Real-time control of water systems

PID controller

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Contents

Description

In this case study, we apply real-time control to keep the water level within the drought (3.2m) and flood (4.5m) levels. A total of three schemes were tested, namely P, PI and PID. In the analysis results, the effects of the schemes on water level and gate opening will be analyzed.

Data

Table 1. Key variables of P controller

Process variables			
Initial gate level	hg_0	3	m
Initial water level	hw_0	3	m
drought water level	hd	3.2	m
flood water level	hf	4.5	m
Area of the reservoir	A	10000000	m2
Gate width	W	3	m
Min. gate level	Min_g	2	m
Max. crest level	Max_g	4	m
Control variables			
gravity coefficient	g	9.8	
Coefficient	Cc	0.61	
Prop. Gain	K	2.090307722	
Time step	dt	7200	s

Table 2. Key variables of PI controller

Process variables			
Initial gate level	hg_0	3	m
Initial water level	hw_0	3	m
drought water level	hd	3.2	m
flood water level	hf	4.5	m
Area of the reservoir	A	10000000	m2
Gate width	W	3	m
Min. gate level=	Min_g	2	m
Max. crest level=	Max_g	4	m
Control variables			
gravity coefficient	g	9.8	
Coefficient	Cc	0.61	
Prop. Gain	K	2.090307722	
Integral Time	Ti	108000	s
Time step	dt	7200	s

Table 3. Key variables of PID controller

Process variables			
Initial gate level	hg_0	3	m
Initial water level	hw_0	3	m
drought water level	hd	3.2	m
flood water level	hf	4.5	m
Area of the reservoir	A	10000000	m2
Gate width	W	3	m
Min. gate level=	Min_g	2	m
Max. crest level=	Max_g	4	m
Control variables			
gravity coefficient	g	9.8	
Coefficient	Cc	0.61	
Prop. Gain	K	2.090308	
Integral Time	Ti	108000	s
Differential Time	Td	33781.55	s
Time step	dt	7200	s

Result and analysis

2.1 graph 1

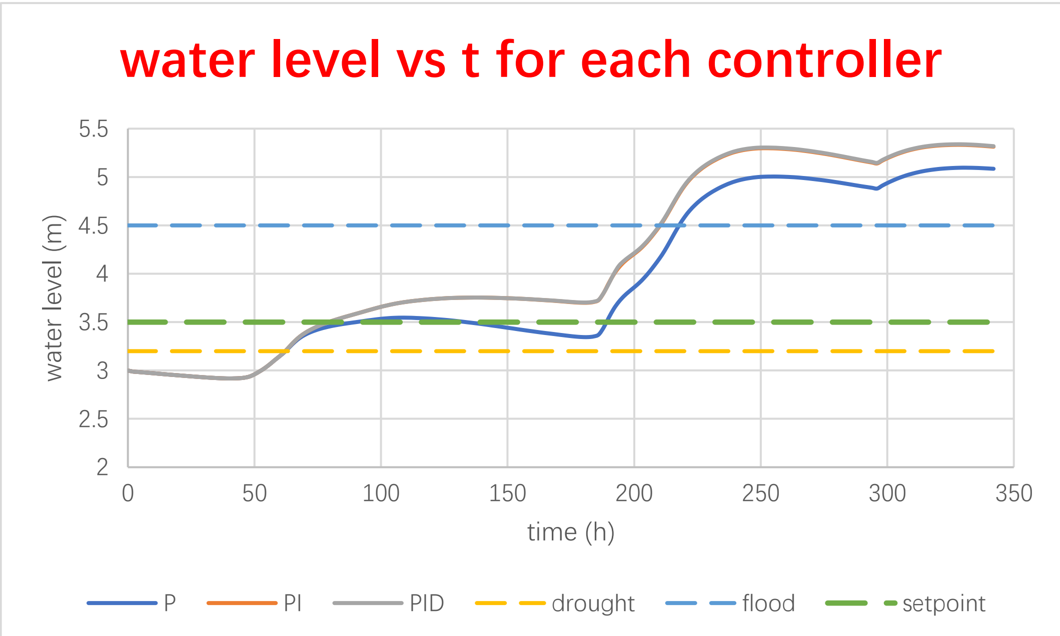

Figure 1. y1 (water level) vs t, for each controller (P, PI and PID)

At 180h, the water level climbs to the setpoint and begins to oscillate. However, due to the flood (large inflow), the water level continues to rise above the flood water level (4.5m), and

then the water level does not rise at around 5m. All three curve show an upward trend, of which P scheme is lower than the other two in the whole procession. However, PI and PID scheme basically coincide, with little difference.
There are three local maximum in the whole, which occur at 120h, 250h and 320h. The parts of three curves between flood water level and drought water level are from 65h to 220h.
Next, the report analyzes the effect of each PID term. For Proportional Controller (P controller), it can set proportion to the existing error assuring controlled reaction over the full range. In the first half of P scheme, it gets closer to the setpoint and doesn't take necessarily overshoot. Since small K value makes the process slow. The P controller is a quite sloppy control and loss of the stabilization ability. Normally, most of the changes are controlled by the P controller.
For Proportional-Integral Controller (PI controller), it sums up all deviations from the setpoint in time, so it's integral action can speed up the process of reaching the setpoint. Therefore, the PI curve is higher than the P curve in the picture and exceeds the setpoint water level.
For Proportional-Integral-Differential Controller (PID controller), it can forecast required action by observing the error changing speed and add correctness actions as the error changing rapidly. But in this figure, it doesn't play the role of D controller.

2.2 graph 2

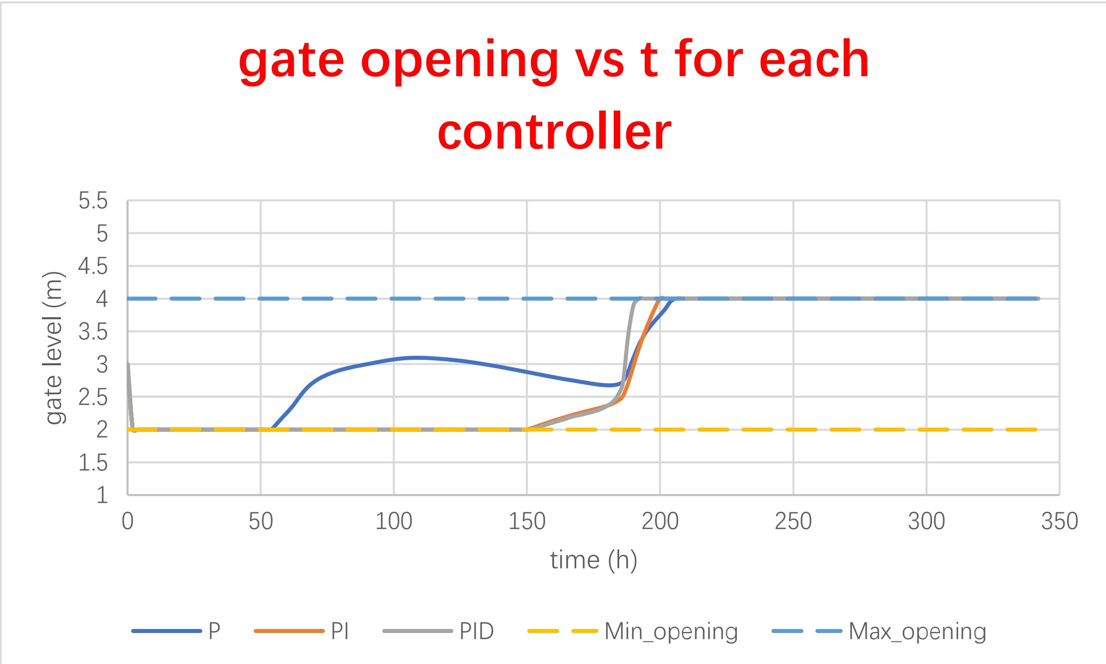

Figure 2. y2 (gate opening) vs t for each controller (P, PI and PID)

The P scheme first keep at the minimum opening level till 52h, and then slowly changes until the opening level reaches the maximum opening level in 200h. The other two curves are roughly similar, maintaining the minimum opening before 150h, and then quickly rising to the maximum opening at 200h. The curve has an inflection point at 180h, when peak inflow appears, and the ascent rate accelerates. The difference between the two is that PI scheme rises faster than PID scheme.
Integral controller keeps the gate low and accelerates water level changes. So, it speeds up

the process of getting the setpoint. Differential controller improves the gate opening rate when the precipitation changes rapidly. That is to correct for rapid system changes by observing the speed in error change.

2.3 graph 3

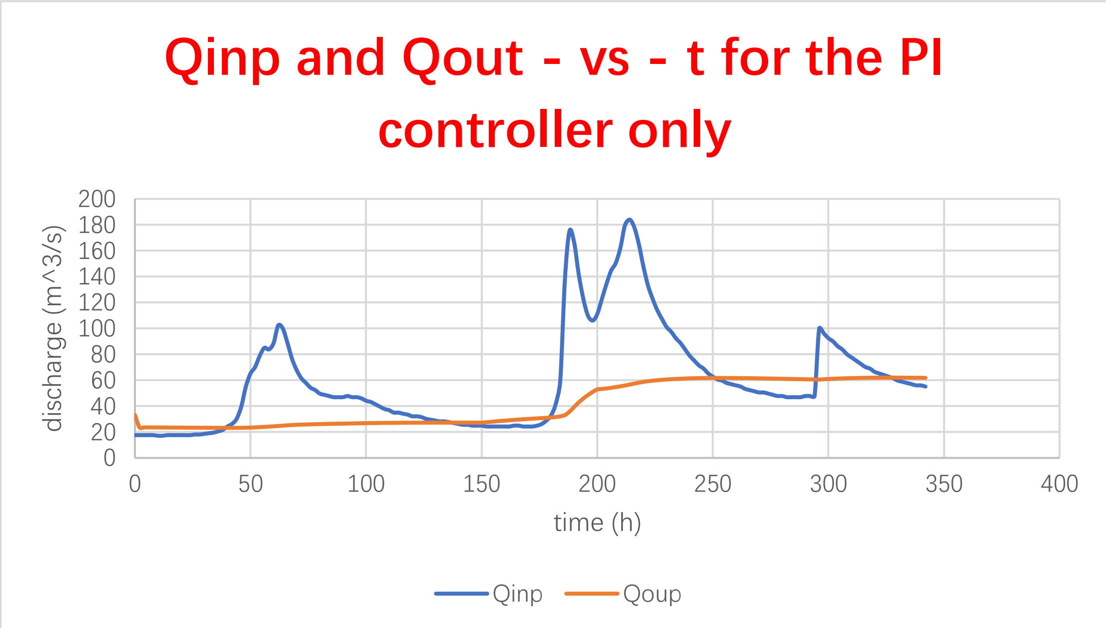

Figure 3. Qinp and Qout vs t for the PI controller only

There are three sections of inflow in 60h, 180h and 300h. For the first and third, the peak value is about 100 m^3/s, which is the range that the reservoir can bear, so the outflow does not change much. However, the instantaneous flow of the second flood is too large to control, causing the outflow to drain quickly, so that the water level does not rise too high. The water level changes only about 10 hours after the occurrence of flood, which can be called a hysteresis.

Coefficient determination method

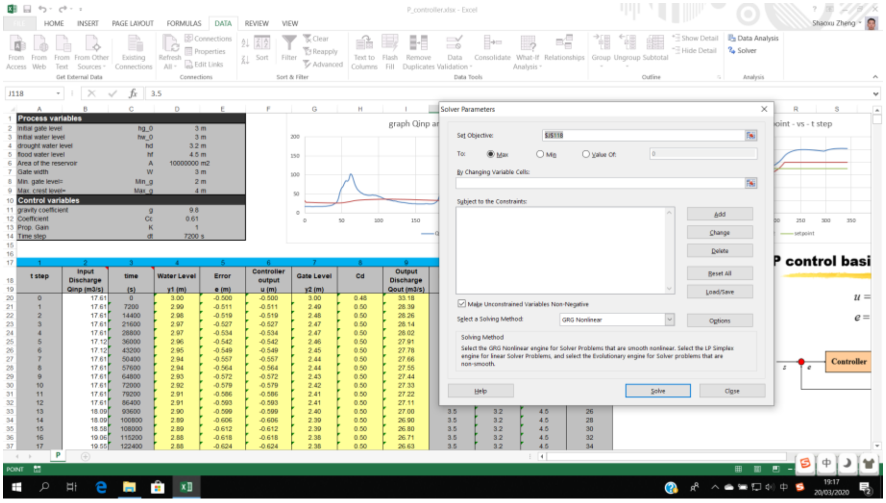

Figure 4. operation surface

• K=2.09: First set only the proportional coefficient K. calculate the absolute error of each time, and then calculate the average absolute error of the entire process. Use the solver in Excel to solve the GRG Nonlinear problem, and minimum the objective function 'mean absolute error'. Note that all solutions are local optimal solutions, and there is no maximum value solution.

• Ti=108000: Second, determine the Integral coefficient Ti. This step is basically like the previous step, except that the decision variable is Ti here, and K is stable using the value of the previous step. In this step, the equation does not converge and has no solution. Therefore, by observing the change in water level in the figure, we choose the smoother image as the approximate maximum solution.

• Td= 33781: Finally, determine the differential coefficient Td. Repeat the above operation and set the decision variable to Td.

Further changes to improve the performance

The entire reservoir system has a poor ability to adjust the water level, and it is easier to modify the gate. The scheme is to modify the gate width from 3m to 5m.

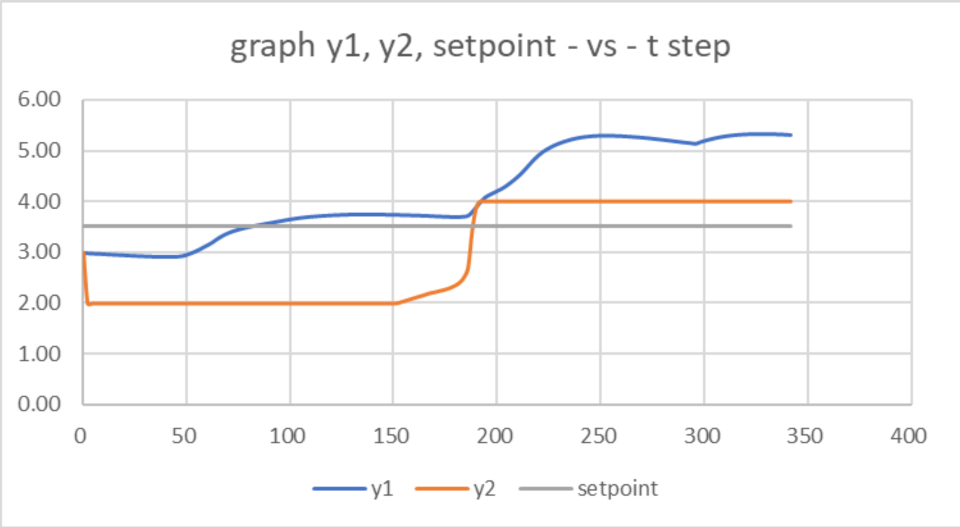

Figure 5. Graph y1, y2, setpoint –vs –t step (W=3m)

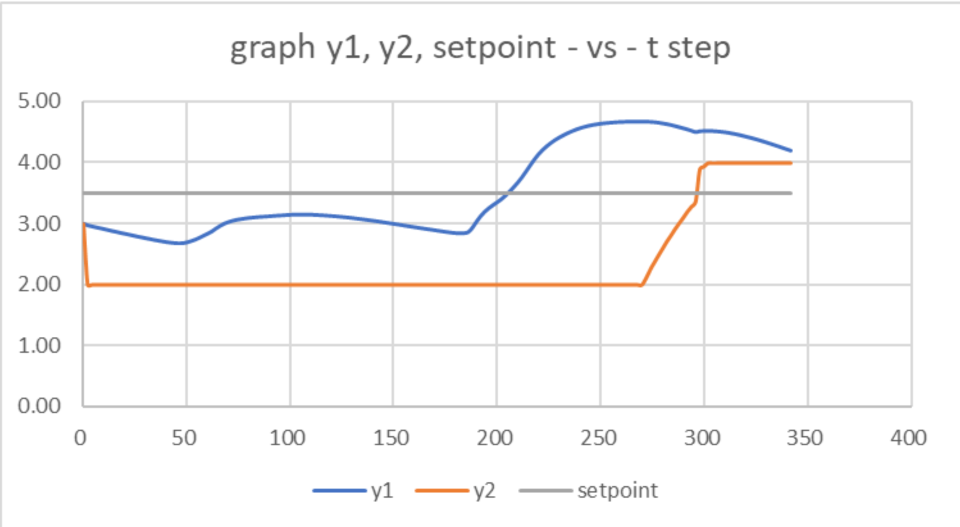

Figure 6. Graph y1, y2, setpoint –vs –t step (W=5m)

By widening the gate width, it is found that the maximum value of the water level dropped from 5.2m to 4.8m, which basically meets the requirements of the water level in the target range.