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Water Use Forecast for Hydropower Generation

J.O. Aribisala
University of Ado-Ekiti, Department of Civil Engineering,
P.M.B. 5363, Ado-Ekiti, Nigeria

Abstract: This study presents a model that can be used in planning a release policy for Kanji hydropower station. This will bring about an optimal release policy. The monthly Reservoir Storage for Kanji hydropower system was plotted to determine the degree of seasonality and to identify outliers. The sample auto-correlation when plotted showed the series to be non-stationary. The Box-Jenkins univariate procedure was adopted for model development. The method of differencing was employed to make the series stationary. The auto-correlation and the partial auto-correlation parameters of the stationary series were used to identify the appropriate model. The decaying pattern of the autocorrelation and partial autocorrelation indicated the need for a mixed model. The mixed model developed was used to forecast storage values. The forecast values were found to compare favourably with the actual data. The model is a short-term forecast method that can be relied for the daily operations of the hydropower system.

Key words: Storage, autocorrelation, univariate, hydropower, energy

INTRODUCTION

The expensive nature of water resources projects and the dependence of reservoir variables on time make it imperative to develop models, that can be used for planning reservoir operations. Planning is the heart of effective hydropower system operation.

Time series is a good tool in forecasting and planning of hydropower systems. Time series analysis is useful when successive observations are dependent. This makes it possible to forecast future values from past observations. The lead-time of the future values determines whether it is a long-term or short-term forecasting. Methods for long-term and short-term forecasting are usually not the same. For hydropower planning short-term forecasts is preferable as decisions are made daily.

In hydropower system, the energy of the falling water is converted to mechanical energy, which is used in rotating the turbine[1]. Doland[2] gave the equation for energy generation as

$$E_t = CQ_tH_te \qquad (1)$$

Where

E_t is the energy generated (GWH)

C is a Conversion constant usually taken as 2725.

Q_t is volume of water released to generating units (Mm^3).

H_t is the average net head (m).

e is the efficiency.

From Eq. 1, the time series variables that affect the performance and operation of a hydropower system can be identified to be the Turbine Release and the Generating Head. Aribisala[2] identified the Turbine Release to be the principal factor affecting energy generation in Kainji hydropower system. The amount of Turbine Release depends on the Reservoir Storage while the Reservoir Storage is a function of inflow. The Reservoir Storage (amount of water in the kainji reservoir) is used in water release policy. This is why the Reservoir Storage values are recorded on a daily basis. If a model for reservoir storage forecast is available, planning will be enhanced.

Hydropower is a renewable source of power, but like other water resources projects, it is very expensive to build[3]. Reservoir inflow, which is the main source of water available for hydropower system is seasonal. Inadequate planning can bring about unutilized water, which can endanger the dam or loss of enormous amount of water in the reservoir to evaporation. A proper planning will bring about improved operation.

Kainji hydropower description: Kainji hydrosystem located in Central Nigeria commenced operation in 1968 with an installed capacity of 760MW. The maximum storage capacity is 12,000 (Mm^3), while the minimum storage capacity is 3,000 (Mm^3). The Reservoir storage trend between 1970 to 1987 shows that the monthly average reservoir storage was always more than the minimum 3,000 Mm^3. This implies unutilized storage that could be loss through evaporation and spillway discharge. The least storage in 1986 was 4218.3Mm^{3}[4], identified the reservoir inflow as the major factor affecting the Reservoir Storage and Turbine Release. The Reservoir storage affects the Turbine Release.

In this study forecasting model is developed for the Reservoir Storage which will help in the planning of the Kainji hydropower system. This is because once the Reservoir Storage can be estimated, it will be easy to determine the Turbine Release needed for energy generation in Eq. 1. it will facilitate a national planning operation, since Nigeria relies both on hydropower and thermal systems.

FORECASTING TECHNIQUE

Chatfield[5] used the terms forecasting and prediction interchargeably. However, authors such as Brown[6] used prediction to describe subjective methods and forecasting to describe objective methods. Brass[7] used forecast to mean any kind of looking into the future and prediction to denote a systematic procedure for doing so. The three major forecast methods commonly in use are the subjective, univariate and multivariate procedures. When forecast is made on judgment and intuition it is classified as subjective. The univariate method refers to when a given variable is based on a model fitted only to past observations. Different univariate procedures available include extrapolation of trend curves (long term forecasting), exponential smoothing, Holt-Winters procedure, Box-Jenkins and stepwise autoregression. The multivariate procedure uses the approach of the multiple linear regression models, where the variable of interest is related to more than one variable. There is no single method universally applicable[5]. Each analyst determines the appropriate procedure for a given set of conditions.

There is no best forecasting procedure. The method to be used depends on the objective of the forecasts, degree of accuracy and the properties of the time series.

Forecasting of future values from previous observations are made possible when successive observations are dependent. Most time series in water resources systems are stochastic. Future values have a probability distribution. The probability model that generated the successive observations can be identified with the auto-correlation coefficients.

Autocorrelation Coefficient is meaningful when the time series is stationary (i.e., contains no trend). Probability models that explains irregular variation in time series were identified by Box[8] as Moving Average or Autoregressive (AR) models. Box[9] Proposed the use of a mixed autoregressive/moving average models. This is because the autoregressive moving average (ARMA) model involves fewer parameters than a pure MA or AR models. Thereby making it more efficient.

The methodology suggested by Box and Jenkins were found to lead to better forecasts than other statistical forecasting methods.

Box-Jenkins technique eliminates inappropriate models until only the most suitable model is left as compared with picking an arbitrary model for the observation.

Box-Jenkins techniques uses a rational structured approach to determine the specific model instead of the usual trial and error procedures.

MODEL DEVELOPMENT

A univariate model is suitable for Kainji hydropower system since the variable of interest (Reservoir Storage) depends only on observations of the given time series. For a series that is not two short, like Kainji hydropower (1970-1987 data), Box-Jenkins procedure is found to be good and to give more accurate results than other univariate methods[10]. Simple approaches like Box-Jenkins are better than complex models as complex models do not give better forecasts than simple model[5].

Box[9] Suggested a systematic approach to modeling and forecasting of discrete time series. This approach has been employed in this work to develop the model.

The main stages in developing a Box-Jenkins forecasting model include, model identification, estimation of model parameters and diagnostic checking. It is very important to plot the series so as to discover outliers and seasonality.

Box-Jenkins is suitable for a series that is stationary. A series is stationary when there is no systematic change in mean (no trend), if there is no systematic change in variance and if periodic variable have been removed[5]. To achieve this the method of differencing which is a filtering procedure was adopted to convert the non-stationary reservoir storage series into a stationary series.

Differencing: Differencing is a filtering procedure used in making a non-stationary process a stationary one, by converting one time series to another. The plot of storage against time, shows that variation in, mean is not noticeable i.e., there is seasonal variation. The plot of the sample auto correlation dampens slowly which suggest that the reservoir storage series is non-stationary.

The sample autocorrelation, which measures the correlation between periods in a time series, is defined by the correlation equation (r_k) i.e.,

$$r_t = \frac{\sum_{t=1}^{n-k}(Z_t - \bar{Z})^2 \, (Z_{t+k} - \bar{Z})^2}{\sum_{t=1}^{n}(Z_t - \bar{Z})^2}$$

$$K = 0,1 \ldots\ldots\ldots K \qquad (1)$$

Where n is the number of observations

Z_t is the observed time series

$\bar{Z}$ is the average deviation

k is the time period

The pattern of time series plot and auto-correlation of the Reservoir Storage show the need for seasonal differencing and not regular differencing.

The equation for both seasonal and regular differencing is given as,

$$Y_t = (1\text{-}B)^d \;\; (1\text{-}B^s)^{d1} \, Z_t \qquad (2)$$

Where d is order of regular differencing

s is season length

d1 is order of seasonal differencing

Since there is no need for regular differencing, d = 0. The seasonal cycle, s = 12, i.e., January to December. After the first differencing, the series was still non-stationary. Stationary series was a chieved after four differencing making d1 = 4. For the Storage series, Eq. 2 becomes.

$$Y_t = (1 - B^{12})^4 Z_t \qquad (3)$$

The stationary time series was achieved after the differencing using Eq. 3.

Model for forecast: A check of the partial auto-correlation pattern shows large values for the first two lags. The autocorrelation pattern shows a second order autoregressive model. The large spike at lag 12 indicates the need to introduce a moving average operator with period 12. a mixed model of the form in Eq. 4 was identified to adequately represent the storage series i.e.,

$$(1\text{-}\phi_1 B \text{ - } \phi_2 – B^{12})Z_t = \;\; (1\text{- }\theta_{12} B^{12})a_t \qquad (4)$$

The estimated parameters were substituted into Eq. 4 to give Eq. 5

$$Z_t = 1.32\, Z_{t\text{-}1} \text{ - } 0.51\, Z_{t\text{-}12} + Z_{t\text{-}12} \text{ - } 1.32 Z_{t\text{-}13} + 0.51\, Z_{t\text{-}14} \text{ - } 0.71\, a_{t\text{-}12} \qquad (3.5)$$

Equation 5 is the model for forecasting the average monthly Reservoir storage.

RESULTS AND DISCUSSION

The model in Eq. 5 was used to forecast Reservoir Storage values. The forecast values were compared with the actual values on Table 1. Forecast was made for January to December, because the data was available. This does not mean long time forecast. In planning for Kainji Reservoir operation, $Z_{t\text{-}1}$ average reservoir storage is the value for the previous month. This implies that only value for one-month lead-time can be forecast. The choice of 1972 as the year of model validation was arbitrary (1). The forecast values compared well with the actual values. The model is good for short-term forecast i.e planning of water release for energy generation on a daily basis. The standard error for the autoregressive parameters, AR (1) and AR (2) were computed to be 0.065 and 0.067 respectively while the standard error for the moving average parameter was computed to be 0.056. This shows a good fit.

The percentage error for each of the months calculated are recorded in Table 1. Errors are high for the months of August and September, 1972. The model application to data of 1987, show that the percentage error for August is-16.36, while that of September is 3.65. This can be explained. Reservoir storage average values for August ranged from 3030.0 Mm^3 (minimum), in 1972 to 6271.6 Mm^3 (maximum in 1974). For the month of September, the minimum was in 1984 with value of 4230.6 Mm^3, while the maximum was 8718.1 Mm^3 in 1985 as shown in the appendix.

The degree of variation in the recorded values i.e high coefficient of variation and standard deviation are responsible for the high errors in August and September. For the other months of the year this type of problem was not encountered.

with the Box-Jenkins procedure.

Table 1: Storage forecast values for 1972

Month	Jan	Feb	Mar	April	May	June
Forecast values	12195.0	1223.4	11544.8	10257.8	7717.6	5516.1
Actual values	11957.5	11994.9	11571.0	9796.6	7481.4	5152
Percentage error	-1.99%	-2.02%	0.23%	-4.7%	-3.2%	-7.1%
Month	July	August	Sept	Oct	Nov	Dec
Forecast values	3365.1	2080.3	6392.7	8332.3	9508.2	11876.7
Actual values	3216.8	3030.0	5414.4	8305.1	10335.9	11474.2
Percentage error	-4.6%	+31.3%	-18.1%	-0.32%	8%	-3.5%

Appendix: Monthly trend in reservoir storage at kainji reservoir Mm^3)

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1970	11933.5	11940.1	11887.2	11041.8	9447	7079	5540.6	4155.9	6155	9838	11053.9	11270.3
1971	11773.9	11968.5	11803.5	10314.2	8384.2	6443.9	4608.9	3259.3	5985.5	8969.3	10093.7	11218.3
1972	11957.5	11994.9	11571	9798.6	7481.4	5152.8	3218.8	3030	5414.4	8305.1	10335.9	11474.2
1973	11790.8	11740.9	1098.1	10289.6	8485.6	6900.4	5620	5294.4	7213.9	9213.2	10651.1	11589.5
1974	11959.2	11899.4	10960.3	9803	9394.7	6942.1	5898.1	6271.8	7203.9	10341.4	11540.1	11892.4
1975	11959.3	11830.9	11489	9939.6	8053.6	6217.1	4732.8	3442.9	5912.8	9848.4	11578.2	11807.8
1976	11887	11973.2	11868	10725.2	8677.4	6031.3	4819.4	4178.9	5370.9	6043.9	6930.7	8376.8
1977	10528.9	11904.8	12000	11229.3	9262.7	7449.5	5453	3676	4149.3	5448.7	6184.8	7557.3
1978	9407.2	9820.3	9185.2	7862.5	6773	5386.6	3543.6	3165.2	5436.9	7381.5	9029.9	10128.8
1979	11054.9	11822.1	11766.6	10788.6	9219.7	7628.6	5939	4704.6	5792.6	8182.5	9882.1	10803
1980	11792.1	12047.8	11667.9	10119.8	8248.9	6591.9	5147.6	5356.3	6595.3	8060	9171.6	10084.1
1981	11312.1	11862.1	10944.4	9246	7536.6	5207.8	3736.4	4151.1	6367.2	7826.7	8878.3	10279.3
1982	11805.2	11980.5	11409.2	9330	7059.2	5039.4	3690	3320.7	5284.3	7448.6	8877.3	10176.7
1983	11415.5	11902	10754.3	9087.6	7198.9	5307	3983.4	3170.6	3941.3	5402.1	6451	8145.3
1984	9514	9618.2	9022.9	9035.4	7243.4	6031.9	4584.2	3774.1	4230.6	6135.3	7835.4	8490.8
1985	8806.8	8429.9	7308.9	6313.8	5053.6	4270.9	4019	5940	8718.1	10255	11009	11879.3
1986	11980.4	11713.5	9882.5	8927.2	7099.6	5295.1	4218.3	4309.9	6374.1	8812.1	10127.6	1085.2
1987	11407.9	11106.9	9776.3	8156	64165	5088.3	3861.7	3390	4335.3	5859.8	7034.6	7786.6
MEAN	11225	11419.8	0555.9	73547.8	60313.1	5488.6	4171.8	5860.2	7870.33	9225.8	10212.1	10211.2
S.D	995.8	10339.2	1270.2	1235.8	1967	999	856.7	983.6	1225.7	1809.3	1790.5	1497.5
C.V	0.0887	0.0905	0.0118	0.0129	0.0267	0.0167	0.0187	0.0236	0.0209	0.023	0.019	0.0143
Min	8806.8	8429.9	7308.9	6313.8	5053.6	5088.3	3216.6	3030	3941.3	4343.9	6184.8	7786.6
Max	11959.3	12047.8	12000	11229.3	9447	7628.6	5939	6271.6	7213.9	10341.3	11518.2	11879.3

CONCLUSION

A model to forecast the amount of water storage in a reservoir was developed.

This model is suitable when the season length is 12 i.e., January to December. Its use can be extended beyond Hydropower Reservoir. It could be adapted for other water resources projects such as reservoirs for water supply and irrigation. The disadvantage is that model for each scheme has to be developed based on the data for the scheme. The use of the model could be extended to other variables such as reservoir level, inflow and Generating Head. The model is for short-term forecasts. Hydropower management needs daily decisions.

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