Scientia Iranica A (2013) 20 (2), 278–285

Sharif University of Technology

Scientia Iranica

Transactions A: Civil Engineering

www.sciencedirect.com

Research note

Fuzzy genetic algorithm approach for optimization of surge tanks

M.R. Chamani [a,*], **S. Pourshahabi** [a], **F. Sheikholeslam** [b]

[a] *Department of Civil Engineering, Isfahan University of Technology, Isfahan, P.O. Box: 84156-83111, Iran*

[b] *Department of Electrical Engineering, Isfahan University of Technology, Isfahan, Iran*

Received 15 November 2011; revised 25 September 2012; accepted 12 November 2012

KEYWORDS

Optimization;
Genetic algorithm (GA);
Fuzzy inference system (FIS);
Transient flow;
Protective devices.

Abstract The fundamental goal of a pipeline utility is to serve its customers with a low cost water supply of acceptable quality. The number, type, size, and location of transient protective devices play a direct role in the pipeline system reliability and expenditure. The purpose of this study is to optimize the design of these devices to prevent water column separation after source pump power failure. The minimum pressures along the pipeline are assumed to be higher than "−10 m" to avoid water column separation. A rational, systematic, and efficient optimization algorithm is constructed by combining the Fuzzy Inference System (FIS) and the Genetic Algorithm (GA). The FIS representing expert knowledge is incorporated into the GA approach to improve its fitness evaluation process. Three cases are presented to demonstrate the effectiveness and efficiency of the proposed hybrid approach.

1. Introduction

One objective of a pipeline system is to provide customers with a low cost water supply of acceptable quality. Despite the many studies conducted on the optimization of pipeline systems under steady state conditions, there is still much to be learned about their operation under transient conditions. Negative and positive transient pressure surges travel along the pipeline, which may cause damage to the system. It is, therefore, necessary to study unsteady flows or transient conditions in pipeline systems. Low pressure transient waves have considerable potential to draw contaminants through leaks into a pipeline system. A motivation for considering the transient waves arises from water quality considerations [1,2].

Transient pressure waves occur in pipelines due to changes in fluid velocity typically caused by pump power failure or valve movement. When velocities in a pipe system change so rapidly that the elastic properties of the pipe and liquid must be considered in an analysis, there is a hydraulic phenomenon commonly known as water hammer. The governing equations of water hammer include two independent partial differential equations, the conservation of mass and momentum equations. The most general and well-known technique for solving these equations is the method of characteristics. Controlled valve movement, pump inertia control, pressure relief valves, air valves, surge tanks (open-end or one-way surge tanks), and air chambers are some of the transient protection devices and methods [3].

Vítkovský et al. [4] applied a forward transient technique and the Genetic Algorithm (GA) optimization technique for leak detection and calibration of pipe internal roughness in water distribution systems. Stephenson [5] presented design nomographs to simplify the process of sizing air vessels for water hammer protection of pumping pipelines. Jung and Karney [1] optimized the location, size, and number of transient control devices in water distribution networks using GA and Particle Swarm Optimization (PSO). They examined a gravity network with different protection strategies in each case. Transient pressure waves were caused by valve closures. Izquierdo et al. [6] used a neural network to optimize the design of air vessels based on system parameters to achieve permissible heads during a hydraulic transient.

The purpose of the present work is to optimize the design of transient control devices to prevent water column separation after pump power failure. The optimization algorithm is combined with a transient simulation program to achieve the optimal solution. The large search space of the problem is

* Corresponding author. Tel.: +98 311 3913831; fax: +98 311 3912700.
E-mail address: mchamani@cc.iut.ac.ir (M.R. Chamani).

Peer review under responsibility of Sharif University of Technology.

Production and hosting by Elsevier

1026-3098 © 2013 Sharif University of Technology. Production and hosting by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.scient.2013.04.002

maintained using a genetic algorithm. The GA deals with a large number of discrete or continuous variables, does not require a derivable objective function, explores a wide search space simultaneously, provides a population of optimum solutions, and works with numerically generated data, experimental data, or analytical functions in extremely complex problems [7]. In this paper, GA is improved using fuzzy inference systems. A fuzzy decision making is incorporated in the GA approach to improve its fitness evaluation process and its capability for handling constraints. The fitness evaluation in this paper does not incorporate cost directly. Each chromosome is evaluated using a fuzzy decision defined after transient analysis.

The basic idea underlying fuzzy logic was suggested by Zadeh [8]. In general, fuzzy logic is concerned with formal principles of approximate reasoning, while classical two-valued logic (true or false) is concerned with formal principles of reasoning. Fuzzy logic uses the continuum of logical values between 0 (completely false) and 1 (completely true). Two of the main concepts that play an important role in many applications of fuzzy logic are the concepts of linguistic variable and fuzzy if-then rules [9]. For example, height is a linguistic variable when its values are defined to be low, medium or high. Each linguistic value is represented as a fuzzy set that is characterized by a membership function, usually taking values between 0 and 1. In general, a fuzzy rule can be represented as:

If x_1 is A_1 and x_2 is A_2 and $\ldots x_n$ is A_n then

y_1 is B_1 and y_2 is B_2 and $\ldots y_m$ is B_m,

where $x_1, x_2, \ldots, x_n, y_1, y_2, \ldots, y_m$ are linguistic variables, and $A_1, A_2, \ldots, A_n, B_1, B_2, \ldots, B_m$ are their respective linguistic values. The goal of using fuzzy systems is to put human knowledge into engineering systems in a systematic, efficient, and analyzable order. Fuzzy systems are knowledge-based or rule-based systems and work very well for many engineering problems [10].

Goulter and Bouchart [11] used fuzzy sets combined with linear programming for network cost minimization. Vamvakeridou-Lyroudia [12] used fuzzy sets for pressure and velocity constraint violation in a dynamic programming algorithm, for optimal design of water supply networks. Xu and Goulter [13] presented a fuzzy linear program optimization method in which the capital costs of the network were minimized while maintaining the nodal heads at demand nodes within a satisfactory region, as defined by the customers at those nodes. Revelli and Ridolfi [14] simulated uncertain parameters, like the roughness coefficient of pipes and the demands of the network, using fuzzy theory. Vamvakeridou-Lyroudia et al. [15] used a fuzzy multi-objective optimization model (minimizing cost and maximizing a benefit-quality function) to the "Anytown" water distribution network. They used genetic algorithms, combined with fuzzy reasoning, for benefit-quality evaluation. They showed that their model manages to find a better solution than any other previous approach in terms of cost, despite the multiple criteria applied for the benefit function being more extensive and stricter. Amirabdollahian et al. [16] applied a fuzzy genetic algorithm to obtain the least-cost design of looped water distribution networks. They used a fuzzy decision system to eliminate the traditional use of the penalty function in the genetic algorithm. They concluded that their proposed method yielded solutions with reduced costs.

Mamdani and Sugeno are two types of fuzzy inference system that are tested and compared in this paper. In Mamdani-type inference, the output membership functions are fuzzy sets, but Sugeno output membership functions are constant. The Mamdani method is intuitive and has widespread acceptance, while the Sugeno method is computationally efficient and works well with optimization and adaptive techniques. The Sugeno method also has guaranteed continuity of the output surface [17]. To demonstrate the effectiveness of the proposed hybrid approach, three cases are presented.

2. Optimization algorithm

The optimization algorithm is combined with a transient simulation program to achieve an optimal solution. In ordinary genetic algorithms, the fitness function that evaluates each chromosome derives from a mathematical formula describing the objective function. Definition of a fitness function is an important and difficult task. The fitness evaluation in this paper does not incorporate cost directly. In the present work, a fuzzy decision making is incorporated in the GA approach to improve its fitness evaluation process and its capability of handling constraints. The objective of the proposed method is to optimize one-way surge tanks with a least cost design subject to the following constraints:

1. Minimum pressures along the pipeline should be higher than "−10 m" to avoid water column separation.
2. Final liquid height in the tanks should be sufficient to prevent vortices at the surge tank outlet.

As will be explained in the next section (Section 3), maintaining the desirable final liquid height in the surge tanks leads to the least cost design of these devices. The final liquid height constraint is regarded as the objective of the optimization subject to the minimum head constraint. In this method, each feasible chromosome (solution) that satisfies the pressure constraint after transient analysis is evaluated in the range of [0, 1] using a fuzzy inference system, with respect to the final liquid height in the surge tanks, as shown in Figure 1. The fitness value for infeasible chromosomes or chromosomes that violate the minimum pressure constraint is set to zero without FIS interference. Normalizing the fitness value in the range [0, 1], it will be possible to find the global optimum solution. Using the fuzzy inference system, determination of the fitness value for each chromosome and satisfying the constraints, are accomplished in an easy and transparent manner. A generalized method is obtained for evaluation of the fitness value that does not change with dimensional characteristics, time, or location.

Mamdani and Sugeno are two types of fuzzy inference system that are tested and compared in this paper. In these fuzzy systems, "minimum" is used as the "AND" operator, and "maximum" is used as the "OR" operator. The weighted average and the centroid methods are used as the defuzzification methods in Sugeno and Mamdani FIS methods, respectively. The input variables and the rules of these two fuzzy systems are the same. In Mamdani-type inference, the output membership functions are fuzzy sets, but Sugeno output membership functions are constant. The binary genetic algorithm has been written in MATLAB, version 7.6.0.324 (R2008a). Tournament selection and elitism (retaining the best solution at each generation) are used. The probability of uniform crossover is 0.8 and the mutation probability is 0.05. The algorithm stops when the fitness value reaches one or when the number of generations is sufficient to converge. The appropriate number of generations will be noted in each case. The optimization algorithm is flexible enough to deal with a variety of pipelines, changing the system characteristics and membership functions.