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Leakage Calibration in Water Distribution Networks with Pressure-Driven Analysis

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EXTENDED ABSTRACT

Introduction

Water distribution networks (WDN) connect consumers to the water sources, and its goal is to fulfil water demand. However, it is a well-known fact that WDN have losses and an important part of them occur at pipe level. Despite all the research efforts focused on this subject, the identification of leaky pipes is still a major challenge.

EPANET [1] is frequently used to simulate WDN models, using a link-node formulation, similar to a graph, where the water demands are assigned to the nodes. EPANET computes the nodal heads and the link flows by simultaneously solving the mass and energy conservation laws. Owing to the presence of nonlinearities, the network formulation cannot be solved directly; therefore, EPANET iteratively solves a linearized system of equations using a (Global) Gradient Algorithm (GGA) [2].

EPANET assumes that the nodal outflows are constant regardless of the network pressures – known as the demand-driven approach (DDA). This approach is quite accurate when the system operates under adequate operational pressures. In scenarios of insufficient pressure, the DDA is not suitable, being required a pressure-driven approach (PDA) that computes the available demand as a function of the current nodal pressure. Generally, the PDA can be achieved by 1) iteratively running demand-driven simulations; 2) using emitters; or 3) embedding a pressure-demand relationship (PDR) into the GGA algorithm (changing the source code).

The demand-driven approach is not suitable for pipe leakage simulation, because leakage depends on the pressure. WaterNetGen [3] — an EPANET extension — allows both demand and pressure driven simulations, including pipes' leakage modelling [4]. However, the leakage parameters (bursts and background leakage coefficients and exponents) must be set manually by an expert — manual calibration — for the whole network or for each pipe.

This work proposes a calibration methodology to estimate the pipe background leakage parameters. The approach is tested on a set of synthetic models, generated by WaterNetGen and then applied to a real WDN to assess its performance on real world conditions.

Methods and Materials

Leakage is assumed to be a function of the pressure and can be modelled with two components, bursts and background leakage [5]:

$$q_k^{leak}\left(P_k\right) = \begin{cases} \beta_k l_k (P_k)^{\alpha_k} + C_k (P_k)^{\delta_k} & P_k > 0 \\ 0 & P_k \le 0 \end{cases} \quad (1)$$

where q_k^{leak} is the total leakage along pipe k; l_k is the length of pipe k; α_k and β_k are parameters of the background leakage model; C_k and δ_k are parameters of the bursts leakage model; and P_k is the average pressure in pipe k computed as the mean of the pressure values of its end nodes.

The exponent α_k depends on the network characteristics (pipe material and failure mode) and can take values between 0.5 and 2.5. The parameter β_k must be set by calibration (initial values can be set around 10^{-7}) [6].

The first goal of this work is to estimate the pipe background leakage parameters (α_k and β_k). This can be achieved by solving an optimization model in which the objective function is the difference between measured and observed flows and pressures and the decision variables are the background leakage parameters. This optimization model is solved by a simulated annealing algorithm [7, 8], with the help of a pressure-driven hydraulic simulation model [3, 4] to assess the hydraulic constraints and estimate the leakage at pipe level.

Results and Discussion

The main goal of the proposed methodology is to identify the most probable leaky pipes in a WDN.

This methodology is applied to a set of synthetic WDN models, generated by WaterNetGen [3], in which all variables are known and controllable ― the ideal scenario for testing. The results obtained for the test set confirmed the effectiveness of the methodology.

Afterwards, the methodology is applied to a real WDN, where the total flow and some nodal pressures are known, and the water demand during the minimum night flow period can be accurately estimated. The goal of this last test is to assess the performance of the methodology under real world conditions.

Conclusions

This work proposes a calibration methodology to estimate the pipe background leakage parameters.

The approach is tested on a set of synthetic models, generated by WaterNetGen and then applied to a real WDN to assess its performance under real world conditions.

By identifying the most probable leaky pipes, the results from this methodology will certainly be of great help in the context of active leakage control, optimizing the resources allocated to the leak location process.

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