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Research on optimal operation method of large scale urban water distribution system

X. Jin[a]*, W. Wu[b]

[a]*School of Civil Engineering and Architecture, Wuhan University of Technology Wuhan, Hubei (China)*
[b]*Faculty of Arts and Creative Technologies, Staffordshire University, Stafford, (UK)* w.wu@staffs.ac.uk

Abstract

In consideration of using fewer decision variables in building least cost pumping operation optimal, the two-phase optimal method is used as the frame. By abstracting pump stations into high level reservoirs, the water distribution system hydraulic model can be modified into a modality, which can be used in first optimal phase of two-phase optimal method. And by building on feasible pump combination database, a new optimal method in the second optimal phase will be proposed. And the proposed new method in the second optimal phase will be embedded into the first optimal phase, so that the problem of results discordant in different phases of two-phase optimal method will be solved. By introducing new concept and improving present optimal method, a more practical optimal operation method of water distribution system (WDS) will be established. By applying to a large scale water distribution system, the practicability of proposed method has been evaluated.

Keywords: Water distribution system; optimal operation; genetic algorithm; decision support system

1. Introduction

Operational cost of pumps in a water distribution system (WDS) represents a significant fraction of the total expenditure incurred in the operational management of WDSs worldwide. Pumps consume a large amount of electrical energy for pumping water from sources to storage tanks and to demand nodes. Therefore, the goal of a pump scheduling problem is to minimize the total pump operational cost, while guaranteeing a competent network

* Corresponding author. Tel.: +86-13659858356.
E-mail address: jinxi1978@126.com

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service. In most cases, this problem is equivalent to the minimization of cost of pumping, while supplying water to consumers at adequate pressures (López 2008). In recent years a significant amount of research has been focused on optimizing pump operation schedules. Since 1970 a variety of methods were developed to address this problem, including the utilizations of dynamic programming (Lansey 1994) linear programming (Jowitt 1992, Eyal 2012), meta-models (Shamir2008, Broad 2010), heuristics (Avi 2008), and evolutionary computation (Van 2004, Fang 2011). Although the methods mentioned above give theoretic ways for solving optimal operation problems of water distribution system , there are few successful application cases in practice. Especially when the methods are used to a large scale of multi-sources WDS. In this situation, a two-phase method was proposed (Zhang 2006, Yuan 2010). In two-phase method, optimal water levels of each source are determined in the first optimal phase, and the optimal pump schedules will be determined in the second phase according optimal result of first phase, so that a complex optimal problem is divided into several relative simpler optimal problems, and the efficiency and effect of optimization get a high improvement. But the two-phase method is not perfect. In present, there are some problems that hinder this optimization method to be applied in practice. In these problems, the most outstanding ones are: (1) since there is no determined pump schedule and in order to reducing computation cost, only meta-models can be used in the first phase optimization. But meta-model is not as robust as hydraulic model, so the reliability of optimization result is low. (2) And another problem is discordant of results in different phases.

For the purpose of solving these problems, a modified hydraulic model and pump combination database are introduced into the two-phase method. By abstracting pump stations into high level reservoirs, the hydraulic model of WDS can be modified into a modality that can be used in the first optimal phase. And by building on feasible pump combination database, a new optimal method in the second optimal phase has been developed. And the new method in the second optimal phase merged into the first optimal phase, will resolve the problem of results discordant in the two phases.

2. Optimal model formulation

Previous studies have dealt with constraints by penalizing the objective function (Boulos 2010, Van 2004). This requires the definition of a penalty function and appropriate penalty values. Penalty values, in general, are obtained either using rudimentary techniques or by trial and error. The penalty function approach imposes a fixed tradeoff between the amount of constraint violation and the value of the objective function. Low penalty values would allow constraint violations in return for small reductions in the objective value, while higher penalty values would require higher objective value differences to compensate for the same amount of constraint violation. For avoiding this, a multi-objective method is used in the optimization. And three objectives are used in the optimal model: minimum electricity cost, minimum number of lower pressure service nodes and minimum error between two optimal phases.

2.1. Objectives

Pump energy costs depend on the energy price as well as on the amount of energy consumed. The minimum electricity cost objective can be expressed by formula 1:

$$Min : C = \sum_{i=1}^{S} P_i \cdot T \cdot t \tag{1}$$

Where S is numbers of source nodes, P_i is the power of the i^{th} pump (kw). In the first phase only supply flow and head of source nodes will be determined, so P_i only can be calculated in the second phase, T is electricity tariff in current period (￥/kwh), t is length of one hydraulic time step (hour).

Objective of minimum count of lower pressure service nodes is expressed by formula 2: