

Optimal operation of water distribution networks by predictive control using MINLP

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Abstract

This paper presents an approach for the operational optimisation of potable water distribution networks. The maximisation of the use of low-cost power (e.g. overnight pumping) and the maintenance of a target chlorine concentration at final delivery points were defined as important optimisation objectives. The first objective is constrained by the maintenance of minimum emergency volumes in all reservoirs, while the second objective would include the minimisation of chlorine dosage and re-dosage requirements. The combination of dynamic elements (e.g. reservoirs) and discrete elements (pumps, valves, routing) makes this a challenging predictive control and constrained optimisation problem, which is being solved by MINLP (Mixed Integer Non-linear Programming). Initial experimental results show the performance of this algorithm and its ability to control the water distribution process.

Keywords: drinking water, mixed integer non-linear programming, model predictive control

Introduction

Durban is the busiest port in Africa, one of the largest economic bases in Southern Africa, and has strong recreational and tourism potential. It is the primary economic centre of the Kwazulu-Natal region. Because of the arrival of rural people from other parts of KwaZulu-Natal, the number of inhabitants in the municipality is increasing continuously creating additional stress on existing infrastructure. This region is also affected by the disastrous impact of the HIV/AIDS epidemic. This is likely to cause large changes in the current population growth rate in the short term, and consequently should lead to a reconsideration of future needs for services delivery. The optimal use of existing infrastructure, such as water distribution systems, seems to be the best solution for the present and that is where this project can play a part.

All of the water services functions of the Metropolitan Area have been included into a single entity named eThekweni Water Services. The network under their supervision extends over a region covering 85 km along the coast and 60 km inland. Approximately 800 km of bulk mains convey treated water to 220 storage reservoirs within the Metropolitan Area. Water is further distributed via 4 500 km of pipes, which radiate outwards from the storage reservoirs. The reservoir volumes are measured on-line and sent to a central SCADA system where all of the relevant data are stored. To deliver potable water with an adequate pressure, even in remote parts of the system, there are 235 pump-stations. It is possible to actuate these remotely by telemetry from the central control room. Approximately 160 test points in the piped potable water distribution system are continuously monitored by eThekweni Water Services to ensure compliance with international health

norms promulgated by the World Health Organisation (WHO) in the third edition (2003) of the *Guidelines for Drinking Water Quality* (http://www.who.int/water_sanitation_health/dwq/guidelines2/en/).

Optimisation of water distribution systems has gained much attention in the past few decades. Research is spurred by the complexities associated with the operation of multiple interconnected reservoirs, which still exceeds the capabilities of existing optimisation tools in finding solutions easily (Teegavarapu and Simonovic, 2002). Mathematical programming techniques are one of many tools available to engineers for determining optimal configurations of a particular process. Recent developments in this field have given rise to new methods for determining the optimal operation of a process. Optimisation of reservoir operations has recently received much attention (Mousavi and Ramamurthy, 1999). Numerous algorithms are being tested on distribution systems by researchers to get the most reliable solutions, using the least computational time possible. Linear programming (LP), nonlinear programming (NLP), mixed-integer linear programming (MILP), mixed-integer nonlinear programming (MINLP), as well as fuzzy logic (FL), stochastic dynamic programming (SDP) and the simulated annealing (SA) are the most promising methods.

Until recently, the topic of optimisation in water systems in the literature has been mainly focused on the design of optimised configurations for pipe-interconnected reservoirs. For more information on this, the reader can refer to Schaake and Lai, 1969; Alperovits and Shamir, 1977; Quindry et al., 1981; Goulder and Morgan, 1985; Fujiwara et al., 1987; Woodburn et al., 1987; Lansley and Mays, 1989; Kessler and Shamir, 1989, 1991; Duan et al., 1990; Eiger et al., 1994; Kim and Mays, 1994; Cunha and Sousa, 1999.

Although most of the research in the field of water distribution optimisation has concerned the optimal design of new networks, a few researchers have tried to develop new techniques for the operational optimisation of existing infrastructures. The objective

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