Modelling the dam and the turbine site at Akosombo using System Dynamics.

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INTRODUCTION

The main aim for the construction of the Akosombo dam in 1961 was to generate hydroelectric power, the dam was designed on the Volta river which flows through six turbines at the powerhouse located at Akosombo. The generation of electric power is influenced by many factors such as volume, rate of flow and water level. Due to these factors, the Akosombo dam serves as an interesting case study for a system dynamics project, and in view of this, this project focuses on the application of the concepts covered in System Dynamics such as Fluid System and Transfer functions to mathematically model the water head of the dam and the mechanism involved at the turbine site.

BACKGROUND

Hydroelectric power is by far the most essential source of energy generation for Ghana and its neighboring countries; Togo, Ivory Coast and Burkina Faso. These countries highly rely on the energy generated by the Akosombo dam hydroelectric plant for socioeconomic and developmental needs. The Dam was built in 1961 on the River Volta, located in the southeastern part of Ghana in the Akosombo gorge and part of the Volta River Authority. Currently, the dam operates at the maximum operating level above 71m provides over 1020MW of power at the plant and supplies to industries and homes through a stepping up and down process.

APPROACH

1. Definition of system: The main dam system and the turbine site.
2. Determination of element: inflow rate, outflow rate, capacitance, resistance, height, valves or channel, turbine, etc.
3. Free body diagrams of the various element involved in the system.
4. Derivation of equation: capacitance, Reynold number, resistance, and Euler formula were used to derived the mathematical model.
5. Matlab was used to implement graphical analysis.

ASSUMPTION

The volume of inflow of water is equal to volume of the outflow of water.

The same amount of water flows through the six turbines.

No water is lost through evaporation.

The turbine has a damper and spring.

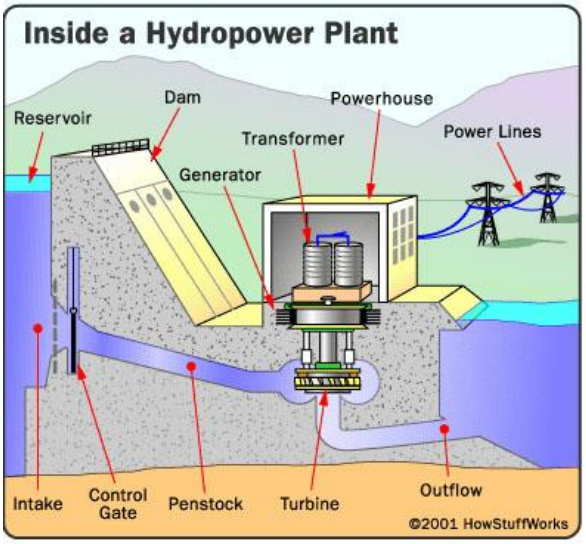

Figure 1. The figures above show the turbine site of a damp and a turbine.

ANALYSIS

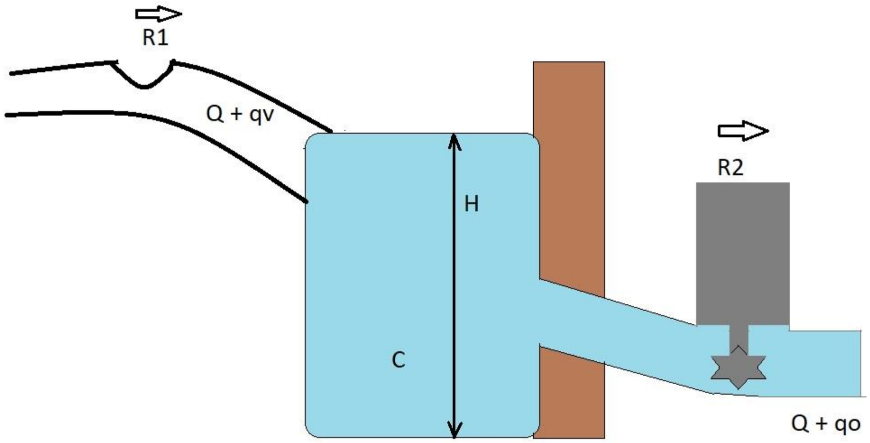

Figure 2. The system shown is a simplified model of the liquid level system at Akosombo Dam.

R1 represents the resistance at the Volta river.

R2 represents resistance at the turbine site.

Capacitance

$$C\frac{dh}{dt} = q_v - q_d$$

At Resistance 1

$$R = \frac{h}{q_v}$$

At Resistance 2: Assuming the outflow is turbulent.

$$R = \frac{2h}{q_d}$$

$$C\frac{dh}{dt} = q_v - \frac{2h}{R}$$

$$C\frac{dh}{dt} + \frac{2h}{R} = q_v$$

$$RC\left[sH_{(s)} + 2H_{(s)}\right] = RQ_{v(s)}$$

$$H_{(s)}[RCs + 2] = RQ_{v(s)}$$

$$H_{(s)} = \frac{RQ_{v(s)}}{RCs + 2} \dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Change in the head as a function of time.

$$H_{(s)} = \frac{\frac{Q_{v(s)}}{C}}{s + \frac{2}{RC}}$$

$$H_{(s)} = \frac{Q_{v(s)}}{C} \; x \; \frac{1}{s + \frac{2}{RC}}$$

$$H_{(s)} = \frac{Q_{v(s)}}{C} e^{-\frac{2t}{RC}} \dots\dots\dots\dots (2)$$

According to Volta River Authority (2010), the following the data were recorded

Maximum Operating level, Height = 84.73m

Maximum annual inflow = 3000m^3/s

Resistance , R = 0.02824

Total storage capacity, C = 148,000m^3

Assuming conditions remain the same through a period of 10 years, which is not possible due to climate change, a study of the water head was carried in Matlab using the data values above. The result is displayed below.

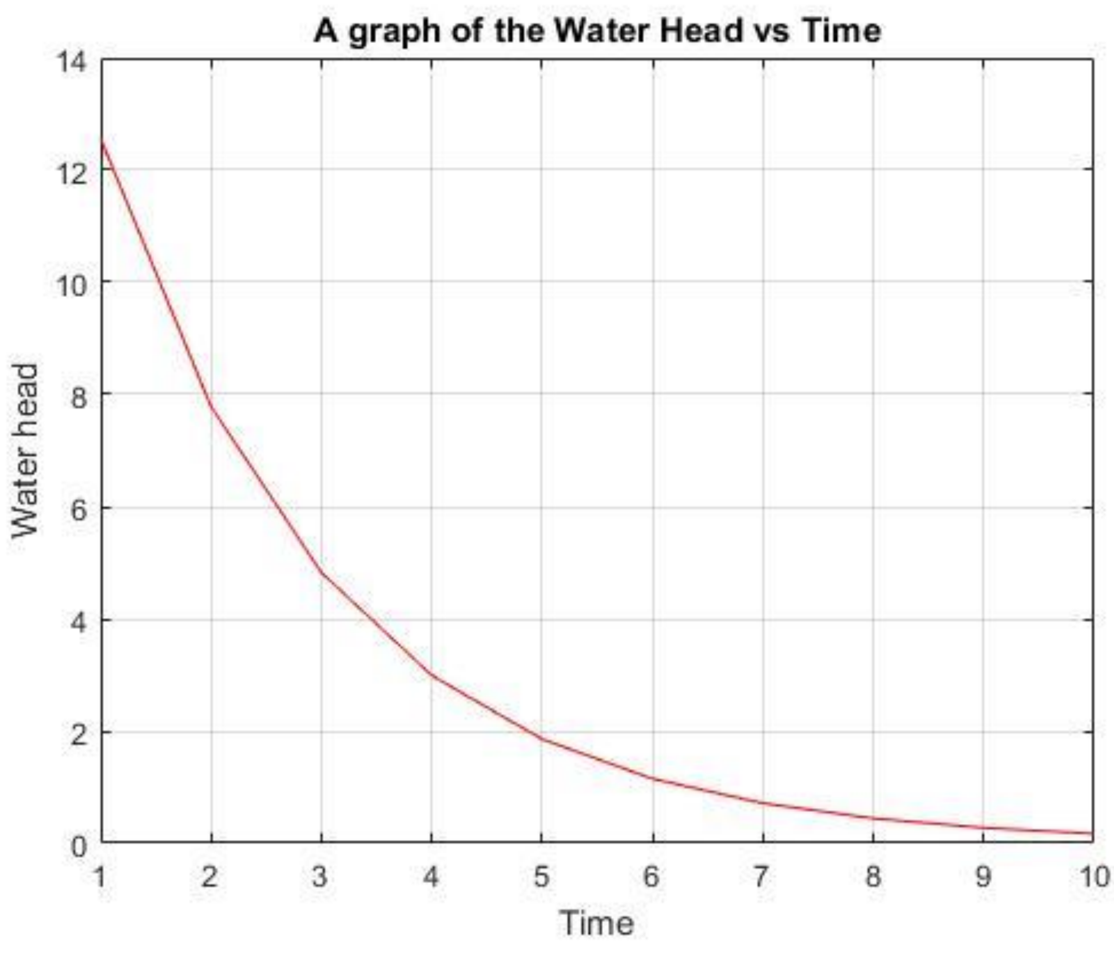

Figure 3. A Matlab simulation of the change in head over a 10-year period.

```
clear all
clc
Q = 3000;                    %  Outflow m^3/s
R = 0.02824;                  %Resistance
C = 148,000;                   %Capacitance     m^3

t = 1:1:10;
H = (Q/C).*exp(-2*t/(R*C));          %Water head
plot(t,H, 'r')
grid on
xlabel('Time')
ylabel('Water head')
title('A graph of the Water Head vs Time')
```

Figure 4.Matlab Code

At the turbine site

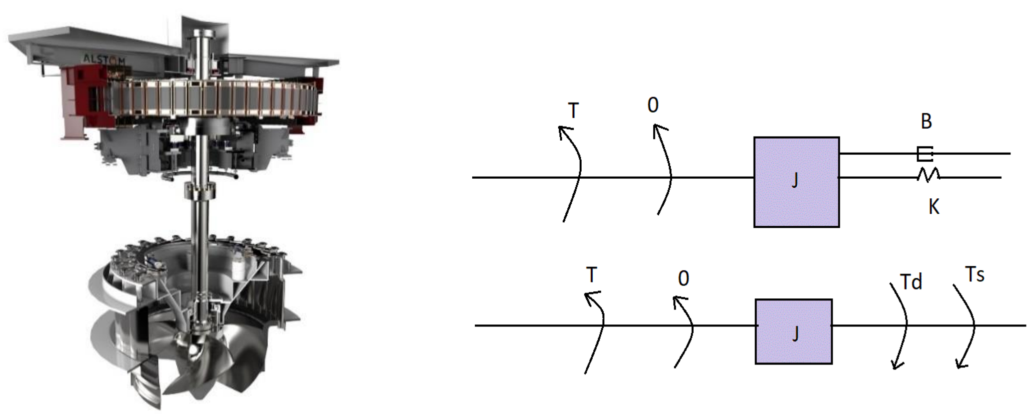

Figure 5. A simplified model of turbine.

Where $T_d = b\dot{\theta}$ $\quad and \quad$ $T_s = k\theta$

$$J\alpha = \sum T$$

$$J\ddot{\theta} = -b\dot{\theta} - k\theta + T(t)$$

$$\theta_{(s)}[Js^2 + bs + k] = T$$

Assuming T = $\delta(t)$

$$\theta_{(s)} = \frac{1}{Js^2 + bs + k}$$

Assuming $T_{(s)}$ as input and $\theta_{(s)}$ as output

$$\frac{\theta_{(s)}}{T_{(s)}} = \frac{1}{Js^2 + bs + k}$$

Block diagram for each turbine.

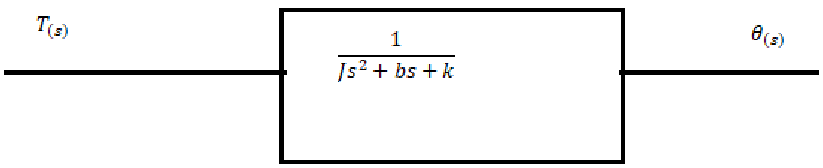

Figure 6. Block diagram for the turbine model.

Limitation

The acquisition of current data (facts and figures) from the Volta River Authority to be used in the calculation of the model developed was difficult. Again, the already existing data about the dam on their website cannot be used to draw conclusions about the current operation of the dam because they were taken under certain conditions some decades ago.

Lessons learned

1. Although it is sometimes complicated modelling large system like dams and waterbodies, system dynamics give it a much-approximated means of getting results of one's model.
2. System dynamics as a course is an effective tool used to analyze how a physical system operates.
3. Modelling is not about finding variables, but also relating them in a way to show interdependency.

Conclusion

This project has been worth carrying out because of the rich exposure to the analysis of the Akosombo dam using concepts already covered in the System Dynamics class. A model of the water head and the transfer turbine site were developed using transfer function and Matlab software. It provided me with an easier and effective information about the operation of the dam. This project has been wonderful because it has taken me through the concept of transfer functions and fluid systems which were not fully grasped by me in class, and also the use of Matlab.

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