OPTIMIZED ALLOCATION OF CHLORINATION STATIONS FOR INTEGRATED QUANTITY AND QUALITY CONTROL IN DRINKING WATER DISTRIBUTION SYSTEMS

M. Drewa[1], M.A. Brdys[1],[2]

[1] *Department of Automatic Control, Gdansk University of Technology, ul G. Narutowicza 11/12, 80 -952 Gdansk, Poland, email:mdrewa@ely.pg.gda.pl, mbrdys@ely.pg.gda.pl*

[2] *School of Engineering, Department of Electrical, Electronic and Computer Engineering, University of Birmingham, Birmingham B15 2TT, UK, email: m.brdys@bham.ac.uk*

Abstract: Providing required quality of water delivered to the consumers is still a challenging operational task at drinking water distribution systems. Water quality meets the quality requirements at the outputs from the treatment plants but it may significantly deteriorate when travelling throughout the system and become not usable at the consumption nodes. It becomes then necessary to introduce secondary chlorine disinfection at certain nodes within the system network. The booster stations are located at these quality control nodes to inject the chlorine so that the quality requirements are met throughout the network, including the consumption nodes. The integrated quality and quantity optimized control can then be safely carried out in the system. The paper proposes a method for allocation of the booster stations such that a desired trade off between several objectives is robustly achieved. An advanced genetic solver of the derived optimization task is applied to determine the optimized allocation. The method is illustrated by application to the case study system.

Keywords: quality control, optimization problems, genetic algorithms, environmental engineering, algorithms, water quality.

1. INTRODUCTION

Drinking water distribution system (DWDS) delivers water to domestic and industrial users. Hence, main objective for DWDS is to meet water demand of required quality at every consumer node (Brdys and Ulanicki, 1994).

Complexity and extensiveness of DWDS as well as amount of domestic water users not allowed to direct and active water quality control at each network node. Hence, the appropriate selection of control quality nodes is very important. On one hand this selection should meet quality requirements at remaining network nodes but on the other hand a number of quality control nodes should be relatively small. Cleary, it is impossible from economical point of view to locate chlorine actuators at every consumer node.

Drinking water quality is characterized by the sequence of parameters but from the consumer point of view the concentration of chlorine residuals is the most important water quality parameter.

Until recently, the only method of ensuring proper levels of chlorine in the network was to add sufficient dose of disinfectant at the water treatment plant supplying water to the network.

However, chlorine in pipelines decays over time as a consequence of reaction with natural organic matters present in the bulk and the biofilms and corrosion products located at the pipe walls (Boccelli, *et al.* 2003). Moreover, if the amount of chlorine dosage is too small, complete chlorine decay in some network areas may occur. Hence, in order to maintain proper chlorine concentrations at the consumer nodes, appropriate chlorine dosage at water treatment station seems to be essential. Unfortunately, chlorine concentration overdose is hazardous for human health as well as causes formation of dangerous disinfection by-products (DBPs) concentration. Some of these compounds are suspected to be possible carcinogenic (e.g. THMs). Moreover, an excessive chlorine concentration leads to consumers complains as the water smells unpleasant. All these lead to strict government regulations in relation to allowable concentration levels of chlorine residuals and DBPs compounds in the water distribution systems.

Introduced by (Boccelli, *et al.* 1998) booster chlorination allows reducing the needed dose of disinfectant added at water treatment plant. This approach assumes adding an extra dose of chlorine in some specific nodes (quality control nodes) throughout the water distribution system. This allows reducing the total amount of chlorine used to maintain water quality within prescribed limits in the DWDS. Additionally, the booster chlorination enables to decrease maximal chlorine concentration which results in a better consumer satisfaction. The received water taste is good and the water quality meets the requirements. Since the publication of Boccelli et al. (1998) a number of approaches to allocation of booster stations and chlorine scheduling have been proposed. Most of the proposed approaches considered the booster station placement and/or chlorine scheduling using a single objective approach (Boccelli *et al.,* 1998; Propato and Uber 2004a,b; Propato *et al.,* 2001; Tryby *et al.,* 2002).

A new approach to the problem solution using multiobjective strategy was proposed in (Prasad et al. 2004). A multiobjective optimization problem was formulated and solved by using multiobjective genetic algorithm. The multiobjective optimization approach was further considered by Kurek and Brdys (2006). A formulation that captures several demand scenarios was proposed in order to ensure that the booster station allocation can meet the quality requirements under different demands. Moreover, a quality controller was imbedded into the allocation problem formulation so that the realistic quality control trajectories were produced during the genetic search for the optimized booster station placement resulting in reducing number of the booster stations needed. The genetic solver was also enhanced in order to cater for specific futures of the application. However, some drawbacks still exist. Namely, although several demand scenarios are considered at the same time the corresponding flows are not produced by a proper quantity controller. The flows are produced as a sort of nominal or extreme ones or by using simple control laws that do not consider usual quantity control objectives. Therefore, conservatism in the solution still exists, which results in an excessive number of the booster stations.

In this paper the conservatism in the multiobjective optimized solution of the booster station allocation problem is further reduced. This is achieved by integrating the controller synthesis with the placement of the water quality control actuators throughout the network. As an interaction between quantity and quality exists the control problem is formulated as an integrated quantity and quality control problem (Brdys *et al.,* 1995). Hence, the integrated approach to booster station allocation problem consists in the simultaneous optimization of operation of the pumps and valves and chlorine injections by booster stations at the quality control nodes (integration of quantity and quality) and placement of the quality actuators, the booster stations. The single and multiple demand scenario cases are considered. The paper is organized as follows. In Section 2 the allocation problem is formulated in a form of constrained and single objective function optimization task. The objective function is build up from several functions describing different objectives of the allocation problem. The functions are then suitably weighted to produce the single objective function. The genetic solver of the optimization is presented in Section 3. The proposed allocation method was applied to DWDS case study in Gdynia, northern Poland and the obtained results are presented in Section 5. Section 6 concludes the paper.

2. PROBLEM FORMULATION

The relation between water quantity and quality is unilateral. Control of water quantity in DWDS has a considerable impact on quality control aspects (Brdys, *et al*., 1995). However, quality control has no effect on water quantity issues. Hence, the quantity – quality interaction is of one way type, which is from quantity to quality. An effective quality control requires then knowledge about quantity control. Such situation calls for formulation of integrated water quantity and quality optimization problem. Hence, proposed in this paper algorithm of facility placement in DWDS will be based on optimizing control of an integrated quantity and quality. A robustly feasible model predictive controller for the integrated quantity and quality optimizing control in DWDS was developed over the recent years in (Brdys *et al.,* 2000; Brdys and Chang, 2002; Trawicki, Duzinkiewicz and Brdys, 2003; Duzinkiewicz, Brdys and Chang, 2005; Langowski and Brdys, 2006; Wang and Brdys, 2006). The controller has been recently applied for the first time with full information feedback by Drewa, Brdys and Ciminski (2007) to the case study DWDS in Gdynia. The allocation algorithm presented in this paper applies only open loop control of an integrated quantity and quality, that is the predictive controller model based optimization with the predicted demands over 24hrs time horizon. It is in order to elevate the computational complexity.

2.1 Single scenario case

In this section the facility location of booster stations is proposed as a single objective optimization with a