The Application of Autoregressive Integrated Moving Average Approach to Modelling Hydrological Data for Power Planning in Nigeria

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Abstract: **- The inability of various efforts of government to curb the energy crisis being experienced in the country can be attributed to inadequate planning for the various power stations. This paper, therefore seeks to develop a model to enable the successful forecast of available water for power generation, in Shiroro hydropower station in Niger state, Nigeria. The Autoregressive Integrated Moving Average was applied to a ten year hydrological time series record. The monthly daily average of headwater elevation necessary for power production, was computed across the years, for this station. 100 and 20 of these observations were used in training and testing respectively, in this analysis. The result showed the Mean Percentage Error, Mean Absolute Percentage Error and Root Mean Square Error of 14.20%, 134.43% and 0.38 respectively. The R^2 and Rof 0.99 and 1.00 respectively, were also obtained. The model developed will enable energy planners in the assessment of the energy capabilities of the hydropower station, based on available water, as well as for proper planning.**

Keywords: **hydro-electricity, power station, dam, auto-correlation, auto-regression, auto-correlation 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. According to Ezeanyim, Okpala, and Agu (2018), inadequate planning to harness the variouspower potential of the countryhas contributed greatly to this lacuna or shortfall in energy supply being experienced, besides other obvious daunting challenges of distribution, vandalization, and unmetered consumption.

Joseph (2014), proposed several measures for power sustainability, through privatization to achieve the industrialization clamour of the state, Nigeria. He chronologically presented the problems therein and equally suggested measures to improve performance. 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 experienced today, nearly 5 years down the line.

Nigeria's power generating stations range from three hydro and seven thermal generating stations situated in various parts of the country as at 2010. The total installed capacity of all put together is about 6,852MW, of which available capacity is 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.

II. THE HYDRO-POWER SECTOR

The hydro-power sector is also not left out in this targeted growth and development. The Zungeru and Mambilla hydro-power plant are also undergoing speedy construction to ensure timely completion with over 6000MW combined energy capacity when 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 power supply in Nigeria, has remained a mirage to many homes as well as industries. Inadequate planning to harness the various power potential of the country, has contributed greatly to this lacuna or shortfall in supply being experienced, besides other obvious daunting challenges of distribution, vandalization, unmetered households etc.

Generating stations are an integral part of the entire power system chain in the country. 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 of the generating capacity of these generating units is a prelude to system improvement, for futuristic operations. This prediction is aimed at meeting the growing consumers' demand, and further more identify areas for improvements.

Shiroro hydro-power station was established in 1990 with an estimated capacity of 600MW. The Shiroro dam reservoir is located in River Kaduna, Nigeria. The hydro-power plant is situated in the Shiroro Gorge on the Kaduna River, approximately 60 km from Minna, capital of Niger State, 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 Shiroro 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. Minimum Lake Elevation is 357m and Normal Maximum Tail Race Elevation is 271.3m. Normal Minimum Tailrace Elevation is 269.8m. Length of Dam is 700m while Spillway Discharge Capacity is 7,500m^3/sec. The total Storage is 6.0000 x10^{9}m^{3,} whereas Maximum Usable Storage is 4.600 x 10^9 m^3. This hydro-power station has continued to produce electricity over the years since its construction.

Various scholarly works have adopted different methods for the control of unpredicted and non-deterministic nature of hydraulic parameters as opined by Ramani and Rom (2007). According to Kishor, Saini and Singh (2007), adequate regulation of turbine poses greater challenge in control system in hydro-power station. They further recommended that there is a need for an advanced modeling and control technique for more effective control. A simplified algorithm was developed by Abbas, Saleem and Ali (2011),using Fuzzy logic approach which classified water level, flow rate, release valve and drain valve control, as input and output parameters.

Masden *et al*, (2009), noted that coupled hydrological and hydraulic simulation models, with numerical optimization algorithm is an effective tool for reservoir optimization by different management objectives. However, Vieira and Ramos (2009), applied linear programming and MATLAB in a water system of a pumping station. This influenced the choice of this approach to forecast for a dam or power station. This approach adopted the power output into a univariate data for this analysis.

The daily monthly average of headwater elevation readings required for energy output were chosen to ensure a better representation of all samples within population. Also, data span of 8 years, (2007 – 2014) a total of 96 months, ensured variability and changes in trend, were equally captured. This approach will further develop an operating model base to enhance productivity, planning and forecasting efforts, in order to meet consumer and industrial needs.

Carles (2015), considered anthropogenic and climate conditions in reservoir construction while Brett *et al* (2004), tried to forecast reservoir thermal conditions by employing one dimensional thermal model to stimulate the thermal effect of a new dam. Petras (2011), applied geographic information system (GIS) software to predict energy output of a hydro-station, using head and flow duration data that gives the time variability of water discharge. However, Ifabiyi (2011b), compiled a gamut of variables in hydro dam operation using multiple regression, factor step-wise regression method, and factor analysis in the Jebba hydro-station's power output.

Abdulkadir (2013), admitted that efficient management of hydropower reservoir variables is apt and used multilayer perceptron neural network to model other key variables across two hydro-power dams. Suleman (2014), emphasized the efficient reservoir operation and management for operational decision making by arraying of hydro-meteorological elements within the dam area using statistical analysis of correlation and regression analysis to determine the spatio-temporal trend. Also, the need for efficient interplay between reservoir elements for sustainable power development of hydro dam capacities was stressed by Ifabiyi (2011a),using descriptive and inferential statistics within the array of identified elements, by Principal Component Analysis (PCA).

III. MATERIALS AND METHODS

The research design modified yearly readings of headwater elevation information for power production from Shiroro hydro-power station into daily monthly average data for univariate data analysis. The model approach was applied to an eight year (96 months) hydrological data from Shiroro dam. A 96 month lagged series (k = 1, 2,…24) 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

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

Where y_t = Time series

ŷ = Average value of the time series

k= the lag

y_{t-k} = Observation k lags behind by k.

In determining the Auto-Correlation Function (ACF), the correlelogram plot or sample Auto-correlation Function as shown in figure 1, suggested the most influential lag for Auto-regression model to be developed. The Sample Partial Auto-correlation function was also determined as shown in fig 2. The Minitab software enabled the computation for ACF and PACF as shown in figures 1 and 2.

Table 1: Average Monthly input for 2007- 2016

Day	Ave. Monthly. HWE	Diff. Ave. HWE	Day	Ave. Monthly. HWE	Diff. Ave. HWE	Day	Ave. Monthly. HWE	Diff. Ave. HWE	Day	Ave. Monthly. HWE	Diff. Ave. HWE
1	374.26		31	355.44	-0.11	61	370.22	3.54	91	359.23	-1.54
2	370.09	4.17	32	364.62	-9.17	62	366.14	4.08	92	361.81	-2.58
3	365.86	4.23	33	378.60	-13.98	63	360.86	5.29	93	370.80	-8.99
4	362.86	3.00	34	381.84	-3.24	64	358.02	2.83	94	377.31	-6.51
5	361.05	1.82	35	381.78	0.06	65	357.16	0.86	95	377.04	0.27
6	359.37	1.68	36	379.50	2.28	66	358.95	-1.79	96	374.40	2.63
7	359.67	-0.30	37	376.75	2.75	67	361.87	-2.92	97	370.75	3.65
8	366.46	-6.79	38	373.54	3.21	68	371.11	-9.24	98	366.34	4.41
9	377.51	-11.04	39	369.76	3.78	69	380.92	-9.81	99	361.99	4.35
10	379.15	-1.64	40	365.29	4.48	70	382.15	-1.23	100	358.63	3.36
11	377.21	1.94	41	362.98	2.31	71	380.93	1.21	101	356.19	2.44
12	374.69	2.52	42	361.61	1.37	72	378.48	2.45	102	356.65	-0.46
13	376.62	-1.93	43	361.82	-0.21	73	375.42	3.06	103	358.21	-1.56
14	369.55	7.08	44	369.03	-7.22	74	372.49	2.94	104	370.81	-12.60
15	366.00	3.55	45	379.97	-10.93	75	368.95	3.54	105	380.84	-10.03
16	362.28	3.71	46	382.30	-2.33	76	363.59	5.36	106	382.24	-1.40
17	358.25	4.03	47	381.99	0.31	77	358.24	5.34	107	380.59	1.65
18	358.74	-0.49	48	380.26	1.74	78	356.81	1.44	108	377.45	3.14
19	358.55	0.19	49	377.95	2.31	79	361.36	-4.55	109	373.98	3.48
20	368.14	-9.59	50	375.76	2.18	80	365.23	-3.87	110	370.28	3.70
21	377.98	-9.84	51	371.96	3.81	81	375.27	-10.04	111	365.43	4.85
22	380.42	-2.45	52	365.99	5.97	82	379.39	-4.12	112	359.02	6.41
23	378.86	1.57	53	358.81	7.18	83	377.69	1.70	113	356.78	2.24
24	376.62	2.23	54	357.31	1.50	84	374.98	2.71	114	359.41	-2.63
25	373.84	2.78	55	358.42	-1.11	85	371.50	3.49	115	362.42	-3.00
26	370.85	2.99	56	361.37	-2.95	86	367.24	4.25	116	369.36	-6.94
27	367.48	3.37	57	371.22	-9.85	87	362.55	4.69	117	377.77	-8.41
28	363.24	4.24	58	377.35	-6.13	88	359.29	3.26	118	382.08	-4.31
29	358.61	4.62	59	376.56	0.79	89	358.78	0.50	119	380.17	1.91
30	355.33	3.28	60	373.76	2.79	90	357.69	1.10	120	377.20	2.97

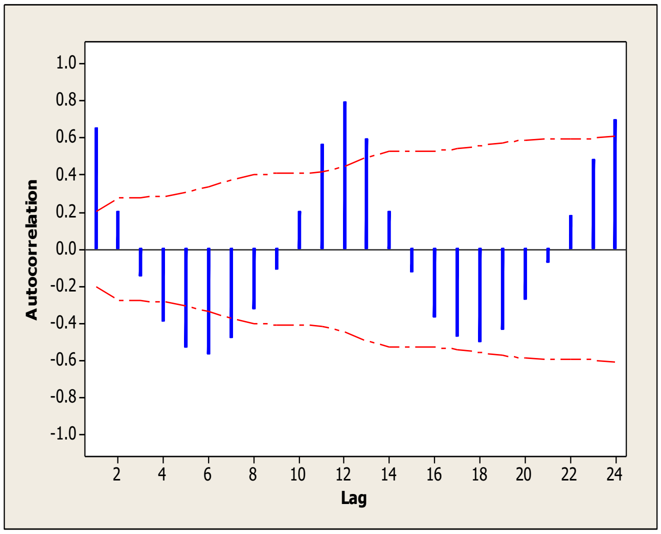

Fig. 1: Sample Auto-correlation function of $Y_t$series

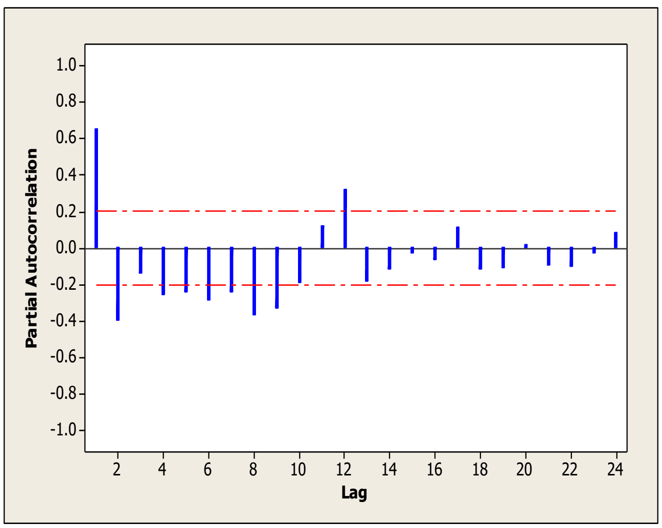

Fig 2: Sample Partial Autocorrelation Function of Y_t series

From the plots in figures 1 and 2, the Auto-correlation function (ρ), ACF (1) = 0.6535 and according to Adhikari and Agrawal (2013), the ARIMA model for a stationary time series when $/\varphi_1/<1$ with constant mean

$$\mu = \frac{c}{1-\varphi_1} \qquad (2)$$

And constant variance

$$\gamma_0 = \frac{\sigma^2}{1-\varphi_1{}^2} \qquad (3)$$

Therefore, c = 0.028. The differenced ARIMA model is given by,

$$y_t = c + \varphi_1 y_{t-1} + \varphi_2 y_{t-2} + -- \varphi_p y_{t-p} + \varepsilon_t - \theta_1\varepsilon_{t-1} + \theta_2\varepsilon_{t-2} - -\theta_q\varepsilon_{t-q} \qquad (4)$$

Simplifying equation (4) gives:

$$y_t - \varphi_1 y_{t-1} = c + \varepsilon_t - \theta_1\varepsilon_{t-1} \qquad (5)$$

Introducing the backshift notation *B*, we have that

$$y_t(1-\varphi_1 B) = c + (1-\theta_1 B)\varepsilon_t \qquad (6)$$

Where $\varphi_1 and \theta_1$ are the i^{th} Auto-regressive and j^{th} Moving Average model parameters respectively. The Moving average parameters were obtained from the ACF and PACF plot of $\mathcal{E}_t$ as shown in figs 3 and 4.

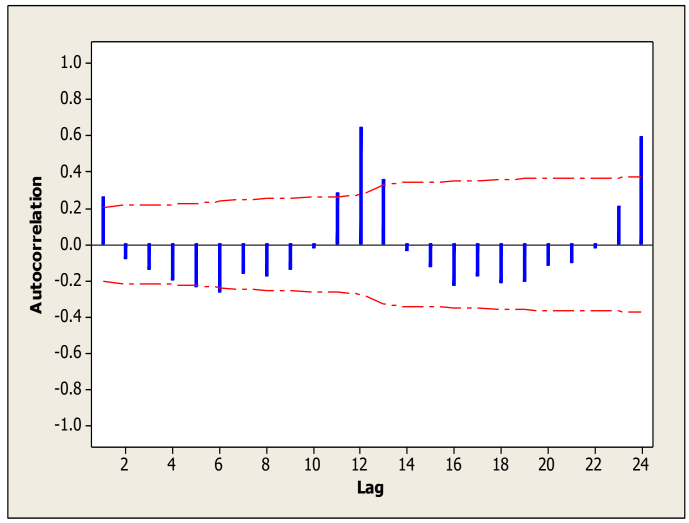

Fig 3: Sample Auto-correlation Function of $\mathcal{E}_t$ series

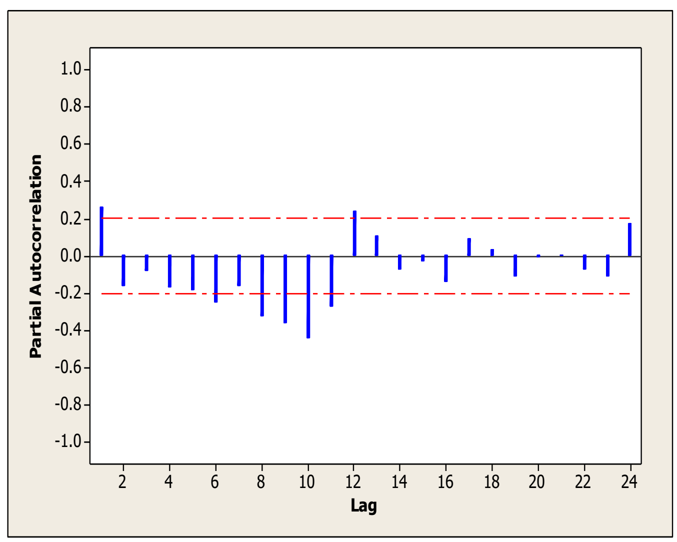

Fig 4: Sample Partial Autocorrelation Function of $\mathcal{E}_t$ series

The ARIMA model developed is given as:

$$y_t = 0.028 + 0.65 y_{t-1} + \varepsilon_t - 0.26\varepsilon_{t-1} \qquad (6)$$

The application of equation (6) gives the details of forecast results as shown in Table 1.

Table 2: Table of forecast results

y_t	forecast	error	/error/	PƐt	/PƐt/	e^2	α	α^2
2.44	3.68	-1.24	1.24	-50.78%	50.78%	-2.48	3.20	10.26
-0.46	2.66	-3.12	3.12	674.58%	674.58%	-6.24	0.30	0.09
-1.56	-0.97	-0.59	0.59	38.11%	38.11%	-1.19	-0.80	0.64
-12.60	-1.90	-10.70	10.70	84.91%	84.91%	-21.39	-11.84	140.12
-10.03	-16.06	6.03	6.03	-60.16%	60.16%	12.07	-9.27	85.93
-1.40	-10.86	9.46	9.46	-673.22%	673.22%	18.91	-0.64	0.42
1.65	-0.08	1.73	1.73	105.00%	105.00%	3.46	2.41	5.79
3.14	2.43	0.71	0.71	22.66%	22.66%	1.42	3.90	15.20
3.48	3.85	-0.37	0.37	-10.78%	10.78%	-0.75	4.24	17.94
3.70	4.04	-0.34	0.34	-9.07%	9.07%	-0.67	4.46	19.90
4.85	4.27	0.58	0.58	11.90%	11.90%	1.15	5.61	31.47
6.41	5.73	0.68	0.68	10.60%	10.60%	1.36	7.17	51.37
2.24	7.56	-5.32	5.32	-238.07%	238.07%	-10.65	3.00	8.97
-2.63	1.87	-4.50	4.50	171.28%	171.28%	-9.00	-1.87	3.49
-3.00	-3.74	0.74	0.74	-24.62%	24.62%	1.48	-2.24	5.04
-6.94	-3.41	-3.53	3.53	50.84%	50.84%	-7.06	-6.18	38.22
-8.41	-8.47	0.06	0.06	-0.69%	0.69%	0.12	-7.65	58.54
-4.31	-9.71	5.40	5.40	-125.24%	125.24%	10.80	-3.55	12.62
1.91	-4.14	6.05	6.05	316.44%	316.44%	12.09	2.67	7.13
2.97	3.26	-0.29	0.29	-9.75%	9.75%	-0.58	3.73	13.93
						SUMMARY		
						MPE	14.20%	
						MAPE	134.43%	
						RMSE	0.38	
						R^2	0.99	
						R	1.00	

IV. CONCLUSION

The model developed has effectively been used in the prediction of future headwater elevation information and requirement for power output production from the hydro-power station using past hydrological data. The forecast performance measure adopted also established a clear correlation between the variables analyzed and furthermore, the model seemliness, where the error margins obtained were also within range. This approach can also be adopted in forecasting the energy potentials of other power stations within the country. This will enable the policy makers to ensure that appropriate planning measures are taken in order to ensure energy adequacy, improvement and sustainability within the country.

This research has also opened other research interests in the combination of dissimilar time series methods to address the error margins observed in this approach. This will lead to the attainment of greater accuracy of developed models.

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