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Expeditious pump rescheduling in multisource water distribution networks

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Abstract

Cost minimization is the main issue for water companies when establishing pumping regimes for water distribution. Remarkable reductions in operation costs can be achieved by optimizing the pump scheduling problem. In this paper a near optimum solution is proposed for internal multi-sources networks with a large amount of pumps per station. The proposed method is based on a local search algorithm which explores the neighborhood of an optimized solution obtained by the subdivision of the network into pumping station influence areas. A real case of study is presented and discussed, results are also compared to the solution obtained with a GA.

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Keywords: Water distribution; Pump scheduling; Optimization; Multi-sources; Graph theory; Elementary districts.

1. Introduction

Cost minimization is the main issue for water companies when establishing pumping regimes for water distribution. Energy consumption and pump maintenance represent by far the biggest expenditure and nowadays there is an urge to optimize the costs of existing water distribution networks, as they are the result of a progressive widening due to the demographical expansion of cities. Without making changes to the basic elements of a water supply system, remarkable reductions in operation costs can be achieved by optimizing the pump scheduling (PS) problem. In most of the cases, objectives such as supply costs and leakage minimization, water quality and efficiency maximization are always coupled with pump schedule optimization.

The importance of optimizing existing water distribution networks is not recently conceived, however for many developed countries a smarter energy management is still an open issue. Since the past decades many are the techniques proposed in literature devoted to determine least-cost policies of pump scheduling. The proposed algorithms are the most different and include linear programming [1, 2]; non-linear programming [3, 4]; dynamic programming [5, 6]; heuristics [7, 8]; meta-heuristics [9, 10]; mixed integer linear programming [11] and mixed integer not linear programming [12]. The techniques developed have become more and more efficient through the years, especially when hybrid methods are implemented, [13, 14].

However, intended users (managers and policy planners) are rarely skilled in writing optimization and simulation models or in integrating the relevant technologies in a flexible and quick way in order to obtain the necessary support for decision making, [15]. Moreover the proposed techniques are in some cases ineffective to be applied to large real water distribution networks, especially in term of calculation time.

In this paper a near optimum solution is proposed for rescheduling the PS of large ground-water supply distribution networks. These systems are generally supplied by well fields connected to a pipe system to deliver water to a central pumping station.

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Central pumping stations are sparse homogenously in the areas to be served. Because of water treatment requirements, water is not delivered directly from ground water to water mains, but to a reservoir from which water is then pumped into distribution network. Therefore the delivery cost for main distribution system and well field can be separated [3], whilst of course a relationship between them exists. As these type of WDNs are characterized by a large number of pumps (lifting water to the distribution mains), corresponding to an enormous domain of possible operation patterns, it could be considered desirable to take advantage of this simplification possibility when dealing with optimization problems.

The optimization procedure proposed in this paper is focused on the minimization of energy consumption of a set of pumping stations, operating between water source (underground aquifer or reservoir) and supply WDN. In the preliminary steps, the network is subdivided into influence areas of each pumping station, called “elementary districts” from the District Metered Areas background (eDMAs). Each eDMA is singularly optimized, taking advantage of the low number of pumps per district using a graph theory algorithm. After that, the overall pumping schedule of the WDN, resulting from the combination of each eDMA schedule (ePS), is optimized by a single scheme of progressive pump switching off. One pump at a time is called out of duty in the hydraulic model of the WDN in order to achieve the greatest energy saving. The procedure is reiterated until, compatibly with pressure and flow velocity constraint, the minimum number of pumps simultaneously active in the system is reached.

The proposed optimization procedure is applied to a real case of study, the WDN of Milan which has 95 pumps distributed in 29 pumping stations. The resulting operation pattern is compared with the original PS of the network with some consideration of network performance. Moreover, the solution found is compared to the one obtained with a genetic algorithm.

Nomenclature

AM	adjacent matrix
BFS	Breadth first search
FM	flow-weighted adjacent matrix
DMA	district metered area
eDMA	elementary district metered area
N_c	number of pump combinations
NL	node list
N_p	overall number of pump
N_s	number of internal water supply sources
PS	pump schedule
ePS	elementary pump schedule
S	identification number for internal water supply sources
SL	source list
WDN	water distribution network
WDS	water distribution system
c	identification number for a generic pump combination
ΔH_k	pump head of the k_{th} pump
η_k	pump efficiency
p	nodal pressure
q_{ij}	pipe flow between the i_{th} and j_{th} nodes
q_k	flow of the k_{th} pump
w_{ij}	weight coefficients in flow-weighted adjacent matrix

2. Methodology

Rescheduling the pump schedule of an existing WDS has many economic advantages that are not merely limited to the energy saving: by reducing the system pressure and thus energy consumption, also losses and pipe bursts are lowered, reaching a higher degree of control and efficiency. However, the optimization of the system from the energy perspective can be difficult due to the interaction between several factors, such as reservoir and pump operations, constrained pressure control and variable energy tariffs. Optimization task becomes even more complex when the number of pumps increases and their types are different.

In the present paper the main focus is on those water distribution network directly supplied by a system of pumps withdrawing water from an underground aquifer. For these systems there is no such strict interaction between pump schedule and tanks, mainly for the availability of water, thus the energy optimization can be carried on separating the problems.

The methodology developed is tailored for WDNs supplied by pumping systems, facing an overall high number of pumps. The proposed method is based on a hierarchical process of progressive improvement of constrained semi-optimal solution. The aims is not to find the “best” mathematical pattern of pump scheduling often difficult to be fully implemented in the real world, but to find a robust approximation of this optimum, with an easier methodology.