DESIGNING AND EVALUATION CONTROL SYSTEM OF THE DEZ MAIN CANAL

CONCEPTION ET SYSTEME DE COMMANDE DE L'EVALUATION DU CANAL PRINCIPAL DE DEZ

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ABSTRACT

In the present study, a water level local upstream PI feedback controller was applied for the west main canal of Dez irrigation system in Iran. Total length of the proposed canal is 93km, in which the first 45km of the canal are considered. The canal has a design discharge capacity 157 $m^3 s^{-1}$ *at its head. There are 14 'in-line' check and 71 offtake structures, and 15 cross-structures along the length of the canal. The model of the proposed canal was formulated in the SOBEK simulation package. The control system was also programmed in MATLAB. To evaluate the control system potential, simulations were done for three months of the real offtakes schedule. The flow control time step and feedback control time were considered both 5 minutes. The performance criteria of the maximum absolute error (MAE), the integral of absolute magnitude of error (IAE), and the steady state error (StE) were determined. The results indicated that the applied control system has considerable potential to closely match the discharge at the downstream check structures with those ordered by water users while maintaining the water level throughout the length of the canal.*

Key words: *Control systems, feedback controller, irrigation canals, PI controller, upstream control.*

RESUME

Dans l'étude actuelle un dispositif de commande des commentaires PI local de l'eau en amont a été appliqué à l'ouest du canal principal du système d'irrigation de Dez en Iran. La longueur totale du canal proposé est de 93 km, dont premier 45 kilomètres font l'objet de l'étude. Le canal possède une capacité de débit nominal de 157 $m^3 s^{-1}$ *en amont. Il y a 14*

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barrages régulateurs, 71 canaux dérivés et 15 régulateurs tout au long du canal. Le modèle du canal proposé a été élaboré dans le logiciel de simulation SOBEK.

Le système de commande est programmé sous format MATLAB. Pour évaluer le potentiel du système de commande, les simulations ont été réalisées pour trois mois pour le régime réel de prise d'eau. Les critères de la performance de l'erreur absolue maximale (MAE), de l'intégrale de la magnitude de l'erreur absolue (IAE), et de l'erreur permanente en régime (STE) ont été déterminés. Les résultats indiquent que le système de commande détient un potentiel considérable pour se rapprocher du débit des barrages régulateurs en aval aux ceux commandés par les utilisateurs de l'eau tout en maintenant le niveau d'eau tout au long du canal.

Mots clés: *Systèmes de commande, dispositif de commande des commentaires, canaux d'irrigation, commande par l'amont.*

1. INTRODUCTION

Irrigated agriculture generally uses large volumes of water compared to municipalities and industry, and competition for good quality water is at an all time high in many regions around the world. Thus it is recognized that improved water management practices in agriculture can lead to substantial benefits in terms of water availability for expanded agricultural activity and for other uses, and can directly address many environmental concerns. Intelligent management of open-channel conveyance and delivery systems is necessary to achieve higher water savings in irrigated agriculture. Nowadays use of control systems in irrigation network for improving efficiency in water distribution and water delivery to users is more applicable. The main purpose of a flow canal control system is to optimize the water delivery based on specific operational objectives related to water levels or discharges or both, which are subject to external perturbations (Mutua and Malano, 2001). Specific operational objectives need to design specific control system for each irrigation system. In the presence of significant system uncertainty, the designer has to develop a robust control system. A robust control system exhibits low sensitivities to unknown demands (disturbances) and is stable over a wide range of disturbance variations. Malaterre et al. (1998) classified different control algorithms for the regulation of irrigation canals based on several criteria. These criteria may include measured variables, operating conditions (e.g. predicted withdrawals) and objectives (e.g. hydraulic targets). All control systems are common in term of using design technique (Malaterre et al., 1998). In principle, two main control techniques can be distinguished: Feedback and Feedforward. Sometimes a combination algorithm of both is also used. In water system controller, a Proportional Integral (PI) Feedback control is the most important control method. This is because the control actions are directly based on the control objective that the controlled system has to achieve. This can be seen in the block diagram of this controller (Figure 1).

With PI control, adjustment of control structures is proportional integral to the deviations. The deviation is calculated from the comparison between target level and measured water level, to determine the control action. The control action has a correcting influence on the controlled variable (water level), which is measured again and compared to the target level, etc. This control loop is repeated with a fixed control time step and, in the end, equalizes the measured water level to the set point. Most of the irrigation canal control methods are designed based on PI control theory, which uses the well-known linear mono-variable controller.

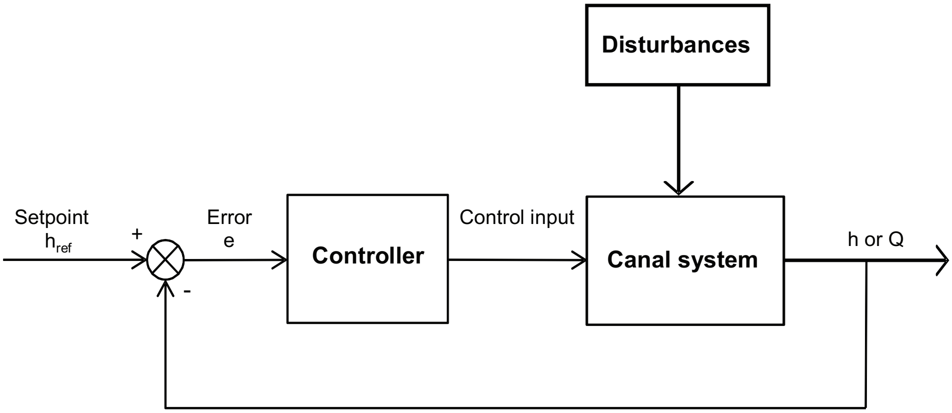

Fig. 1. Feedback PI controller

Local control (or distributed control) is where the control actions are computed using only measurements taken near the structure. With centralized control, measurements from all sites can be used to compute the control actions for all structures along the canal. As more information can be used, centralized control can potentially result in a higher performance than local control (Schuurmans et al. 1999; Wahlin and Clemmens 2002). On the other hand, centralized control requires more hardware, which makes the chance of system failure higher. For example, communication links can easily be damaged by cable cuts or radio interference. Under one scenario both centralized and local control might be available. During normal operating conditions, centralized control is active and water levels are maintained close to their target levels, even under largely fluctuating turnout flows. When there is a failure, the system can be switched to local control until the problem is solved. During this period the turnout flows should not be allowed to change (at least not too much), as the ability to deal with disturbances is lower for local control than for centralized control (Overloop et al. 2001). So in the design of a centralized canal or open-water channel, local control should be considered as an option, either as the main system or as the backup system.

In the present study, a local Proportional Integral Feedback control is designed and evaluated for the west main canal of Dez irrigation system in Iran.

2. MATERIALS AND METHODS

Proposed canal

Dez irrigation system is located in South west of Iran in North of Khuzestan province. The main canal in this system has been designed for the conveyance of irrigation water from Dez river to the irrigated areas in North of Khuzestan province. The irrigation system includes three large main canals. This study has focused on West main Canal of Dez irrigation system. Total Lengths of the proposed Canal is 93 km and in this study the first 45 km (13 pools) are considered. West main Canal design discharge capacity at the head is 157m^3/s. There are

14 "in-line" check structures along the length of this part of the canal. All the check structures are radial gates. There are 71 offtake structures and 15 cross structures like inverted siphon, culver and check-siphon on the main canal. These laterals are used for delivery of water for farmers and other user. Until presently, the canal is manually controlled. The operators deliver the demands of water users according to their requests. As the demands of the water users, in terms of flexible delivery, are increasing, there is an urgent need for supporting the operators by automating (parts of) the structure operations.

Designing control algorithm

PI controllers are the simplest and most widespread controllers (Aström et al., 1995; Litrico et al., 2006a; Montazar et al., 2005 and van Overloop 2005). The calculated control action is proportional to the magnitude of the output water level error (with a factor K_p), proportional to the magnitude of the integral of the output error (with a factor K_i). In continuous time, this is represented as follows:

$$u = K_p.e + K_i.\int edt \tag{1}$$

where u = control action, e = error, K_p = proportional gain factor and K_i = integral gain factor. The controller parameters can be changed, to improve the settling time or to reduce the maximum error or to minimize a given performance criterion.

A filter can be necessary to control a canal which is influenced by resonance behavior. Then we added first order low pass filter thorough the designed controllers to remove the resonance waves which play a dominant role in the water movements. Hence, a PIF-controller is a PI controller applied in series with a first order low-pass filter. Besides the proportional and integral gain factor, also a filter constant has to be determined, which is used to filter out the effect of resonance waves on the measured water level.

In an open canal system with different pools like Dez irrigation system under local upstream control, a control action not only tries to adjust the water level just upstream of the control structure the, but it also has a direct unintended effect on downstream water level. When the series of canal pools is controlled by a centralized controller, this effect can be taken into account. But in local control system the interactions between the pools are not considered. Figure 2 shows the scheme of this controller. The control actions as output are calculated based on the magnitude of the water level deviation which is as input to the controller. The calculated value is added to the downstream gate directly to make a centralized controller. In case of local upstream feedback control, the water level at the end of a pool is controlled by adjusting the gate at the downstream end of the pool, in reaction to deviation from set point. This type of control is called source oriented, because this controller provide the user demands by taking into account the available water in the upstream reach. Hence, this controller because of the difficulty of predicting precisely the actual water demand, upstream control have problem in downstream end of system which the users receive more or less water than they need. This problem can be solved by applying automated local upstream control.

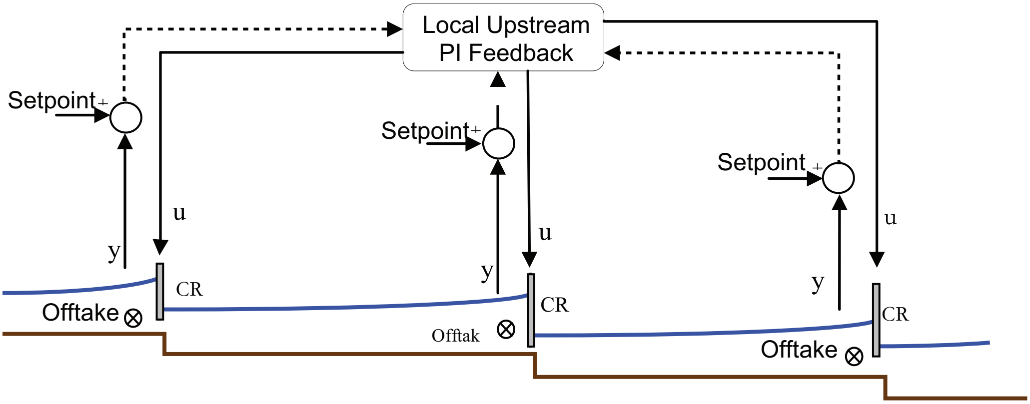

Fig. 2. Block diagram of local upstream PI feedback control

Simulations

The model of the West main canal of Dez irrigation system is simulated with SOBEK simulation package. The latter allows user defined controllers to be programmed in MATLAB with access to water levels and gate position from simulation through special function calls. SOBEK uses the WL|Delft Hydraulics (2000) implicit finite difference scheme. In this study, the hydrodynamic and real-time control modules are used. Real-time control is used to adjust the control structures depending on the actual situation. In these study a robust local upstream control systems for west main canal of Dez irrigation system is programmed in MATLAB. For evaluating the controller the simulation for is performed for three month of real offtake schedule. The data are gathered from the site for three month of 2006 from 21th March to 21th of May. Based on Dez irrigation system operation behavior, the offtake schedule during the first month of simulation have variable amount. The controller maintains the water level at target level (set-point) at the downstream end of the canal pools. Due to schedule variation of offtake for operation purpose, the set-point deviations are taking place at the end of each pool. The local upstream PIF controller calculates a desired flow change for check structure on downstream end of canal pools. The check structure flow controller adjusts the gate setting to provide the desired flow using the formula of the structure's depth–discharge relation. The parameters of the PIF controller are tuned according to the tuning rules for open channels (Schuurmans, 1997).

Performance indicators

In order to assess the performance of the controller and to have quantitative comparison, the performance indicators are computed for each controller. Calculated indicators for controlled variables are: the maximum absolute error (*MAE*), the integral of absolute magnitude of error (*IAE*) and the steady state error (*StE*). These indicators are defined as:

$$MAE = \frac{\max\left|y_t - y_{setpoint}\right|}{y_{setpoint}} \tag{2}$$

where y_t is computed water depth from model at time (t) and $y_{setpoint}$ is target water depth at the end of each pool. The integral of absolute magnitude of error is:

$$IAE = \frac{\frac{\Delta t}{T}\sum_{t=0}^{T}\left|y_t - y_{setpoint}\right|}{y_{setpoint}} \qquad (3)$$

where Δt regulation time step and T is is time period for simulation and StE is:

$$StE = \frac{\Delta t}{(t_0 + \Delta t).y_{setpoint}} \sum_{t=T-t_0}^{T}\left|y_t - y_{setpoint}\right| \qquad (4)$$

where t_0 is 2 hours

These indicators are calculated for controllers for each pool in Dez irrigation system in same period of simulation. The steady state error is shows the ability of controller to damping the perturbations which occur in pools. For calculating this index for each pool the last two hours of simulation is considered.

Tuning of the applied controller

Feedback PI-controllers are the most widely used controllers in the world, but the tuning of a controller still remains a difficult and tedious task. The parameters of the controller (K_p and K_i) have to be chosen such that the PI-controlled system is brought back to set point fast, with minimal overshoot. Furthermore, the water level has to return exactly to set point, without constantly overshooting. In practice, the controller is either designed for a worst case scenario. If the controller is stable under a wide range of conditions, the design is said to be robust (Litrico et al. 2006b). The settings for designed controllers are determined for all pools under low flow 10%, under medium flow 50% and under high flow 80% of design discharge.

The canal characteristics are used in the tuning rules derived by (Schuurmans, 1997), this method gives the possibility to tune a controller based on characteristics found from model data by applying system identification (Miltenburg, 2008). The pool characteristics that are required as input for the ID tuning method of PIF controllers are Storage Area (m^2), Delay Time (Sec), Resonance Frequency (Rad/Sec) and Resonance Peak. These characteristics are determined by applying simple identification techniques (Weyer, 2001). The resonance characteristics from a canal pools are necessary to design a PIF-controller. A tuning method, based directly on the canal characteristics was derived by (Schuurmans, 1997).

These tuning rules provide parameters for Proportional Integral control, valid for various ID model parameters corresponding to different flow regimes. Table 1 shows The Proportional Integral parameters for the proposed controller. To design a controller that performs well, the hydraulic characteristics of the irrigation system need to be determined. However, because the ID model only gives an accurate description of the dynamics when no resonance occurs, this method is not applicable in all canal pools. When the influence of the resonance waves can be filtered out of the signal that the controller uses to calculate a control action, the results of the controller can be better. In the same work, tuning rules for a so called PIF controller have been derived. A PIF controller is a PI controller applied in series with a first order filter. For resonance-dominated pools the PIF tuning rules have been shown to result in high performance (Overloop et al., 2005). The set of tuning rules for the PIF controller require the resonance frequency and the height of the resonance peak, in addition to the ID-model parameters of the delay time and the storage area. For tuning the local upstream FB control the already proposed multiple-model optimization of PI controller on canals is used (Overloop et al., 2005). In this technique, a linear controller is tuned in such a way that it stabilizes all models (for all sets of flows) and optimizes an objective function that is a sum of individual objective functions, each valid for one of the models from the set. By applying a multiple model optimization that minimizes the water-level deviations from target level in all pools, the tuning of decentralized PIF controllers on canals can be done in one design step, without an extensive trial-and-error procedure.

Table 1. Controller parameters resulting from system identification

Pool no.	1	2	3	4	5	6	7	8	9	10	11	12	13
K_p	29.33	24.24	34.44	51.38	33.64	36.24	35.92	40.86	36.62	35.78	35.41	32.09	28.69
K_i	0.76	2.11	0.49	0.37	0.69	0.68	0.90	1.05	1.16	1.57	2.57	3.12	9.19

3. RESULTS AND DISCUSSION

There are 70 offtake on the proposed main canal. Figure 3 presents the discharge schedule of six offtake on Dez canal. The offtake W2 and W1L13 have the highest and lowest discharge and flow change values, respectively. Daily operation of the canal to deliver the water demand to users is accomplished during the cropping period. The real gathered offtake schedule is programmed to simulate a real flow delivery by controller. Figure 4 shows the discharge of check structures for distance downstream FB controller. As can be seen in the figure, the offtake W2 which has the highest change in flow is more effect on the discharge of check structures. The discharge of check structures are similar to discharge variation of W2, which controller tried to deliver the demands of offtake schedule more sufficient.

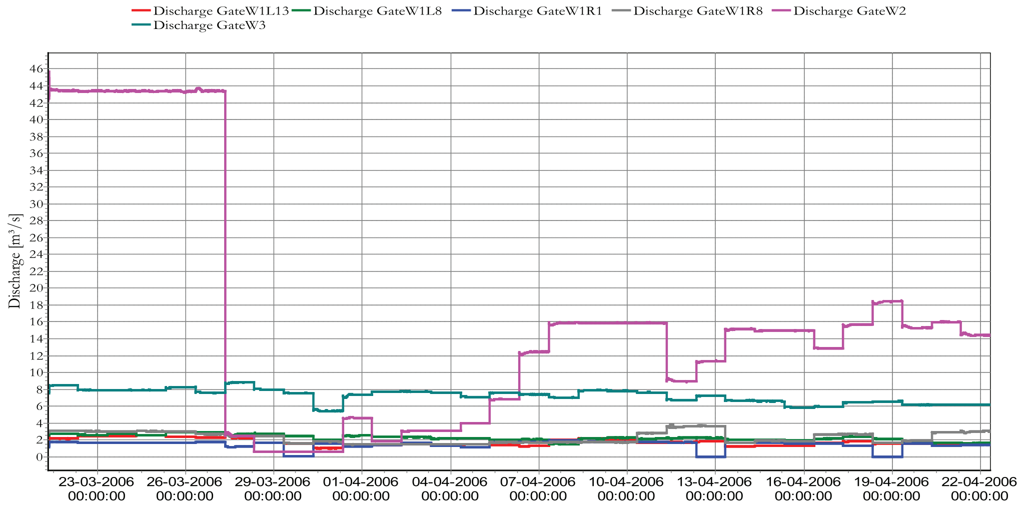

Fig. 3. Offtakes flow changes schedule

The water level at the upstream side of check structure for controller is presented in Figure 5. This figure clearly shows that controller tries to achieve the desired water levels as quickly as it possible. It should be mentioned desired flow rates of offtake can provide when the desired water level at the canal achieve sufficiently. Based on operation behavior of Dez canal, the offtakes flow for simulated month has more changes. The discharge of W2 changes from 43 m^3/s to 1.70 m^3/s. This flow change in offtake schedule cause a large distribution at the upstream side of check structure D2. It can be seen in this controller the effects of perturbations are in both upstream and downstream pools. Because in this controller the interactions between the pools are not taken to account. From implementation viewpoint this controller has more costs as because of using decouplers between the pools it will need the transmission lines or wireless connection devices along the canal. Local upstream control is the automated form of the current operation in Dez irrigation system. It can be mentioned this controller also has more benefits associated with to the manual operation.

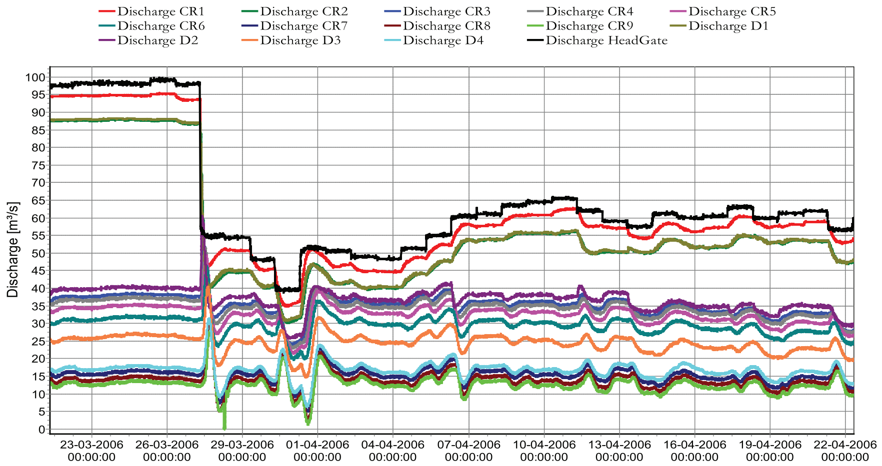

Fig. 4. Discharge of check structures for the proposed control (first month of simulation)

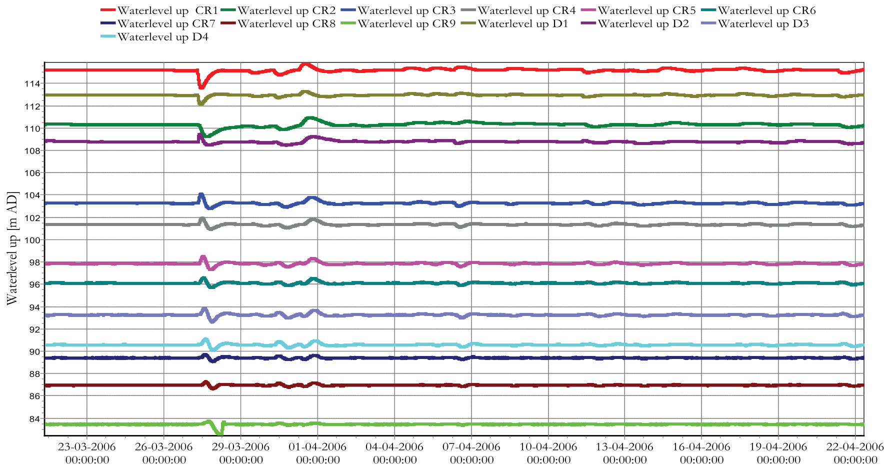

Fig. 5. Water levels at the upstream side of check structures for the proposed controller

Table 2 presents the calculated performance indicators for designed controller. These indexes demonstrate that the controller is robust control system which during worst scenario of simulation has ability to control the water level at the setpoint with less deviation from desired setpoint. The value of *MAE, IAE* for pool no. 4 has a maximum value. Due to the branching large offtake from this pool, the significantly greater oscillations occur in water levels which cause the increasing of these indicators. The index *StE* is calculated for the last remained 2 hours of simulation for each pool. This indicator presents the ability of controller to bringing the controlled variables back to set point fast and without constantly overshooting. These values show controller could maintain the water level to the setpoint. The average value of *MAE, IAE* and *StE* for controller respectively is 0.229, 0.016, and 0.005.

Table 2. Performance indicators of the pools

Pool no.	MAE	IAE	StE
1	0.342	0.019	0.001
2	0.318	0.019	0.006
3	0.283	0.029	0.003
4	0.285	0.026	0.016
5	0.246	0.018	0.006
6	0.175	0.016	0.010
7	0.189	0.016	0.006
8	0.145	0.013	0.005
9	0.189	0.015	0.002
10	0.154	0.013	0.003
11	0.134	0.011	0.003
12	0.120	0.010	0.002
13	0.399	0.009	0.001

4. CONCLUSIONS

This paper presents a local upstream controller for west main canal of Dez irrigation system in Iran. In the design of a centralized canal or open-water channel, local controller should be considered as an option, either as the main system or as the backup system. Successful implementation of water-level control with these structures using local PI controllers depends heavily on the tuning of the control parameters. The results of designing and tuning of this controller show that the proposed controller have significant potential to closely match the discharge at the downstream check structures with those ordered by water users while maintaining the water level throughout the length of the canal.

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