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Locating leaks in water distribution networks with simulated annealing and graph theory

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Abstract

This paper addresses the problem of locating leaks in water distribution networks. The approach presented here is based on steady-state modelling, supported by monitoring tank flow and pressure at strategic nodes. The selection of the pressure monitoring nodes is done applying graph theory concepts adapted to water distribution networks. Pressure monitoring data is then used to build an optimization problem: the objective function is the minimization of the differences between estimated and measured pressures at the monitoring points, the constraints are the common energy and mass conservation laws and the decision variables are the leak locations and flows. This optimization problem is solved by a simulated annealing algorithm presented in a previous work. The application of this approach in a set of case studies produced some encouraging results and this paper describes the complete procedure and draws some conclusions.

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Keywords: Leak location, water distribution network, simulated annealing, graph theory.

1. Introduction

Water losses in water distribution networks (WDN) affect water utilities and the society, and their negative impacts are: operational (lower service level), economic (lower income and higher operating and capital costs), environmental (higher amount of water and energy usage, and consequent higher water and carbon footprints), public health (potential focus of contamination) and social (service disruptions, traffic disturbances and damage to

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people and their belongings). For these reasons, water loss control is a major concern for water utilities. The increase of operational cost due to real losses, the loss of revenue due to apparent losses and water scarcity issues stimulate water utilities to implement water loss control programs.

It is considered good practice to approach the leak location problem with small sequential steps. Firstly, the WDN can be divided in small sectors called District Metering Areas (DMA). Then, water balance can be periodically applied to each DMA to assess water losses and conclude if it is necessary to implement a strategy to fight them. These water losses include apparent losses (unauthorized consumption and customer meter inaccuracies) and real losses (leakage on transmission and/or distribution mains, leakage and overflows at utility's storage tanks and leakage on service connections up to the point of customer metering point) [1]. Nevertheless, in a WDN (or DMA) a quicker way to detect leaks is to monitor the Minimum Night Flow (MNF). An increase of the MNF can be interpreted as the occurrence of a new leak in the WDN, and the leak flow corresponds to the change of the MNF.

Real losses due to pipe leakage can be reduced by implementing active leakage control, but this usually implies hard work and sophisticated and expensive equipment [2, 3]. Commonly, the leak location activities require on-field analysis with acoustic devices [4, 5, 6, 7], or the use of tracer gas, infrared imaging or ground penetrating radar [8].

This paper presents a methodology to locate leaks based on modelling and optimization techniques. This methodology is almost automatic and uses affordable equipment [9, 10] to monitor flow and pressure during the MNF period. However, the success of methodologies based on pressure measurements is quite dependent on the number and placement of the pressure transducers [11, 12, 13, 14]. Thus, an innovative tool based on graph theory concepts was developed to help in selecting the nodes for pressure monitoring.

The potential of these methodologies is illustrated with a set of case studies, considering different flows in a single leak or in two leaks located in different parts of the WDN. The results presented here include: (I) a sensitive selection of nodes for pressure monitoring; (II) a sensitivity analysis of the leak flow on the quality of the final solutions; (III) a critical analysis of the solutions including pipes incorrectly selected as leaky pipes. The results are discussed and the solutions obtained show the benefits and drawbacks of the methodologies.

2. Methodology for identification of probable leaky pipes

First, a computational methodology was developed to help in locating unreported leaks and estimating its flow. This methodology results from linking a hydraulic simulation model [15] to an optimization model. The hydraulic simulation model performs steady state analysis to estimate the WDN behaviour. The optimization model aims to minimize the difference between estimated and measured pressures (monitoring nodes), and the decision variables are the locations and flow of unreported leaks.

Second, a selection of the nodes to be monitored is made with a methodology that resulted from the adaptation of graph theory concepts.

Third, it is assumed that the unreported leakage flow equals the change between consecutive MNF periods and a sensitivity analysis is performed with different leakage flows (from one or two simultaneous leaks) and locations. The results of the methodology are discussed to confirm if the leaky pipes are correctly identified.

Fourth, the final results allow a better problem diagnosis by identifying the leaky pipes. Pipes not identified in any solution can be discarded for the field survey with leak location equipment. The consequence is a quicker response due to an inspection work better supported by previous planning.

2.1. Link between the hydraulic simulator and the optimization model

Given a WDN with a certain total leakage flow, the methodology proposed here is intended to identify the most probable leaky pipes with a known leakage flow. It uses a calibrated model of the WDN to predict its hydraulic behaviour assuming that water consumption during the MNF period is known.

The WDN is being monitored (tanks are equipped with flow meters and a set of nodes is equipped with pressure transducers). The information gathered in the past has been used to calibrate the WDN model and the actual pressure monitoring data will now be used to locate the leaks.