**PERFORMANCE ASSESSMENT OF HYDROPOWER GENERATING PLANTS**

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**ABSTRACT**

This paper studies the performance of a hydropower scheme in Nigeria which contributes to an acute electricity supply and has effects on the country’s development. This does not only restrict the socioeconomic activities to basic human needs, but also adversely affects the quality of life too. The expected full load installed capacity for the hydropower scheme is 522.74MW but the generated capacity for the period under review is 305.147MW. Only about 40% of the installed capacity was available. Average Capacity factor for this hydropower scheme is 47%, min. of 25% in 2014 and max. of 83% in 2013 as against the industrial best practice of 50 – 80%. Total generation reduction due to downtime of the hydropower scheme is 28165773MWh amounting to 53% of the total installed capacity. Based on Power generation reduction of 53% the loss of revenue in naira was about 186 Billion naira. To improve the annual power generation, a complete overhauling of all the generators and adequate water management practice must be in place so that the available water can sustain generation throughout the year.

 **Keywords:** *Downtime, Running hour, Reduction, Capacity*

1. **INTRODUCTION**

The unreliability of public electricity supply in Nigeria is responsible to a large extent for the relatively low industrial development in the country. The Power Holding Company of Nigeria, (PHCN) the body that has the monopoly of power generation and distribution has been unable to effectively meet the electricity needs of the country according to Hart, (1992).

NEPA (as formerly called) as at June, 1992 had an installed capacity of about 600 megawatts from its eight major power stations. The maximum actual generating capacity of NEPA has however been about 3392.5 megawatts and this occurred around 15 March, 1992. This includes about 60 megawatts that is generated at Ajaokuta and other smaller stations. If this quantity is subtracted from the 3392.5 megawatts stated above, it means that only about 56% of the installed capacity is available for power generation from the major stations, (Hart, 1992). The problem of NEPA has been a long standing worry for everyone in the country but the situation seems to have defied all solutions. Before now, most of the reasons proffered for the continuing problem had not been looked at from the technical point of view according to Hart.

The prime mover of economic growth and development is energy. It is a major requirement in every home, offices and factories, therefore the issue of power generation is of utmost importance and the prosperity of any country is dependent upon the efficient and rational use of energy according to Akinbode, (2004). The world is currently experiencing a period of energy crisis of which Nigeria is not an exception. Nigeria as a country has been generating her own power for over one hundred years even right from the colonial era as noted by Akinbode, (2004). There has been a steady rising demand for energy needs in the country as a result of growth in population and infrastructural facilities. Coping with the rising demand of energy needs has been a great challenge to the agency that is responsible for generation of power in Nigeria, the Power Holding Company of Nigeria PHCN.

 ***1.1 Principle of Hydropower***

The controlling rule behind hydropower is the fundamental law of energy in which energy is neither created nor destroyed but can be changed from one form to another. The component includes the change from potential energy to kinetic energy of water. Whereas Potential energy is the energy contained in a body by virtue of height or position, the Kinetic energy of a body is the energy contained in the body by virtue of motion.

Water from the region, is either used directly as in ROR types or gathered in big reservoirs and made to keep running from higher height to lower rise through a penstock. The water turns a water turbine or wheel, and by means of a shaft connected to an electrical generator, produces power (Figure 1). The combination of the turbine and generator operations converts mechanical energy into electrical energy.

At a hydropower plant, Energy is created by the power of falling water unlike thermal plant; this power is created without the generation of gas emissions. The water used to deliver power is not consumed and can be accessed for different purposes downstream. Some Energy plants are situated on waterways, streams and trenches. As a rule, a dam is obliged to store water so it is dependably accessible when expected to create power and for different purposes. The reservoir can be likened to a battery which stores energy (water) to be used later.

At the point when the control doors are opened, the reservoir water goes into a pipe called the penstock. Water moving through the penstock can be controlled and specifically coordinated to one or more turbines to generate power. Hydropower producing units have four primary parts: a stator, a rotor, a turbine, and a shaft joining the turbine to the rotor. They are shown in Figure 1. Water falls through the penstock into the turbine. The wicket doors as seen in this figure permit the measure of water guided into the turbine to be varied. The magnitude of the falling water against the razor sharp edges of the turbine pivots a shaft connecting the rotor and turbine. The pivoting shaft turns the rotor or moving bit of the generator. The outside edge of the rotor is comprised of exceptionally solid electromagnets. These electromagnets are shaped by wrapping copper wires around a steel core (pole). These magnets are positioned in order to give north and south poles around the edge of the rotor.

The stator is the doughnut shaped structure encompassing the rotor. The key part of a stator is the stator conductors or winding. In a bigger generator, stator windings are comprised of coils made of numerous turns of copper wire which is a superb conductor of electrical energy. The development of the electromagnets in the rotor causes power to flow in the copper wires (conductors).

The turbine shaft is specifically connected to the rotor. As the turbine is turned by the power of the falling water, the rotor turns. The electromagnets on the edge of the rotor sweep over the stator thereby inducing electric current. By changing the quality and strength of the electromagnets in the rotor and varying the flow rate of water in the penstock, the voltage and power generation of the generator can be controlled.



**Figure 1**: Schematic diagram of a Generator and Turbine **Source: U.S. Army Corps of Engineers**

***1.2 Hydropower in the World***

The most important source of renewable energy for electrical power production in the world is Hydropower. The technically feasible hydro potential of the world is estimated as 14,371 Tera-Watt hour per year (TWh/year), which is equal to the global electricity demand today. Whereas the economically feasible proportion of this is 8,080 TWh/year. The exploited hydropower potential in the world in 1999 was 2,650 TWh which is about 19% of the world’s electricity according to Paish (2002).

In 2001, Canada was the world’s biggest producer of hydropower generating 350 TWh/year which is 13% of the global output. United States, Brazil, China and Russia are behind Canada in hydropower production.

 

**Figure 2:** Hydropower Productions and Economic Potential of some Countries

**Source: Paish (2002)**

As we move forward in the 21st century, global energy consumption is rising to record levels never anticipated in the past. Economic development in emerging countries and the worldwide increased dependency on electric devices drives this energy consumption further to an ever-increasing scale. Yet, the majority of our energy is derived from fossil fuels, that is, oil, gas and coal that are finite (i.e. non-renewable) resources on our planet. Thus, there is a great emphasis in today’s energy and technology research to increase and improve sustainable energy options. Many people think of renewable energy as solely solar or wind energy, however above 90% of all renewable energy worldwide actually Comes from hydropower production (International Hydropower Association [IHA], International Commission on Large Dams [ICOLD], International Energy Agency [IEA] & Canadian Hydropower Association [CHA], (2000). Hydropower is considered a renewable energy because it is based on the energy provided by the Sun that drives the hydrological cycle.

Many countries produce large shares of their total electricity generation with the energy derived from water. For example, Norway, Brazil and Venezuela produce 95.7 per cent, 83.8 per cent and 72.8 per cent, respectively, of their domestic electricity with hydropower (IEA, 2011). So too does Switzerland, with approximately 54 per cent of its electricity production coming from more than 550 large hydropower installations (Bundesamt fur Energie [BFE], 2012a). The remaining share is largely produced by nuclear power with approximately 41 per cent and other electricity sources with 5 per cent. However, due to the dramatic events of the nuclear disaster in Fukushima, Japan in March 2011, the Swiss energy policy has radically changed its course. After the event, the Swiss Federal Council decided that nuclear power production will no longer be part of the Swiss electricity supply mix and shall be phased out until 2034. Naturally, this means a great change for the Swiss electricity industry and it raises the issue of how to replace the base electricity supply, which is currently provided by nuclear power plants.

***1.3 Hydro-Electricity Potential in Nigeria***

World Bank Study (2001) of hydro-electricity potential in Nigeria revealed that hydro power could be tapped to supplement the coal fired plants as a source of electricity. Consequent upon this, the Kainji hydro-electric power station was built. However, it was discovered that the Kainji dam encountered a season of fluctuating water levels following draught in the Sahel region and damming of the waterways in neighboring countries. To address this problem, Government built two more hydro-electricity power stations at Jebba and Shiroro. This helped a great deal in raising the hydroelectric potential of the country but the problem of water level in River Niger affects electricity production from these hydro-electric plants.

1. **METHODOLOGY**

Data was collected from plant records. Information on the following parameters was used in the course of this study.

i. Gross Energy Generated (MW h).

ii. Running hours (h).

iii. Energy utilized by the plant (MW h).

iv. Energy delivered (MW h).

v. Installed capacity (MW) of the plant and the individual units.

**2.1 The Plant performance indices**

For the purpose of this study only the following Power Plant performance indices will be employed;

1. Plant capacity (PIC)
2. Plant factors (Load factor LF, Capacity factor CF, Utilization factor UF)
3. Efficiency of the plant

Other key performance indices employed in evaluating a plant’s performance are: Generation unit cost, water volume utilization efficiency, breakdown maintenance, staff productivity etc.

The Economic factor considered in this work is outage cost for the plant.

The plant performance indices used in this work are as follows;

**Plant Capacity (PC)**:

EPC $=$ PPC (MW) $×$ Running Hours (h) (1)

EPC = energy plant capacity,

PPC = power plant capacity.

**Capacity Factor (CF):**

CF = $\frac{E\_{p}}{C\_{in }× T\_{h}}$ (2)

$E\_{p}$ = total energy generated (MW h) in a given period,

$C\_{in }$= the installed capacity of the plant, and

$T\_{h}$ = the total hours of the year.

**Plant Use Factor (PUF):**

 PUF $= \frac{E\_{p}}{C\_{in }× T\_{Oh}} $ (3)

 $T\_{Oh}$ = total number of operating hours in the given period (one year).

**Load Factor (LF):**

LF = $\frac{L\_{av}}{L\_{md}}$ (4)

Where $L\_{av}$ is the average (demand) load generated and

$L\_{md}$ is the maximum (demand) load generated in a given period (one year).

Also, Load factor is given by;

$\frac{Total Energy Generated}{Available Capacity × Hours witin the period } ×100$ **(5)**

**Utilization Factor (UF):**

UF = $\frac{L\_{md}}{C\_{in}}$ (6)

**Generation unit cost**:

$\frac{Total Expenditure}{Total Energy delivered}$ (7)

Measured in naira per kilowatt hour

**Generation unit index:**

$\frac{Actual Generation}{Available Capacity} ×100$ (8)

**Capacity Utilization index:**

$\frac{ Available Capacity}{Installed Capacity} ×100$ (9)

**Water Volume utilization index:**

$\frac{Actual Generation}{Available Capacity} $ (10)

Measured in m3/MWh

**Energy utilised by the generating station:**

$\frac{Total Energy generated-Energy delivered }{Total Energy generated}×100 $ **(11)**

**Staff cost index:**

$\frac{ Total staff cost}{No. of employees}$ (12)

Measured in Naira per Head

**Staff productivity index:**

$\frac{ Energy delivered}{No. of employees}$ (13)

**2.2 Power Outage Cost**

Hydropower outage cost can be determined using the following equations;

$$P\_{T}=\sum\_{i=1}^{n}P\_{Ai}$$

 (14)

Where PT is the total power outage cost due to system downtime for n number of years and PA is the annual power outage cost for m number of units.

But,

$P\_{A}= P\_{R} × P\_{F} × C\_{U}$ (15)

$$P\_{R}=\sum\_{j=1}^{m}P\_{r}$$

 (16)

$P\_{A}= P\_{IC}- P\_{GC}$ (17)

$P\_{F}=\frac{\sum\_{}^{}G\_{C}}{\sum\_{}^{}I\_{C}}$ (18) Oyedepo *et al* (2014)

Where PR is the annual power generation reduction for m number of unit,

Pr is the annual power generation reduction for individual unit,

PIC is the annual installed energy capacity in MWh for individual units.

PGC is the annual generated energy capacity in MWh for individual units,

PF is the annual power factor for m number of units,

GC = generated power capacity in MW for individual units,

1. **RESULTS AND DISCUSSIONS**

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| **Table 2:** Total Energy generation from 2004-2014 |
| **Year** | **Actual Energy Generation (MWh)** |  |
| **Average Running Hours** | **Capacity Factor** |
| 2004 | 2878774 | 7808.248 | 0.52 |
| 2005 | 2586929 | 7808.248 | 0.45 |
| 2006 | 2366716 | 7304.106 | 0.43 |
| 2007 | 2816749 | 7377.249 | 0.51 |
| 2008 | 2695223 | 6632.087 | 0.49 |
| 2009 | 2505663 | 6961.706 | 0.52 |
| 2010 | 2300991 | 6478.8 | 0.48 |
| 2011 | 1769060 | 5682.557 | 0.37 |
| 2012 | 1392353 | 6420.172 | 0.34 |
| 2013 | 935868 | 7456.653 | 0.83 |
| 2014 | 735062 | 5389.286 | 0.25 |
| Ave | 2089399 | 6847.192 | 0.47 |

**Source: Fieldwork: 2015**

**Table 2:** Cost of power outage for the Hydropower plant scheme

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Year** | **Energy Plant Capacity (MWh)** | **Energy Generation Reduction (MWh)** | **Cost Of Power Outage** **(Naira)** | **% Power Reduction** | **% Power Available** |
| 2004 | 5529600 | 2650826 | 20262913940 | 49 | 52 |
| 2005 | 5529600 | 2942670.65 | 19465766350 | 53 | 47 |
| 2006 | 5529600 | 3162883.45 | 19992586290 | 57 | 43 |
| 2007 | 5529600 | 2712850.6 | 20338240950 | 49 | 51 |
| 2008 | 5529600 | 2834577 | 20417458130 | 51 | 49 |
| 2009 | 4838400 | 2332737 | 17831441630 | 48 | 52 |
| 2010 | 4838400 | 2537409 | 17903957923 | 52 | 48 |
| 2011 | 4838400 | 3069340 | 16694140260 | 63 | 37 |
| 2012 | 4147200 | 2754847 | 13768725310 | 66 | 34 |
| 2013 | 1123200 | 187332 | 11775111894 | 17 | 83 |
| 2014 | 2937600 | 2202539 | 8094330825 | 75 | 25 |
| Total | 50371200 | 28165773.7 | 186544673500 | Avg = 53 | 47 |

**Source: Fieldwork: 2015**

**Fig. 3:** Variation of capacity factor with year

**Fig. 4:** Power available vs. power reduction

**Fig. 5:** Energy Generation from 2004-2014

***3.1 Research Findings***

1. The expected full load installed capacity for the hydropower scheme is 522.74MW but the generated capacity for the period under review is 305.147MW. Only about 40% of the installed capacity was available. This is as a result of ageing generating facilities as seen in figure 5 showing that energy generation depletes over time.
2. The average Energy generated within the period under review is 2089399MWh at average running hours of 6847.19 hours. This is far from the installed capacity
3. Average Capacity factor for this hydropower scheme is 47%, min. of 25% in 2014 and max. of 83% in 2013 as against the industrial best practice of 50 – 80%. The low capacity factor of the plant in 2014 signifies that the average energy generation is low. Generally, low CF indicates frequent failure of the plant or inadequate water supply to boost the operating head of the station, which implies that the plant’s capacity for major parts of the year remains unutilized. If scheduled maintenance of the plant is significantly improved, the rate of failure will be minimized, the quantity of water in the reservoir will be judiciously utilized as against spilling of such water as a result of overflowing dams caused by unutilized amount of water in the dams. Thus, a higher capacity factor will be attained.
4. Load factor for the scheme varies from 25% to 83% with an average of 47%. This is low when compared with the international best practice of 80% (Abam et al, 2011). The load factor is an indication of the utilization of the power plant capacity.
5. Total generation reduction due to downtime of the hydropower scheme is 28165773MWh amounting to 53% of the total installed capacity.
6. Based on Power generation reduction of 53% the loss of revenue in naira was about 186 Billion naira.

1. **CONCLUSION**

This study has shown that the performance of this hydropower scheme is slightly below the international best practice standards, but offers an avenue for improvement.

The revenue loss as a result of power generation reduction from this study can be considerably reduced via improvement in the Plants operational practices and the general housekeeping of the plants, which includes overhauling of the plant at least at 25yrs intervals. Good water management practices should be implemented.

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