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Canal System Response Analysis of Interactively Coupled Canal Pools

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***Abstract**: This paper represents the Canal System Response Analysis of Interactively Coupled Canal Pools which requires in design the Auto-tuning PI Controller for interactive coupled Water Levels of canal pools of canal conveyance system. The Step Input Response (SIR) is the method to model a dynamic process which can be done easily, conveniently and very efficiently. In the design of auto-tune of PI Controller the root locus technique is also used. In this paper MATLAB is used for modeling and Response Analysis of Interactively Coupled Canal pools system. The simulation results of the interactive coupled water level process can be satisfyingly illustrated the transient response and the same is used for modeling thesystem in MATLAB.*
***Keywords**-Coupled pool, interacting water level process, PI Controller, canal system, response analysis, etc.*

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I. INTRODUCTION

Proportional plus Integral (PI) Controller Algorithm based on approximate and linearized relationship between the inflow and the depth of interactive coupled canal pools of the canal system of the Sardar Sarovar Project, Gujarat, India is used for study the response analysis of interactively coupled canal pools. It is for the purpose of arriving at the water depth required for the steady state while the discharge is varying in the interacting canal pools. This helps in decision making as how to operate the gates of the cross regulator between the canal pools. Gate operations of the cross regulator is critical as it leads finally to the steady state and if it is not done properly, the steady state may be attained with much delay. The transfer function for interactive coupled canal pools is envisaged with the consideration of resistance to flow in canal pools in terms of head losses. The control actions i.e. Proportional (P) and Integral (I) applied to the transfer function and the results are compared with a properly validated simulation model - Unsteady State Simulation Model i.e. NPUSM [1].

II. THE INTERACTIVELY COUPLED CANAL POOL SYSTEM

The schematic view of interactive coupled canal pools system [3] is shown in Figure – 1. It shows that interactively coupled canal pools have a control structure in between. It can be a cross regulator or a valve. Figure – 2 shows the variations of water levels in two consecutive interactively coupled tank process. These variations are actually in the form of fluctuations of water levels. They are required to be considered at different instances up to attainment of the steady state.

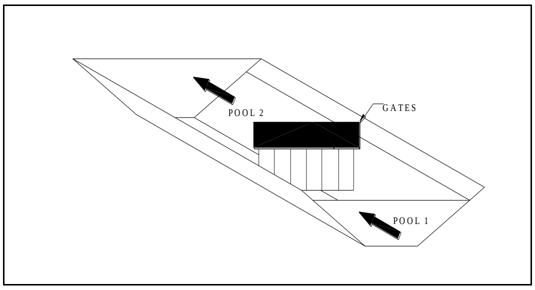

Figure - 1 Schematic View of Interactively coupled Canal Pools

In the initial stage, the water tank system is considered & the steady state of flow is assumed in two consecutive pools. The inflow rate and outflow rate both are considered as Q and flow rate between the tanks or interaction in terms of flow between the two tanks is assumed zero.

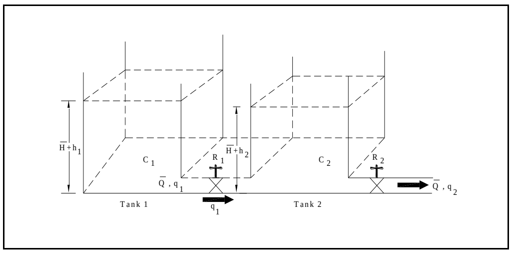

Figure-2 Liquid Level System in Interactively coupled Tank Process

As described above all the losses which occur in liquid level systems are assumed as lumped losses at the flow control valve itself. In the canal pool, however, the frictional losses to flow occur along the entire wetted perimeter and along length of canal pool. With due consideration of losses for non-uniform and transient flow condition in the canal pools, the modified equations for variations of heads in canal pools are as follows.

$$For \quad Tank \quad 1$$

$$C_1 dh_1 = (q - q_1)\, dt$$

$$q_1 = \frac{h_1 - h_2}{R_1}$$

$$\frac{dh_1}{dt} = \frac{1}{T_1}[q - (h_1 - h_2)] \qquad \ldots\ldots\ldots \qquad (1)$$

$$For \quad Tank \quad 2$$

$$C_2 dh_2 = (q_1 - q_2)\, dt$$

$$q_1 = \frac{h_1 - h_2}{R_1}$$

$$q_2 = \frac{h_2}{R_2}$$

$$\frac{dh_2}{dt} = \frac{1}{T_2 R_1}[R_2 h_1 - h_2 (R_1 + R_2)] \qquad (2)$$

where,

C_1- capacitance of Tank1, C_2- capacitance Tank2, h_1 - head in Tank1, h_2 - head in Tank2, q_1 - discharge from Tank1, q_1 - discharge from Tank1, q_2- inflow in Tank1, R_1 -resistance offered by valve between Tank1 and Tank2, R_2 -resistance to outflow from Tank2, dh-change in head in time interval dt, T_1 -time constant for canal pool 1, T_2 -time constant for canal pool 2. As the canal pool system can be assumed linear or can be linearized by keeping the changes small within the time interval. The linearized equations are as follows:

$$For \quad Tank \quad 1$$

$$\frac{dH_1}{dt} = \frac{1}{T_1}[q - (H_1(t) - H_2(t))] \qquad (3)$$

$$For \quad Tank \quad 2$$

$$\frac{dH_2}{dt} = \frac{1}{T_2 R_1}[R_2 H_1(t) - H_2(t)(R_1 + R_2)] \ldots\ldots\ldots\ \ldots\ldots\ldots\ \ldots. \quad (4)$$

The variations of heads i.e.H_1 &H_2 in Tank1 & Tank2 respectively due to change in steady state discharge i.e.Q .The same equations can be represented in Laplace form as below:

$$\frac{H_1(s)}{Q(s)} = \frac{R_1 R_2 C_2 s + 1}{R_1 C_1 R_2 C_2 s^2 + (R_1 C_1 + R_2 C_2 + R_1 C_2)s + 1} \qquad (5)$$

$$\frac{H_2(s)}{Q(s)} = \frac{R_2(R_1C_1 s + 1)}{R_1C_1R_2C_2 s^2 + (R_1C_1 + R_2C_2 + R_2C_1)s + 1} \quad (6)$$

III. CONTROL SYSTEM MODEL

The control system consists of two canal pool system with due consideration of interaction between pools is shown vide Figure-3.. The PID controller tool of MATLAB is used with zero parameter for Derivative control action. The discharge passes through the control structure i.e. gate is dominantly governed by the water levels on either side of gate i.e. upstream & downstream level respectively. Hence, the interactive influence of water level of one pool to another pool is considered in the form of feedback signal from downstream pool to upstream pool.

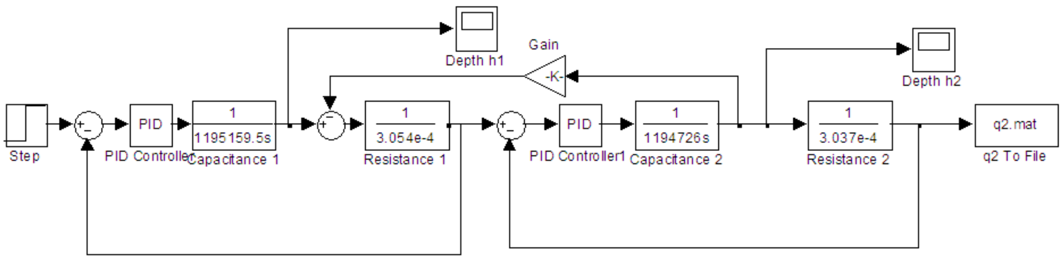

Figure-3 Control System Structure

IV. RESPONSE ANALYSIS OF SYSTEM:

In the canal system, the change in gate opening is a disturbance to steady canal system i.e.Steady State. Same way the step input is applied to above control system model as an disturbance to the steady state and the response to this input in terms of depth fluctuation in Canal Pool 1 and 2 are plotted in MATLAB and presented vide Figure - 4 & Figure – 5.

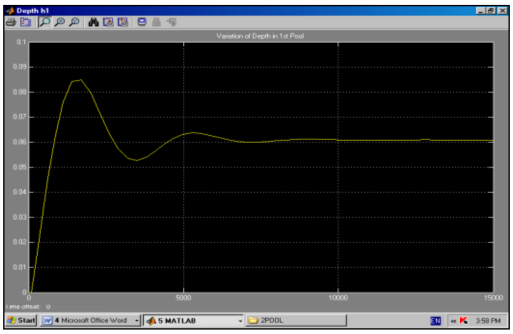

Figure – 4 Step Response of canal pool 1

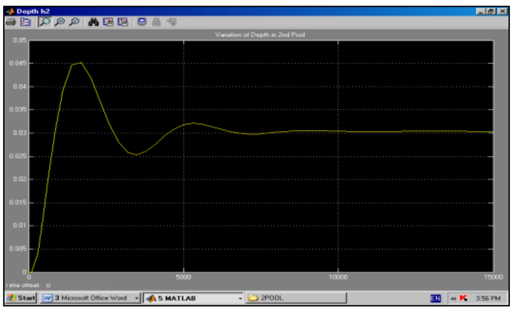

Figure – 5 Step Response of in canal pool 2

V. ROOT LOCUS SYSTEM

The design of the controller must be defined the characteristic of transient response and steady state response that can be explained as

1) The characteristic of transient response can be described in form of percent overshoot (P.O.)
2) The characteristics of steady state response can be described in form of settling time ts

The method to design for satisfying response at the transient state and steady state can be applied as explained in following steps.
Step 1. Finding the damping ratio: ξ and under damped natural frequency: ω_n by considering the characteristic of transient response and steady state response from the Equation (7) &(8).

$$\frac{C(s)}{R(s)} = \frac{\omega_n^2}{(s+\xi\omega_n + j\omega_d)(s+\xi\omega_n - j\omega_d)} \qquad (7)$$

$$where \; ,$$

$$\omega_d = \omega_n\sqrt{1-\xi^2}$$

$$Max. \; Percent \; Overshoot \; (P.O.)$$

$$= e^{-\left(\xi/\sqrt{1-\xi^2}\right)\pi} * 100 \qquad (8)$$

$$ts^{(\pm 2\%)} = \frac{4}{\xi\omega_n} = 4T$$

$$s_d = -\sigma + j\omega_d$$

$$OR$$

$$s_d = -\xi\omega_n\sigma + j\omega_n\sqrt{1-\xi^2} \qquad (9)$$

From the Simulation results the values of above parameters are worked out as below:
Case I : The time constant T=360, ξ=0.575 and ω_n = 0.00463 and the
P.O.$\leq$ 9.46%, $t_s \leq$309 sec
Case II The time constant T=450, ξ=0.575 and ω_n = 0.00386 and the
P.O.$\leq$ 7.656%, $t_s \leq$450 sec
The root loci of both the pools are given vide Figure - 6 & Figure – 7.

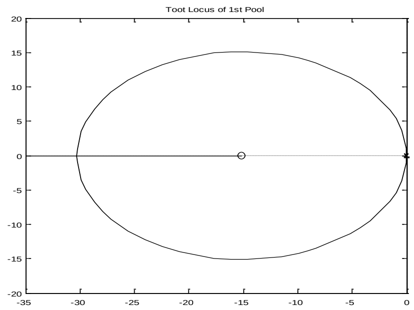

Figure – 6 Root Locus of canal pool 1

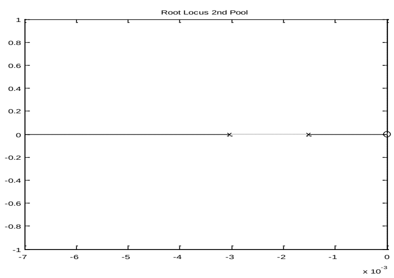

Figure – 7 Root Locus of canal pool 2

VI. SIMULATION RESULTS

The simulation analysis of interactive coupled canal pools are carried out by using the (Narmada Project Unsteady State Model) NPUSM and the results of essential parameters are presented herewith vide Table 1 below.

TABLE - 1

Sr.No	Discharge variation	Settling Time (min)	Time Constant(Sec)
1	800 to 740	360	360
2	934 to 854	400	450

The graphical presentation of variations of depth (Downstream depth because of Downstream Control Algorithm) of Interactive Coupled Canal Pool Nos. 1 and Pool 2 are presented vide Figure – 8 and Figure - 9.

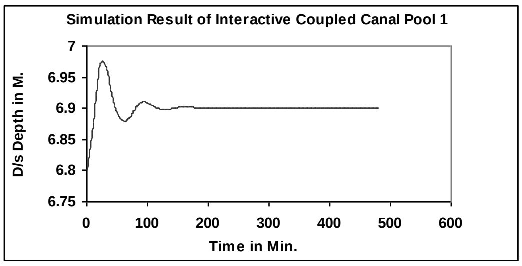

Figure – 8 Simulation Result of Canal Pool 1

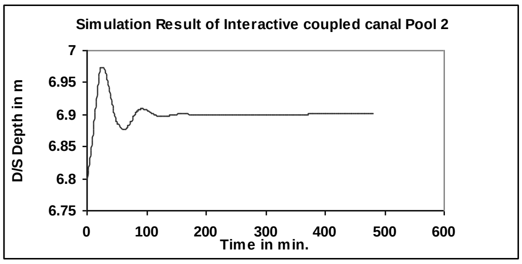

Figure – 9 Simulation Result of Canal Pool 2

VII. CONCLUSION

This paper presents the design of Auto-tuning PID controller by using Step Input Response (SIR) in order to model the process. The interactive Water Tank Process used as a basic tool for development of Transfer Function for Interactive Coupled Canal Pools and the MATLAB is to be a tool for modeling and testing the system. In this article, the transient response of the modeled system from SIR is very similar to the modeled system on nonlinear model, but there is some error not more than 5 percent that is under the condition of control system design. The results of SIR for Canal Pool 1 & 2 are compared with the proven model NPUSM and phenomenally depth fluctuations follow the same dynamic behavior. In both the case it reaches the peak asymptotically and after peak it show fluctuations and then steady state is finally achieved which is the ultimate aim of canal operation. So, it can be concluded that the developed Control System Structure can represent the dynamic behavioral of interactive coupled canal pools of canal conveyance system.

"Data Availability Statement"
Data, models, or code generated or used during the study are available from the corresponding author by request as follows:

1. Proportional Constant (P)
2. Integration Constant (I)
3. Derivative Constant (D)
4. Resistance R
5. Capacitance C

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