A System Dynamics Modeling of Akosombo Dam using Fluid Systems and Transfer Functions.

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***Abstract*—With the increasing rate of load shedding all over Ghana, it has raised concerns on ways to improve the current major source of electricity for the country. Drawing inspiration from concepts studied in system dynamics, this paper seeks to analyze the capacitance of the dam coupled with the turbine site using electromechanical variables and existing data.**

Keywords—transfer functions, fluid systems, capacitance,

I. Introduction

Hydroelectric power is by far the most essential source of energy generation for Ghana and its neighboring countries; Togo, Ivory Coast, and Burkina Faso [1]. 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 step-up and step-down processes. The Akosombo dam was purposely constructed for the generation of hydroelectric power for the people of Ghana. The dam built on the Volta River has six turbines through which water flows through at the powerhouse located at Akosombo. As of the year 2000, Ghana was among the top African countries with high access to electricity, and even supplying electricity to neighboring countries like Cote D'Ivoire. Up until 2009, the country's power systems began to decline with excessive load shedding as its consequences affecting businesses and productivity leading to the popular name, "Dumsor", which means a persistent, irregular, and unpredictable electric power outage [2].

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 and in the aim of increasing access to electricity, the Akosombo dam serves as an interesting case study for power generation modeling, This paper focuses on the application of the concepts as Fluid System and Transfer functions to mathematically model the water head of the dam and the mechanism involved at the turbine site[3][4].

II. Methodology

A. Experimental Approach

1. Definition of the 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 elements involved in the system.

4. Derivation of the equation: capacitance, Reynold number, resistance, and Euler formula were used to derive the mathematical model.
5. MatLab was used to implement the graphical analysis.

B. Assumptions

1. The volume of the inflow of water is equal to the volume of the outflow of water.
2. The same amount of water flows through the six turbines.
3. No water is lost through evaporation.
4. The turbine has a damper and spring.

III. Visual Representation

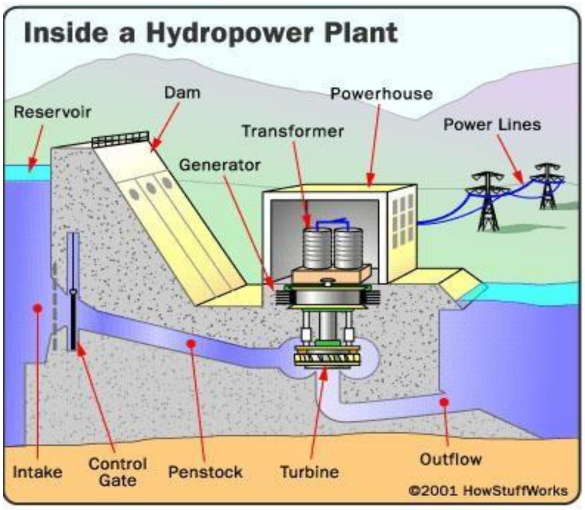


Figure 1. The turbine site of a dam and a turbine.

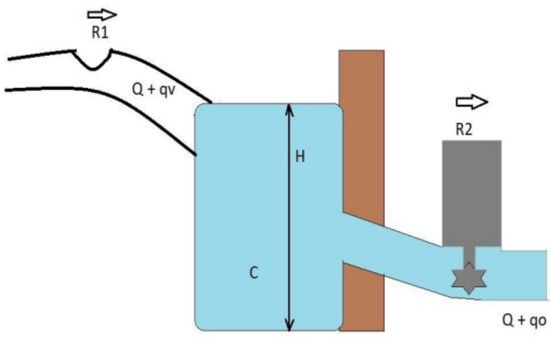


Figure 2. A simplified model of the liquid level system at Akosombo Dam

R1 represents the resistance at the Volta river.
R2 represents resistance at the turbine site.

A. *Capacitance Modeling*

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

At Resistance 1, R1: $R = \frac{h}{q_v}$

At Resistance 2: Assuming the outflow is turbulent

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

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

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

$$RC[sH_{(S)} + 2H_{(S)}] = RQ_{V(S)}$$

$$H_{(S)}[RCs + 2] = RQ_{V(S)}$$

$$H_{(s)} = \frac{RQ_{V(S)}}{RCs + 2} --- (1)$$

In the head as a function of time.

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

$$H_{(S)} = \frac{Q_{V(S)}}{C} e^{-\frac{2t}{RC}} --- (2)$$

B. *Test Data*

The following data was the existing information about the data as of 2010 [1].
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 over 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.

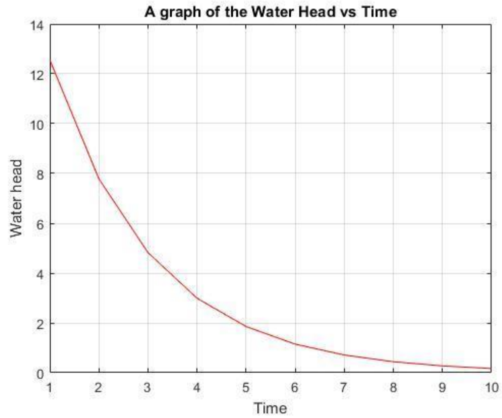


Figure 3. A plot of water head vs time over 10 years.

Looking at the graph above, it can be deduced that should condition remain the same, the Waterhead at Akosombo Dam will decline within 10 years. This, therefore, raises the urgent need to research on finding other alternate sources of energy for electricity or even boost the current system that can generate enough power with a minimum flow rate. Hence, it is advisable to also study the turbine site to know its capacity concerning power generation.

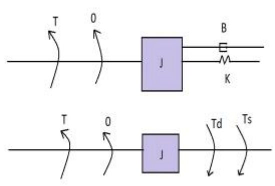
C. *Matlab Code*

```
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')
```

D. *Turbine Site*

The Akosombo dam consists of six impulse turbine and a similar turbine device looks like the image below. The turbines operate on the tangential flow of water on one side of the turbine runner.



Where $T_d = b\theta$ *and* $T_s = k\theta$

$$J\alpha = \sum T$$

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

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

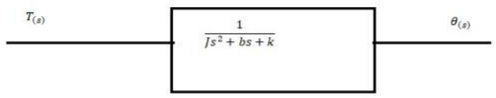
Assuming T = $\delta(t)$

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

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.



- The abbreviation “i.e.” means “that is”, and the abbreviation “e.g.” means “for example”.

IV. 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 conclude the current operation of the dam because they were taken under certain conditions some decades ago.

Although it is sometimes complicated modeling large systems like dams and water bodies, system dynamics give it a much-approximated means of getting results of one's model. System dynamics is an effective tool used to analyze how a physical system operates. Modeling 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 a fluid system and transfer functions. A model of the water head and the turbine site were developed using transfer function, fluid system, and Matlab software. These concepts provided 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

ACKNOWLEDGMENT

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