For the purpose of this study, U_c value is given as ₦27.2/kWh (as at 2017) from Power Holding Company of Nigeria (PHCN).

3.0 Results and Discussion

The economic and performance of Kainji Hydro Power station was investigated using capacitor factor, plant use factor, plant availability, annual power outage cost and generated revenue as performance metrics. Applying equations (1) to (7) to analyze the data obtained, the results obtained for each of the performance metric employed was presented in Table 2 yearly.

Table 2: Summary of Performance and Economic Analysis

Year	Power Generation (MW)	Capacity Factor (%)	Plant Use Factor (%)	Availability (%)	Annual Power Outage Cost (₦)	Generated Revenue (₦)
2008	349.33	40.48	45.96	88.07	4,562,500,791	33,696,822,324
2009	313.42	37.64	41.24	91.26	2,691,397,548	28,106,741,625
2010	476.95	34.56	62.76	55.07	32,041,336,936	39,277,351,672
2011	321.25	26.57	42.27	62.86	12,015,976,168	20,339,622,318
2012	364.43	20.91	47.95	43.60	23,484,867,938	18,153,791,442
2013	361.11	14.06	47.52	29.58	28,788,348,048	12,095,246,932
2014	292.44	11.04	38.48	28.69	19,119,257,034	7,693,424,572
2015	355.22	24.07	46.74	51.49	19,188,786,322	20,371,328,251
2016	406.30	36.43	53.46	68.15	16,485,232,823	5,269,028,002
2017	394.81	40.51	51.95	77.99	10,756,589,689	38,113,315,577

The plant full load installed capacity is 760MW, however, Table 2 showed that the generated power for the period under review ranges from 292.44MW to 476.95MW. A graphical illustration depicting how the generated power varies the selected years under review was as shown in Figure 2. This indicates a significant gap between installed capacity and actual power generated per year, which may be due to ageing equipment, seasonal variation in the volume of water coupled with poor maintenance culture. Also, for the period under review, this short fall in generation ranges from 61.5% to 37.2%, which is against acceptable values of from 5% to 10% (Obodeh and Isaac, 2011).

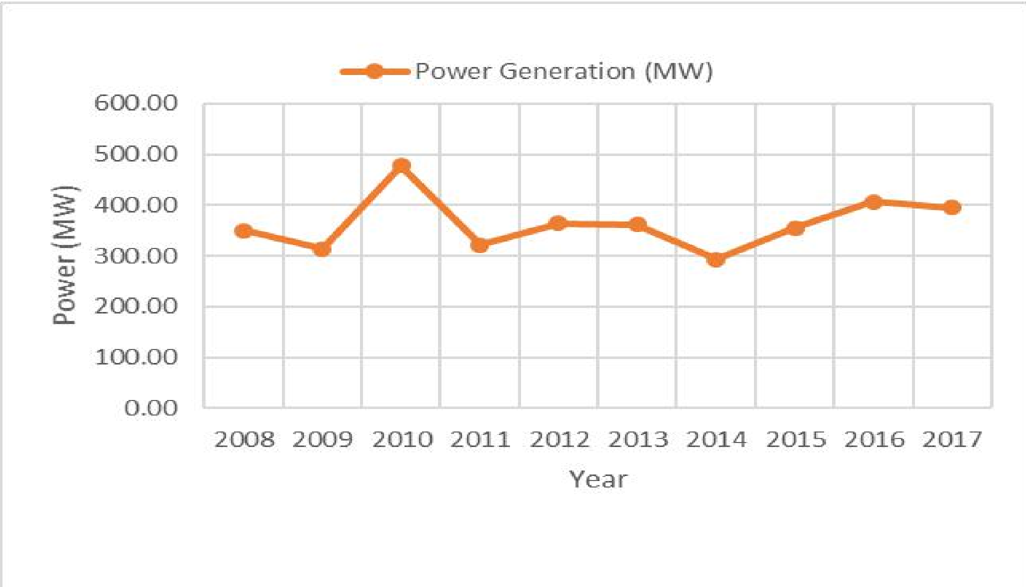

Figure 2: Power Generation from 2008-2017

The plant CF ranged from 11.04% to 40.51% for the period under review as shown in Figure 3. This is as against industrial best practice of from 50% to 80% (Oyedepo et al., 2015). Low value of CF is an indication of low energy generation and by economic implication, the accrued revenue will be appreciably less than operational cost. Notable among other factors that can be held accountable for low value of CF is recurrent plant failure; frequent plant failure most often caused under-utilization of the plant for major part of the year (Ekeh, 2008). It needs to be reiterated that high CF is beneficial and desirable for economic operation of the power plant and

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to sustain high CF value, scheduled routine maintenance should be encouraged, this will in no doubt reduce if not eliminate the occurrence of recurrent plant failure. Consequently, the above trend will be drastically improved (Akinbulire et al., 2007).

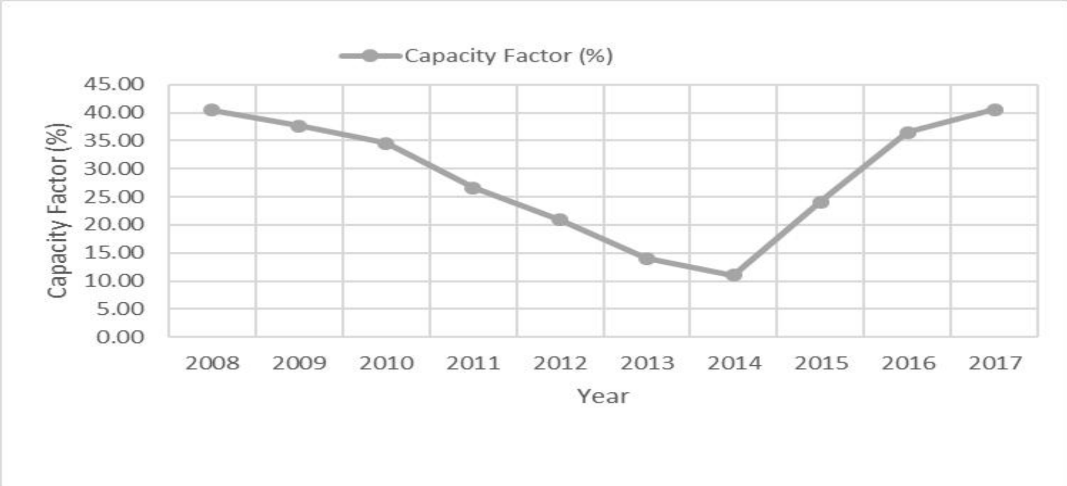

Figure 3: Capacity Factor from 2008-2017

Presented in Figure 4 is the plot of PUF values obtained against the reviewed years, it was observed that PUF ranges between 38.48% in 2014 to 62.76% in 2010, these values are comparatively lower as measured to the international standard of over 95% for hydropower station (Oyedepo et al., 2015). PUF indicates how the plant is well managed in terms of downtime. The ranges of the PUF for the period under review shows huge downtime which can be attributed to excessive plant failures most often caused by poor maintenance culture (Oyedepo et al., 2015).

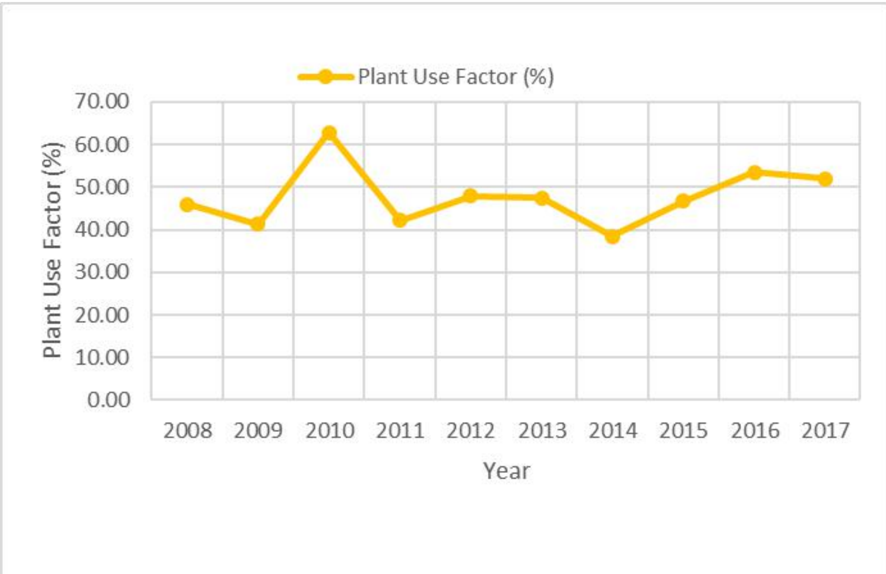

Figure 4: Plant Use Factor from 2008-2017

Figure 5 shows the plant availability for the period under review (2008-2017). It was found that the plant availability ranges from 28.69% in 2015 to 91.26% in 2009. These values of availabilities are against the recommended standard of 99.99% (Oyedepo et al., 2015). The poor plant availability is as a result of huge downtime which can be significantly improved upon by proper routine maintenance and personnel training on technical know-how knowledge (Chris et al., 2017).

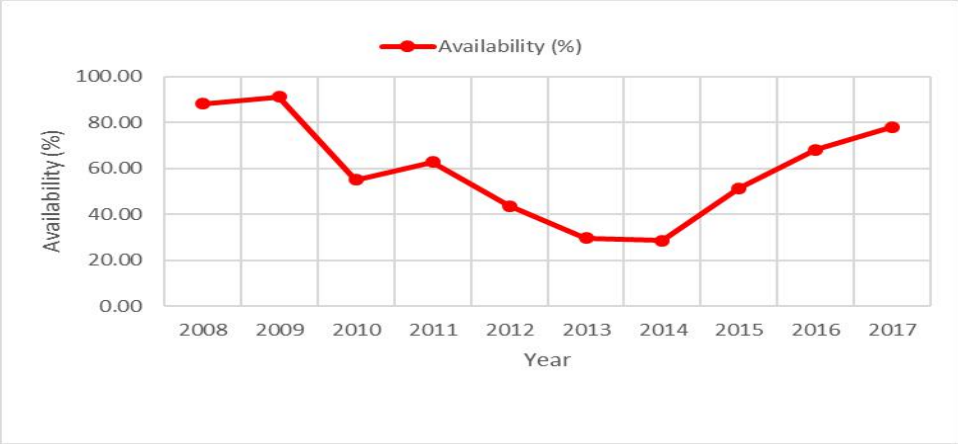

Figure 5: Availability of Plant from 2008-2017

Figure 6 shows the plant revenue loss and revenue generated from 2008-2017. The result revealed for the period under review, the total revenue generated was ₦253,116,672,716, while the total revenue loss due to system downtime was ₦169,134,293,297. The revenue loss is about 66.82% of revenue generated which is by no means a huge amount. The management of the power station should embark on routine preventive maintenance in order to mitigate this huge revenue loss to get good returns on their investment.

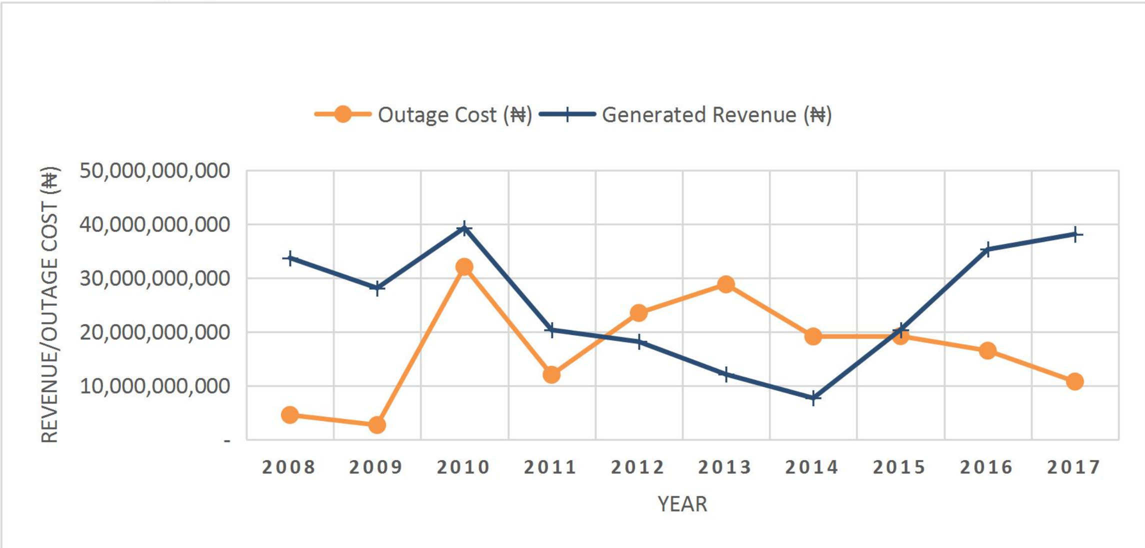

Figure 6: Cost Analysis of Plant

Furthermore, the study revealed that for the period under review, the plant cost of outage due to system downtime was ₦169,134,293,297, which is about 66.82% of revenue generated. The analysis carried out showed that the value obtained for the all the performance metrics revealed the deplorable state of the power station and as a matter of concern, the economic operation of the power station is far behind the standard. This is by no means a small value and an eye opener for the authorities concerned to do more by investing in the power plant in order to get good return on investment.

4.0 Conclusion

In this study, performance and economic analysis of Kainji Hydropower Station has been investigated with specific emphasis on some key parameter indices which includes: Capacity Factor, Plant Use Factor, Availability and Economic (Cost of outages and revenue generated)

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value of plant. The study revealed that for the period under review, the capacity factor ranges from 11.04% (2014) to 40.51% (2017) as against the acceptable value of 50%-80%. The plant use factor also ranges from 38.48% (2014) to 62.76% (2010) as against accepted value of 95% and above. Again, the availability of the plant ranges from 28.69% (2014) to 91.26% (2009), also against international best practices of 99.99%.

The above evaluated parameters for the plant are low compared to international best practice standard. These could be attributed to a number of reasons that may include poor maintenance culture, ageing equipment, lack of personnel training, lack of spare parts among others. This study therefore recommends that routine maintenance should be given priority, in addition staff training, particular on hands-on experience should be embraced routinely and most importantly, the ageing-equipment should be replaced according to the standard specification. If these suggestions are taken into consideration, system downtime, hazard to equipment and personnel will be drastically reduced, and plant's operational efficiency will be sustained.

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