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Sequential Multi-Objective Evolutionary Algorithm for a Real-World Water Distribution System Design

F. Rahmani[a], K. Behzadian[b,c,*]

[a]Amirkabir University of Technology, Department of Civil and Environmental Engineering, Tehran, Iran
[b]University of Exeter, Centre for Water Systems, College of Engineering, Mathematics and Physical sciences, Exeter, EX4 4QF, UK
[c]Amirkabir University of Technology, Environmental Research Centre, Tehran, Iran

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Abstract

This paper presents a methodology based on a three-stage multi-objective optimization model for solving the problem of Battle of Background Leakage Assessment for Water Networks (BBLAWN) at WDSA2014 conference. At the first stage, the optimal design of pipeline rehabilitation, pump scheduling and tank sizing is formulated and solved on the skeletonized network by a optimizing (1) the costs of pipes, pumps and tank upgrading and (2) the cost of water losses and energy. Three optimal solutions are used for a second optimisation step on the full network (i.e. not skeletonised). The third optimisation step is then performed starting from second stage optimal solutions considering the three objectives of the original problem.

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Keywords: water Distribution system, sequential multi-objective, leakage, cost

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1. Introductions

Previous researchers have formulated and solved various optimisation models for designing optimal water distribution system (WDS). Some of the common objectives used in these models are to minimise cost, leakage, and system failure, or to maximise reliability, efficiency and resilience. Among these metrics, leakage minimisation has been selected in the main purpose of the Battle of Background Leakage Assessment for Water Networks (BBLAWN) in WDSA2014 conference [1]. There are different ways to reduce the water loses in WDS. Pressure management by using pressure control valves (PCVs) or pumps scheduling is one of the most common ways to control the water loss.

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* Corresponding author. Tel.: +44-1392-724075; fax: +44-1392-217965.
E-mail address: K.Behzadian-Moghadam@exeter.ac.uk

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However, the main challenge of PCVs is to find the best locations for installing and their associated settings. Pipeline rehabilitation is another common way for leakage control although finding the appropriate pipes for rehabilitation in a proper time can be challenging. In one of the recent work, Araujo et al. (2006) used a genetic algorithm technique to optimize the number and location of control valves for pressure control decreasing the leakage amount [2]. Design/rehabilitation of water distribution systems using multi objective algorithm such as genetic algorithms has been widely attracted researchers during the last decade. Halhal et al. (1997) proposed an approach for identifying the rehabilitation method using the multi-objective messy genetic algorithm to minimize the costs and maximize the benefits [3]. Kapelan et al. (2005) considered cost and system reliability to formulate the problem with a two-objective optimization method [4]. Giustolisi et al. (2008) presented a hydraulic simulation model based on pressure-driven demand to calculate the leakage amount more accurately [5]. Fu et al. (2012) proposed use of a many-objective approach for water distribution system design or rehabilitation problems combining ε-NSGA-II and interactive visual analytics [6]. The main problem in the optimization methods in large scale case studies is complexity between computational efforts and large number of decision variables. Fu et al. (2011) screened insensitive decision variables using global sensitivity analysis as a screening tool to decrease the complexity of WDS multi-objective optimization problems [7].

This paper strives to solve the Battle of Background Leakage Assessment for Water Networks (BBLAWN) real-time design problem by using a multi objective evolutionary algorithm to reduce the cost incurred by background leakage, energy, pipeline rehabilitation and energy pump. In order to tackle large scale water distribution system, this paper suggests a sequential method to decrease the computer time use for solving the problem. Different optimization stages with increasing in complexity were designed and solved and the Pareto optimal frontier were fed into the next stage as an initial solution. More detail of the suggested method is described in the next sections.

2. Problem description

A brief problem description is presented here as further details can be found in WDSA2014 website of the BBLAWN [1]. The BBLAWN problem is mainly to control the leakage amount in the C-Town WDS by minimising three categories of costs including (1) pipes, pumps and tanks upgrading; (2) water loss and energy; (3) PCVs. The available facilities to achieve the minimum cost are: pipelines rehabilitation (replacement and duplication), pump scheduling and upgrading, tank upgrading, closing the pipelines using isolation valve and addition of PCVs. The constraints are: (1) minimum pressure of 20 meters in nodes with positive demands and positive pressure in nodes with no demand; (2) each tank has to have at least the same volume of water at the end of simulation in comparison with the beginning of the simulation; (3) pumps and throttle control valves cannot be controlled by PLC (e.g. by flow or time) and must be controlled by hydraulic conditions. The model is simulated for an extended period of one week with deterministic water demands in WDS.

3. Methodology

The proposed methodology used in this paper to solve this problem is a three-stage sequential optimisation models which are outlined below. During each stage an optimization model is used to obtain better solutions. The optimisation model used in all stages is non-dominated sorting genetic algorithm (NSGA-II) proposed by Deb et al. (2002) [8] and the simulation model used for the WDS is EPANET software tool (Rossman, 2000) [9]. A pressure driven demand method proposed by Germanopoulos (1985) is used for pipeline leakages calculation [10].

3.1. Stage #1

To speed up the optimisation algorithm, a skeletonised network is used in the first stage in which all the branched pipes are trimmed such that the critical head losses from the trimmed pipes are added up to the minimum pressure of the end of the remained nodes from trimming. As a result, 286 pipes (i.e. around 37,800 meters) were remained after skeletonising. The optimization method developed at this stage is to find optimal pipelines rehabilitation, pumps scheduling and tanks size by minimising the two objectives: (1) cost of pipes, pumps, and tanks upgrading; (2) cost of water loss and energy. The decision variables (genes) for each solution (chromosome) of the optimisation model is