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Near real time pump optimization and pressure management

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Abstract

Management of existing systems can be interpreted as sets of decisions to make regarding pumps and valves to create hydraulic conditions able to satisfy the demand without operational problems such as pressures lower or higher than the normative pressure values. However, among the large number of combinations, some of them manage to reduce energy consumption, by finding the best operating point for pumps, and also water losses, by finding the best operating point for pressure reducing valves (PRV). Several works may be found in the literature using recent and advanced optimization techniques to define pump and valve operation. However, the processing time to define operational rules is a limiting factor for real time decision-making. Taking into account the need to improve the models in terms of optimal rules to apply in near real-time operations, this work presents a hybrid model (simulator + optimizer) to find pump speeds and PRV set points, aiming at combining energy savings with pressure control while reducing water losses. PSO is applied as the main optimization algorithm, which can also work in cooperation with other bio-inspired concepts to deploy an effective and fast search algorithm. The results allow comparisons with other techniques and show the ability of PSO to find an optimal point of operation

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1. Introduction

The challenge of urban development for this century is bringing environmental resources savings and availability to serve citizens with quality. In this way, the smart city concept appears as a way to manage urban systems with high technology. A smart water system may be characterized by the way the system is managed following the well-known Smart City paradigm [1]. This paradigm, given a water system, implies that the companies operate the system using the available technology to reduce energy consumption and water losses, while respecting consumers' needs. Usually, the operation of water distribution systems (WDSs) is based on the expertise of operators to manage valves and pumps to guarantee the supply safely and as efficiently as possible.

The costs associated with water pumping stations in WDSs are the most significant for the water supply companies, according to [2]. Following the current tendency, some important studies have been developed in an effort to find a better approach of the energy consumption problem. Water management problems have been treated successfully with the application of optimization techniques [3] and the definition of pump schedules during a determined period of time, usually 24 hours. The use of various bio-inspired algorithms is the most important approach for energy saving in WDSs, as can be inferred from [4, 5, 6, 7], for example.

Bio-inspired algorithms have been widely applied to water management problems, especially due to their easy integration with hydraulic models, which allows estimating energy consumption and hydraulic state of the network during a specific period. [4] apply Ant Colony optimization (ACO) to determine the hourly schedule of pump operation for 24 hours by switching pumps statuses (on/off). The authors consider damage risks for the pumps and limit the number of switches to three. [5] present a modified classical optimization variant for pump schedule, using hybrid linear programming linked to a greedy algorithm to find the optimal schedule for pumps. The method is compared with GAs to show high efficiency while maintaining the accuracy when applied to various benchmark networks.

Considering the possible damage for pumps associated to the status switch approach for optimal pumping schedule, and taking into account the management improvement when variable-speed drive (VSD) is used, [6] propose the use of Particle Swarm optimization (PSO) to define the best speed of pumps aiming the near-lowest energy cost for 24 hours. This approach allows better long term management, once the pump station is protected. However it requires the installation of VSD. The use of hydraulic simulators coupled with optimization algorithms requires high performance capabilities to solve the pumping problem because the objective function, usually defined to consider energy cost, has to be calculated, thus increasing the processing time.

Getting rid of the simulation need, [7] apply a meta-modelling technique with artificial neural networks (ANNs) trained under several scenarios to define the hydraulic state of the water distribution network. For the energy saving problem, the meta-model is coupled with a GA algorithm to define pump status and tank operation. The authors show a daily cost reduction of 15% when applied to a real network in UK.

In addition to the energy costs, water losses have been widely studied as a way to improve the global efficiency of water systems. Management of pressure through control valves, mainly by PRV, is the flagship strategy used by water utilities. In this way, the determination of the optimal set point for PRVs is an optimization problem for which several researchers have proposed solutions. [8] highlight the susceptibility of aged and high pressures zones for leakage occurrences in water networks. The authors present an integrated model to define optimally the number, position and set point of PRVs aiming to water loss reduction. A model of extended period simulation (EPS) coupled with GA optimization is applied to find the optimal solution.

Taking into account water losses reduction, [9] propose an alternative hydraulic network model for PRVs coupled with non-linear optimization algorithms to find the best operational set point of valves. The importance of water loss reduction is strictly linked with economic and environmental challenges imposed by climate change and growth of cities. [10] present a multi-objective optimization process based on GAs to solve the location and set point determination problems to reduce water losses. The main advantage of this work is the reduction of the space search for the location problem through energy dissipation evaluation for the pipes.

Even though several studies have been developed to reduce energy costs in pump operation and water loses, real-time approaches have gained importance in this research field recently. One of the pioneers in real-time control for WDSs is [11], which presents a real-time optimal operation model aiming at cost reduction, meeting the required demands at minimal pressure. Water demand is updated hourly, allowing a new adjustment of pump statuses. The