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Optimal Water Distribution Network Design Accounting for Valve Closure

Nekha Jose[a], K S Sumam[b*]

[a]*Student, Govt. Engineering College, Trichur, 680009, India*
[b*]*Professor,Govt. Engineering College, Trichur, 680009, India*

Abstract

Flow regulation is always carried out by means of flow controlling devices like valves, flow meters etc.Valve closure is carried out in a pipe network for planned or unplanned operating conditions (e. g. pipe failure) in order to isolate a part of the network. It creates unusual working conditions in the network due to topological modifications. Analysis of distribution system for isolation by means of valve closureshould always be performed as a part of the assessment of system reliability. Thus, a challenge for network designers is to optimize pipe diameters versus system management under these abnormal working conditions. The present study accounts for the mechanical reliability with respect to pipe failures due to valve shutdown, and deliver a strategy for the optimal design. The network modification considering valve shutdown is aimed at changing the hydraulic capacity of the connected network by modifying the pressure at the critical nodes. Two types of analysis namely, Demand driven and Pressure driven analysis were performed in this study. A real network in Thrissur district is selected to test the developed strategy for the optimization.Optimization results provide us with four sets of diameter values, which are to be adopted to avoid a condition of pressure deficiency for any type of isolation.

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*Keywords:*Water Distribution Networks (WDN); Optimal Design; Isolation Valve System (IVS)

1. Introduction

Among the various natural resources available on earth, water is one of the most important natural resource. It is an essential commodity for human life and indeed for all life on earth. Hence, every human has an important role in

* Corresponding author. Tel.: +919496167977.
E-mail address: sumam@gectcr.ac.in

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water-caring. Public water services provide more than 90 per cent of water supply in the world. A well maintained conveyance system is a critical component of a safe drinking water supply system and it plays an important role in the distribution of potable water to the consumers. In this condition, the design and analysis of a water distribution network gains prime importance.

Optimal water distribution network design is a classical issue. [1] and [2] first introduced the idea of solving pipe sizing optimization problem using genetic algorithms (GA). Several other studies done in this area also concluded that GA can be used as an efficient tool for the reliability based optimization of water distribution networks [3].

For isolating subsystems in water distribution systems, valves play a major role in the system reliability and security by providing a shutoff function.For knowingthe system reliability, isolation valve system should always be analysed first.

The word reliability refers to the ability of the distribution system to provideadequate services for the customers undervarious abnormal operating conditions [3]. It is usually studied according to two general classes of failure events: mechanical and hydraulic failures [4]. Mechanical failures includes system components failures, such as pipe breaks and pumps out of service, whereas the hydraulic failures includes variability of demands and/or pipe hydraulic resistances etc.

For the optimal design of WDNs considering the mechanical reliability, various reliability measures (like network resilience, WDN nodal capacity reliability) andstrategies were developed [5,4]. Similarly, several strategies were formulatedin the design procedure to account for the hydraulic reliability [6,7].

For computing the approximate values of the capacity reliability of WDNs, the first-order reliability method (FORM) based algorithm was first introducedin [3]. [6] presented a methodology for the least cost design of water distribution networks under uncertain water demands. It related the uncertainty in the nodal head with the system performance. Similar study made in this area used FORM for an adaptive surface response method for performing the reliability analysis of WDNs [7].

For the design of a water distribution network, a multi-objective genetic algorithm model was used in[5]. The objectives considered are, the minimization of the network cost and the maximization of network resilience. A multi-objective strategy was used to achieve optimal design and operational solutions [4]. This study considers a deterministic modelling of multi-objective optimization problem to account the network reliability.

Distribution network should be divided into various subsystems in order to repair broken components such as pipes or to perform maintenance works. There may be situations where one pipe or segments of pipes need to be removed from the rest of the network for some hydraulic needs. So, in order to separate a portion of a network from the rest, isolation valves must be included in the network. Many studies have been conducted, for the development of methodologies for the optimal design of water distribution systems. Valve closure is carried out in a pipe network for planned or unplanned operating conditions (e.g. pipe failure) in order to isolate a part of the network. The use of isolating valves causes the disconnection of distribution system into various segments consisting of isolated pipes and nodes. Methods to analyse the isolation valve system (IVS) and the generated network configurations have been proposed in[8].

So far, no optimization studies have been taken place considering the actual modification of the network layout resulting from the isolation of network segments [9]. Therefore, the present study accounts for the mechanical reliability with respect to pipe failures due to valve shutdown, and deliver a strategy for the optimal design. The network modification considering valve shutdown is carried out by changing the hydraulic capacity of the connected network by modifying the pressure at the critical nodes.

Two types of analysis namely, ‘Demand Driven’ and ‘Pressure Driven’ analysis (DDA and PDA) were performed in this study. In demand driven analysis, the demands are fixed in the model as a basic assumption. The assumption on demand which is independent of pressure, simplifies its algorithm and computation. In pressure driven analysis, the demands are not fixed a priori but they are dependent on pressures in the network. This analysis takes into account the relationship between pressure and demand.

As a case study, a large sized network (Kunnamkulam Water Supply Scheme in Thrissur district composed of 204 pipes and 167 nodes) is taken to carry out the optimization.