Power Generation Performance Analysis of a Hydropower Station in Nigeria

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Abstract:-**The paper examined the performance of power generation efforts at Shiroro hydropower station located in Nigeria since its establishment. Power generated for 26 years within its existence was used in this analysis. The autocorrelation function was also deployed in the development of an Auto-regressive model for futuristic prediction for planning and management of the power production system. The result showed the production trend across each month of the year, over these years and furthermore, the predictability of the power output. The R^2 value of 0.05 was obtained and MAPE of 11% of forecast. The developed model will be used in forecasting for power output from that power station. It also forms a useful information for willing investors in this area of investment and equally suggested ways for increased productivity.**

Keywords: **Hydroelectricity, Autocorrelation, Auto regression, Autocorrelation function.**

I. INTRODUCTION

The Nigerian power sector is bedeviled with epileptic supply and inconsistencies in various planning programs. This development has led to the nation's lowest ranking in net electricity generation per capita rate in the world. Despite various reforms instituted by different government and agencies, sustainability and reliability are yet to be achieved. Joseph (2014), presented the problems of incessant power outages as well as the adverse effects it has on the economy, and equally suggested measures to improve performance, he noted that the privatization of the energy sector when properly organized will achieve the industrialization clamour of the nation. The recent privatization efforts by government in November 2013, has opened up the electricity market to teaming investors with a view to ensuring system improvement and competitiveness. The dividends of this initiative are yet to unfold in full with the energy crisis still being experiencednearly 5 years after.

Nigeria's power generating stations range from three hydro and seven thermal generating stations situated in in various parts of the country as at 2010. The total installed capacity of all the generating stations put together is about 6,852MW, of which available capacity is only 3,542MW. Recently, plans are also ongoing to increase the nation's power capacity to 20,000MW by 2020. Several independent power programs (IPPs) are currently under construction to achieve this, which already has an estimated 1600MW contribution to the national grid.

The hydropower sector is also not left out in this targeted growth and development, as the Zungeru and Mambilla hydropower plants are also undergoing speedy construction to ensure timely completion, with over 6000MW combined energy capacity when fully on stream. Remarkable efforts in funding, equipment procurement, and manpower development have been made towards power improvement programs within the country. However, despite all these efforts made over the years, power supply in Nigeria has remained a mirage to many homes and industries.

Inadequate planning to harness the various power potential of the country has contributed greatly to this lacuna or shortfall in energy supply being experienced, besides other obvious daunting challenges of distribution, vandalization, unmetered consumption etc.

Generating stations are an integral part of the entire power system chain in the country, as their optimal performance and reliability is key to the sustainability of the power industry. Furthermore, the reliability of these stations is a function of the generating units within the station. Adequate planning based on informed assessment of the generating capacities of generating stations/units is a prelude to power system improvement for futuristic operations. These predictions are aimed at meeting the growing consumer demand and furthermore identify areas for improvements while also guiding energy managers in making informed decisions.

II. SHIRORO HYDROPOWER STATION

Shiroro hydropower station was established in 1990 with an estimated capacity of 600MW. The hydropower plant which is also known as Shiroro dam reservoir is situated in the Shiroro Gorge on the Kaduna River, approximately 60 km from Minna, the capital of Niger State, which is in close proximity to Abuja, Nigeria's federal capital. The reservoir is filled by streams from coastal highlands in the lower Niger valley and the plateaus in the North. The dam reservoir surface area is 320km^2, lake widest cross-section of 17km whereas the lake length is 32km.

The maximum Pool Elevation is 382.2m and operational Maximum Reservoir Elevation is 382m, while Crest

Maximum Elevation is 385m. The minimum Lake Elevation is 357m and Normal Maximum Tail Race Elevation is 271.3m. Its Normal Minimum Tailrace Elevation is 269.8m, while the length of Dam is 700m with Spillway Discharge Capacity of 7,500m^3/sec.

Also, the dam's Total Storage is 6.0000 x10^{9}m^{3,} whereas Maximum Usable Storage is 4.600 x 10^9 m^3. Thus the hydropower station has continued to provide electricity over the years since its construction.

III. REVIEW OF PAST LITERATURE

Ramani and Rom (2007), noted that numerous researchers adopted variant methods in the control of unpredicted and non-deterministic nature of hydraulic parameters. The need for testing and evaluating the performance of hydropower plants according to Verma and Kurma (2017), are because of the following problems: the involvement of subcontractors with no domain in design, construction or installation of hydropower plants; the replacement of established manufacturers with newcomer equipment suppliers without much experience; non-transparent contractual relationships between the plant owner, designer, contractor and supplier; and unavailability of standards and guide-lines prepared for and addressing the issues related to hydropower plants.

In their work, Zoby and Yanagihara (2009), observed that power plants have particular control systems to ensure stable operation, as the satisfactory operation of a power system requires a frequency control that keeps it within acceptable limits when the system is submitted to significant load variation. They pointed out that this is because the electric network frequency is common to all the system, a change on the active power at one point will be reflected on the net as a frequency variation, as the design of proper control systems for hydraulic turbines remains a challenging and important problem due to the nonlinear plant characteristics, increasing number of interconnections, development of large generating units and big load changes and disturbances.

However, Priya darshana (2014), explained that in order to enhance small hydro power plant efficiency it is very important to conduct both absolute and relative efficiency tests of hydro turbines, as it is invariably in the best interest of a power plant to have the efficiency of its hydraulic turbines to measure at the start of operation and subsequently at regular intervals. He noted that normally large type turbines performance is determined initially in model test and consequently absolute installation and testing, as during the efficiency testing of the turbine it's normally tested whether the manufacturer recommended performance have been met, and checking for the adjustments of blades and gate mechanism as well as the hydraulic governor.

In their research, Feng et al (2013),highlighted that hydraulic turbines' stage efficiency is the ratio between turbine shaft power and water power, and that considering the difficulty in measuring the turbine shaft power, the efficiency of the hydraulic turbine units can be calculated out by applying the same method as that in the prototype efficiency experiment, and then the efficiency of hydraulic turbines can be producedby converting and calculating the characteristic efficiency curve of the turbine power generator.

Jarry-Bolduc, and Cote (2014), explained that to measure the turbine and generator efficiency, the mechanical energy at the inputof the turbine and the electrical power at the output of the generator have to be determined. Also, they noted that to measure water discharge (flow) entering the turbine, several techniques can be used, such as current-meter, acoustic, thermodynamic, and pressure-time methods, and that each method requires a particular instrumentation and has its advantages and disadvantages depending mainly on the power plant configuration.

IV. METHODOLOGY

The research design adopted yearly readings of power output data from Shiroro hydro power station into a univariate data for this analysis. The model approach was applied to 26 year energy output from Shiroro dam. A 26 year lagged series (k = 1, 2,…5), was structured. The Auto Correlation Function Coefficient was used to develop a model for a time series by establishing a transfer relation of the form;

$By_t = y_{t-1}$

Where B = transfer function

$$r_k = \frac{\sum_{t=1}^{T=k} (y - \hat{y})(y_{t-k} - \hat{y})}{\sum_{t=1}^{t=T} (y_t - \hat{y})^2} \qquad (1)$$

Where y_t = Time series

ŷ = Average value of the time series

k= the lag

$$y_{t-k} = observation\ k\ lags\ behind\ by\ k$$

Table 1: Lags for k = 1 to k = 5

k/t	Y_t	Y_{t-1}	Y_{t-2}	Y_{t-3}	Y_{t-4}	Y_{t-5}
1991	166429.58					
1992	191666.83	166429.58				

1993	176663.08	191666.83	166429.58			
1994	170661.67	176663.08	191666.83	166429.58		
1995	162068.75	170661.67	176663.08	191666.83	166429.58	
1996	171548.92	162068.75	170661.67	176663.08	191666.83	166429.58
1997	185837.00	171548.92	162068.75	170661.67	176663.08	191666.83
1998	194767.92	185837.00	171548.92	162068.75	170661.67	176663.08
1999	188540.17	194767.92	185837.00	171548.92	162068.75	170661.67
2000	185805.92	188540.17	194767.92	185837.00	171548.92	162068.75
2001	222933.42	185805.92	188540.17	194767.92	185837.00	171548.92
2002	183245.33	222933.42	185805.92	188540.17	194767.92	185837.00
2003	211569.50	183245.33	222933.42	185805.92	188540.17	194767.92
2004	202135.75	211569.50	183245.33	222933.42	185805.92	188540.17
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
2013	207136.17	222052.50	197832.75	201759.67	190174.92	161778.67
2014	173167.08	207136.17	222052.50	197832.75	201759.67	190174.92
2015	153696.17	173167.08	207136.17	222052.50	197832.75	201759.67
2016	223979.17	153696.17	173167.08	207136.17	222052.50	197832.75

In determining the Autocorrelation function (ACF), the correlelogram plot below suggested the most influential lag for Autoregression model to be developed.

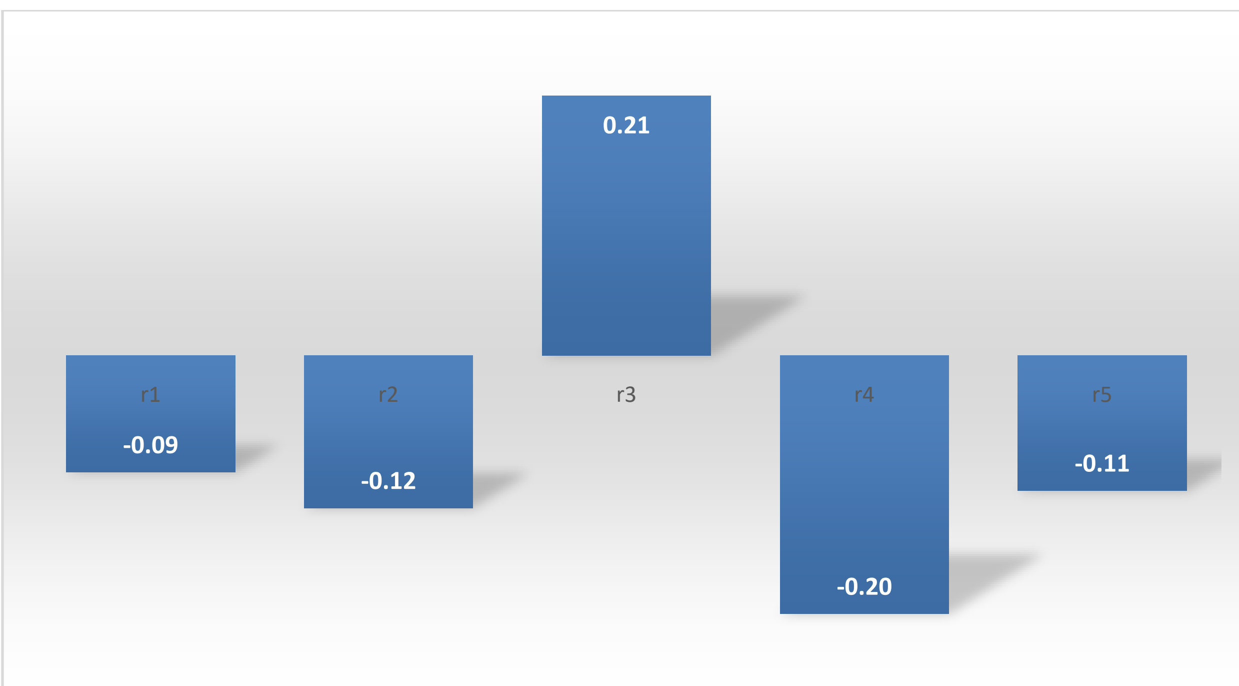

Fig 1: Correlelogram or Serpentine function graph

As shown in the Correlelogram plot in the figure above, r_3 ranked as highest candidate lag variable that will be admitted into the Autoregressive model.

Therefore, the lag y_{t-3} will be chosen for the first order regression model. In other words,

$$\hat{y} = \beta_0 + \beta_1 y_{t-3} \quad (2)$$

Substituting for $y_{t-3} = x_3$ to give;

$$\hat{y} = \beta_0 + \beta_1 x_3 \quad (3)$$

The above equation is similar with the straight line equation viz:

$$y = a + bx \quad (4)$$

Table 2: Derived table from Autocorrelation Function

year	Y_t	Y_{t-3}	$(Y_{t-3})^2$	$(y_t)*(Y_{t-3})$
1994	170661.67	166429.58	27698806209	28403150074
1995	162068.75	191666.83	36736175000	31063204095
1996	171548.92	176663.08	31209845013	30306360561
1997	185837.00	170661.67	29125404469	31715252148
1998	194767.92	162068.75	26266279727	31565792794
1999	188540.17	171548.92	29429030810	32343861340
2000	185805.92	185837.00	34535390569	34529614136
2001	222933.42	194767.92	37934541363	43420277120
2002	183245.33	188540.17	35547394447	34549105688
2003	211569.50	185805.92	34523838668	39310864886
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
2012	222052.50	190174.92	36166498929	42228815683
2013	207136.17	201759.67	40706963093	41791723941
2014	173167.08	197832.75	39137796973	34258120305
2015	153696.17	222052.50	49307312756	34128618049
2016	223979.17	207136.17	42905391541	46394185997

Recall also that for linear regression:

$$b = \frac{n\sum x_3 y_t - \left(\sum x_3\right)\left(\sum y_t\right)}{n\sum x_3^{\ 2} - \left(\sum x_3\right)^2} \quad (5)$$

Substituting the values of a and b in equation (4), the Autoregressive model is as shown:

$$\hat{\mathbf{y}} = \mathbf{141511.3 + 0.2444 y_{t-3}}$$

Model Fitting and Diagnostic

Table 3 shows the outcome of the model, when fitted to the yearly power output.

Table 3: Table of Forecast outcome

Y	Ŷ	e_t	$/e_t/$	e_t^2	$P\varepsilon_t$	σ_t	σ_t^2
170661.67	182186.72	-11525.06	11525.06	132826900.47	7%	-16395.50	268812529.55
162068.75	188354.71	-26285.96	26285.96	690951731.45	16%	-24988.42	624421134.10
171548.92	184687.79	-13138.87	13138.87	172630028.18	8%	-15508.25	240505921.45
185837.00	183221.04	2615.96	2615.96	6843225.91	1%	-1220.17	1488814.83
194767.92	181120.93	13646.98	13646.98	186240149.53	7%	7710.75	59455614.16

188540.17	183437.89	5102.28	5102.28	26033247.11	3%	1483.00	2199279.11
185805.92	186929.9	-1123.98	1123.98	1263334.82	1%	-1251.25	1565634.90
222933.42	189112.62	33820.80	33820.80	1143846551.72	15%	35876.25	1287105074.89
183245.33	187590.55	-4345.22	4345.22	18880932.19	2%	-3811.84	14530098.77
211569.50	186922.3	24647.20	24647.20	607484390.22	12%	24512.33	600854322.03
202135.75	195996.27	6139.48	6139.48	37693218.64	3%	15078.58	227363574.82
103006.75	186296.49	-83289.74	83289.74	6937181541.90	81%	-84050.42	7064473102.18
202720.00	193218.93	9501.07	9501.07	90270402.03	5%	15662.83	245324243.61
185896.75	186944.5	-1047.75	1047.75	1097782.70	1%	-1160.42	1346574.58
161778.67	166686.17	-4907.50	4907.50	24083583.11	3%	-25278.50	639002730.77
190174.92	191056.11	-881.19	-881.19	776496.01	0%	3117.75	9720344.28
201759.67	186944.5	14815.17	14815.17	219489126.07	7%	14702.50	216163408.23
197832.75	181050.04	16782.71	16782.71	281659453.00	8%	10775.58	116113124.34
222052.50	187990.09	34062.41	34062.41	1160248046.80	15%	34995.33	1224673121.81
207136.17	190821.4	16314.77	16314.77	266171574.64	8%	20079.00	403166107.14
173167.08	189861.66	-16694.58	16694.58	278708954.91	10%	-13890.09	192934507.61
153696.17	195780.97	-42084.81	42084.81	1771130964.06	27%	-33361.00	1112956543.41
223979.17	192135.42	31843.75	31843.75	1014024281.08	14%	36922.00	1363233837.85
				MAPE	**11%**		

Test for model adequacy

Arising from the outcome of table 3, it has become imperative to test for adequacy of model as a predictive tool.

The coefficient of determination (R^2) is given by

$$R^2 = 1 - \frac{\left[\sum \left(y_i - \ddot{\mathrm{y}}\right)^2\right]}{\left[\sum \left(y_i - \bar{\mathrm{y}}\right)^2\right]} = 0.05 \qquad (6)$$

Furthermore the coefficient of correlation (R) is given as

$$R = \sqrt{R^2} = 0.23 \qquad (7)$$

V. CONCLUSION

The AR Model developed can be used to predict the energy output of Shiroro hydropower station. This model considered previous yearly performances of that power station in arriving at this. The beauty of the AR model is that they can be used to predict both past and future energy output. Other areas of time series research interest have been opened by these outcome to ensure reduction in error margin and the moderate measure of association between the two variables. This informative exposé will guide the energy managers in their various planning programs aimed at stabilizing power output and capacity building of power stations for overall energy sustainability in the country. Nigeria as a nation will benefit from this outcome in a bid to tackle the energy crisis currently being experienced.

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