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Reservoir Operation Analysis Aimed to Optimize the Capacity Factor of Hydroelectric Power Generation

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Abstract. A reservoir operation was reviewed to optimize the total annual hydroelectric power generation. Analysis were conducted in a week period of time using daily data of reservoir level, turbine release, power generated, rainfall and evaporation. The length of data varies from 4-20 years (1991-2010). A trend test for historical daily power generation was performed using Nonparametric Mann-Kendall's test to verify the improvement. The test results indicated that there is no trend in the generation of electricity. Optimal turbine release was found through genetic algorithm optimization model. The model results showed that the four-year average hydroelectric power generation capacity factor was improved from 31.48% to 33.62%, with better reservoir level and less variation in turbine release rates.

Keywords: Capacity factor, Genetic Algorithm, Hydropower, Optimization, Trend Test

1. Introduction

Hydroelectric power generation is mainly a function of overall efficiencies of the plant, rate of turbine release, and the difference between headrace and tailrace levels. Capacity factor is one of the parameter used to evaluate the power generated. The higher the capacity factor, the better the production. In the case of storage type of hydropower plant, the capacity factor depends on the maintenance time (shutdown period), output curtail, and availability of water in the reservoir. This study focused on the third influential parameter, i.e. availability of water. The aim of the research is to optimize the annual hydroelectric power generation through careful releasing of stored water (reservoir operation) and getting a better capacity factor. Generally the operation for hydropower reservoir scheduling is a daily or weekly exercise [1].

Many real-time reservoir operation models have been developed since the 1960s. These include linear programming, dynamic programming, nonlinear programming and simulation. The models have been classified on the basis of various methods and algorithms that they have used [2]. There is no universal solution for reservoir operation problems [3]. Mathur and Nikam [4] mentioned that researchers still searching the best reservoir optimization model. Zahraie and Karamouz [5] applied a time decomposition approach to model the operation of the two parallel hydropower reservoirs in Iran. The model was divided into three different time periods; long-term (monthly), mid-term (daily) and short-term (hourly). Shiau [6] applied hedging rules using multi-objective Genetic Algorithm (GA) to optimize the operation of Nanhua reservoir in Taiwan. The rule mainly depends on three parameters; the Starting Water Availability (SWA), Ending Water Availability (EWA) and Hedging Factor ratio (HF). When the availability of water exceeds EWA, hedging is not implemented where as water availability falls below SWA, no additional hedging being enforced. Jalali *et al.* [7] used improved Ant colony optimization algorithms to model Dez reservoir operation in Iran. The model was applied on a finite time horizon and predetermined optimality criterion. The result of the model compared well with those GA and global optimum. Cheng *et al.* [8] mentioned that GA model has been widely applicable in water resources system optimization. Mathur and Nikam [4] stated GA gives better result, but it required careful parameter selection. Azamathulla *et al.* [9] compared Linear Programming (LP) and GA model to maximize irrigation reservoir operation. In the case of real–time reservoir operation, GA model was found superior to linear programming model.

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2. Study Area

Perak River is the second longest rivers in Peninsular Malaysia. Along the river Temengor, Bersia, Kenering and Chendroh dams were built in cascade. The main purposes of the dams are to generate hydroelectric power and to mitigate flood. The research was conducted on Temengor hydropower dam reservoir operation. It is the third largest dam in Malaysia, located the most upstream in the cascade system (Fig. 1). The maximum dam height above foundation is 127 m. At full supply level the volume of the reservoir is 6050 million cubic meter. The reservoir water surface area at EL245 m is 152 square kilometer. The maximum operating level is EL248.42 m and the minimum operating levels are EL236.5 m and EL221 m for three units and one unit respectively. The installed capacity of the plant is 348 MW (4 x 87 MW).

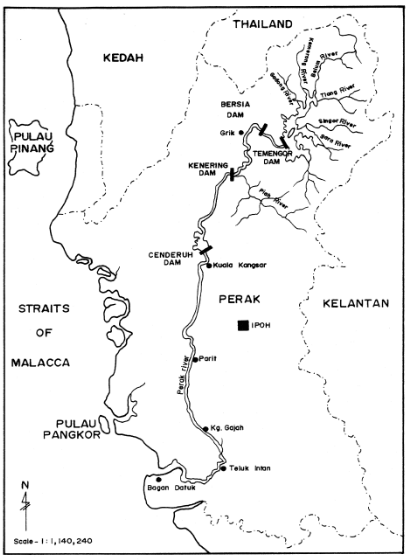

Fig. 1: Perak river basin, Malaysia

3. Materials and Methods

3.1 Input Data

Daily turbine release, hydroelectric power generation, reservoir level, rainfall and evaporation data were used to analyze the reservoir operation. The length of data varies from 4-20 years (1991-2010). Missing data were filled with correlation techniques. Reservoir operation analyses were made in week period of time. It is assumed that parameters are constant throughout the week. The difference between rainfall and rate of evaporation were equated and overall efficiencies of the plant were computed. Statistical parameters were used to examine the weekly variation of reservoir level, i.e. head.

3.2 Power Generation Trend

Trend test was conducted to check the historical time series power generation had increase or decrease with time. The result of trend test used to predict the future. Nonparametric Mann-Kendall test was used. It is a ranked based approach that consists of comparing each value of the time series with remaining in the sequential order. Typically, the null hypothesis, H_o, is that there is no trend in the population from which data were drawn. Consequently, the alternative hypothesis, H_1, is the trend exists. The time series data were arranged into sequential groups of 45 each had 30 days. The statistic *S* is the sum of all counting as given by Eq. (1):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k) \tag{1}$$

Where

x_j *and* x_k - Sequential data values

n - Length of the data set

$$sign(x_j - x_k) = \begin{bmatrix} 1 & if & (x_j - x_k > 0) \\ 0 & if & (x_j - x_k = 0) \\ -1 & if & (x_j - x_k < 0) \end{bmatrix} \tag{2}$$

For $n \geq 10$, Eq. (3) used to compute the variance of *S*:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p (t_p - 1)(2t_p + 5) \right] \qquad (3)$$

Where

q – the number of tied groups,

t_p – the number of data points in the p^{th} group

S and *VAR(S)* used to compute the normalized test statistic *Z* using Eq. (4). Then *Z* is checked against the standard normal distribution to determine the critical region.

$$Z = \begin{cases} \dfrac{S-1}{[VAR(S)]^{1/2}} & if \;\; S > 0 \\ 0 & if \;\; S = 0 \\ \dfrac{S+1}{[VAR(S)]^{1/2}} & if \;\; S < 0 \end{cases} \qquad (4)$$

Probability density functions for a normal distribution was computed using Microsoft excel function *NORMSDIST (Z)*. The trend is said to be decreasing if *Z* is negative and the computed probability is greater than the level of significance and increasing if *Z* is positive and computed probability is greater than the level of significance. If the computed probability is less than the level of significance, there is no trend [10].

3.3 GA Model

GA model were developed to optimize a weekly average power generation. The objective function was to minimize the difference between actual and installed capacity. State transformation equations, maximum and minimum reservoir levels and turbine releases were used as constraints. The model was performed using population size of 80 and generation of 100 according to [11]. The capacity factor due to the model results were presented and compared to the historical recorded. Statistical analysis applied to evaluate the average weekly variation of reservoir stage. Stage influences the efficiency of unit water.

4. Results and Discussion

The average weekly evaporation exceeded the average rainfall in most of the seasons. Figure 2 shows that rainfall varies from 0.18-5.82mm per week and that of evaporation 2-7mm per week. The overall effect had negative impact on reservoir water level, but it is insignificant compared to inflow rate.

Historical daily hydroelectric power generation trend is shown in Fig. 3. The nonparametric Mann-Kendall's trend test result showed that the statistical *S* and *Z* values were 10 and 0.09 respectively. A 5% of level of confidence was taken. The result shows the null hypothesis is true. Hence, the annual power production was neither increasing nor decreasing (no trend). It can be predicted, there is little or no improvement in its capacities.

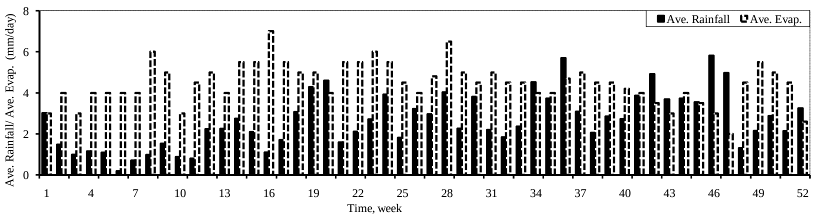

Fig. 2: Average rainfall and Evaporation

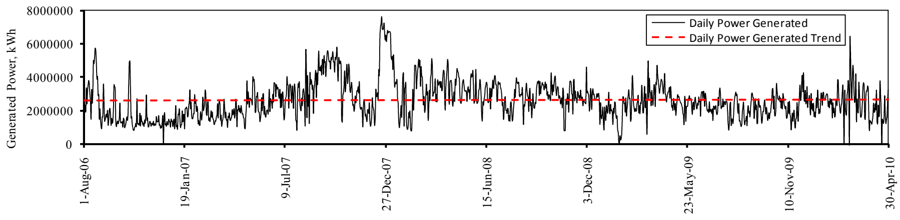

Fig. 3: Daily hydroelectric power generation (Temengor plant)

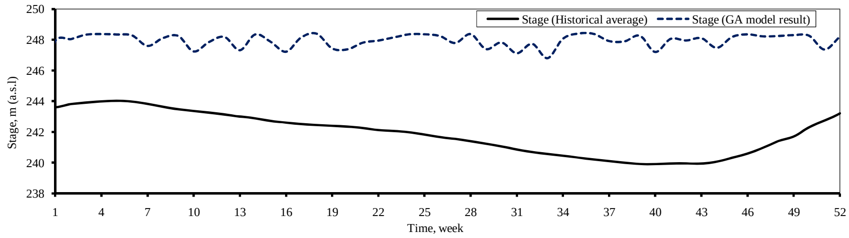

Fig. 4: Variation of reservoir level (long-term average and model decision)

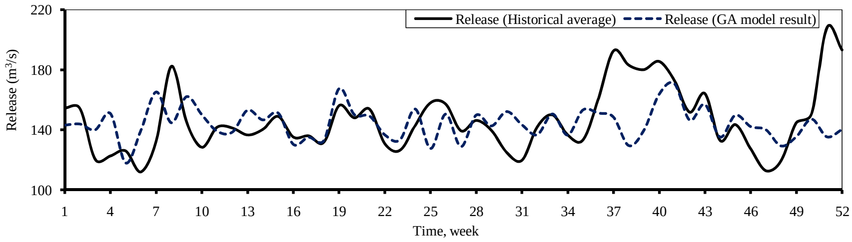

Fig. 5: Weekly average Release and Model decision

Table 1: Reservoirs level analysis

	Statistical Parameters							
	Maximum level	Minimum level	Range	Mean	S.D.	Skewness	Kurtosis	Coefficient of Variation
Historical Average	244.02 m	239.90 m	4.12 m	241.88 m	1.36 m	-0.01	-1.32	0.56%
GA Model Result	248.41 m	246.81 m	1.60 m	247.81 m	0.41 m	-0.94	-0.10	0.16%

The historical average annual electricity production was 31.48% of its capacity. GA model was used to optimize the annual electricity production. The model improved the daily average hydroelectric power generation by 7.5 MW and its capacity factor to 33.62%. The average annual historical release volume equivalent to the annual model release volume. But the average weekly historical releases fluctuation is higher than the model decision (Fig. 5.). In the case of reservoir level, all over the year the model result was higher than historical data (Fig. 4). Statistical analysis of reservoir level indicated that the model result is less range, standard deviation and negatively skewed (Table 1).

Table 1, Fig. 4 and 5 indicated that the GA decision was better than the historical average values in two ways; higher reservoir level and less release fluctuation. Hence, the higher reservoir level leads to better unit water efficiency and the less release fluctuation implies the constant water supply to downstream which may ease for management. GA model has a capacity to enhance the efficiency of a real world reservoir operation [7].

5. Conclusions

The following conclusions are made based on model result and historical data analysis:

- Average evaporation exceeds the average rainfall. This had negative impact on reservoir level. Since the inflow rate much higher, the influence is small.
- The Mann-Kendall's trend test on daily power generation showed that there is no trend (neither increasing nor decreasing). Hence the power production does not have any relationship to time.
- GA model gave a better release and reservoir level as compared to historical operation. GA also increases the capacity factor from 31.48% to 33.62%. The advantage of GA is not only in optimizing the power generation but also better reservoir level. Higher reservoir level is important to get higher unit water efficiency.

6. Acknowledgements

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