Investigation of Some Performance Indices in Design of Water Distribution Network Based on Hydraulic and Mechanical Reliability Criteria

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ABSTRACT

Due to the high costs of running a water distribution network, the design of the least cost and most reliable networks is of great engineering importance. One issue that has been the focus of recent years' research is the comparison of indices and their relative success in measuring the reliability of water distribution networks. Many studies have been conducted to date on the reliability of water distribution networks. In the present study, the performance of various hydraulic and mechanical parameters was compared to each other under pipe failure conditions. This study provides more performance indices than previous studies. In this paper, The investigation on the nodal pressure performance index, velocity, pressure difference, combined velocity and nodal pressure index, network flexibility performance index (NRI), minimum head surplus index (MSH) and entropy performance index (ERI) on the Hanoi and Pescara water distribution network were performed using NSGA-II optimization algorithm and Epanet software. The results showed that in the design of small water distribution network (Hanoi), the network flexibility index (NRI) performs best and in the design of medium water network (Pescara), at low cost level, node pressure performance index (PIP) and at high cost level, the Network Flexibility Index (NRI) performed the best among the other indices; The two indices have, on average, created more pressure than other indices on the network and increased surplus energy in the network. Also, in case of accidental failure of several pipes, the nodal demands of network is more than other indices.

KEYWORDS

Urban water distribution networks, Optimization, Reliability indices, NSGA-II

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1.Introduction

Reliability of water distribution systems is one of the most important indices in the design and management of these systems under normal or critical operating conditions (such as failure). In general, reliability is the probability that the system will perform its mission and task with a set of specific constraints, within a specific time and space. Specifically for a water supply system there are concerns about the system's ability to supply the water required at each demand point and with sufficient pressure under conditions of accidental failure of various components of the system or changes in demand. Hydraulic reliability refers to the ability of the network to cope with demand changes over time and is one of the essential parameters for measuring network efficiency (Tabesh, 2016). Indices such as resilience (RI[2]), network resilience (NRI[3]) and modified resilience (MRI[4]) are the most common indices in assessing hydraulic reliability of the water distribution network. The RI index was first introduced by Todini in 2000 as an index of hydraulic reliability. They computed the surplus power in the network and the loops available therein by taking into account the number of inlet and outlet pipes to each point of consumption simultaneously. In addition to these two indices, Farmani et al. (2005) introduced the (MSH[5]) as a hydraulic reliability index. This index indicates the minimum difference between the available pressure and the minimum acceptable pressure at the points of consumption. In fact, MSH indicates the surplus head at the critical point of the network, and the larger this value indicates the greater the network capacity in the face of abnormal conditions. Current Entropy Index (ERI[6]) is one of the most common indicators in measuring the mechanical reliability of a network, which is calculated based on the number of possible flow paths. For the first time Awumah et al. In 1990 introduced the concept of entropy to measure the reliability of water distribution networks based on Shannon's (1984) function. Then, in 1993, Tanyimboh & Templeman developed the ERI index to examine water distribution networks. ERI measures the uniformity of flow in pipes. The purpose of this paper is to investigate seven different reliability indices and compare their performance in a single framework for designing water distribution networks.

[2] Resilience Index

[3] Network Resilience Index

[4] Modified Resilience Index

[5] Minimum Surplus Head

[6] Entropy Reliability Index

2.Methodology

In this section of the paper, various reliability indices include, Node Pressure Performance Index, Pipe Speed Index, Node Pressure Performance and Pipe Speed Index, Network Pressure Difference Index, Network Flexibility Performance Index (NRI), Surplus Minimum Head Index (MSH) and entropy index (ERI) are introduced and the network design problem based on the aforementioned indices for two sample water distribution networks (reference network) will be described using NSGA-II optimization algorithm and EPANET hydraulic solver.

$$1)\, Minimize\ Cost = \sum_{i=1}^{Nm} f\,(D_i).L_i \qquad (1)$$

$$2)\, Maximize: \begin{cases} I)\, NRI \\ II)\, MSH \\ III)\, ERI \\ IV)\, PIP = \dfrac{\sum_{j\in N_n} PIPE_j}{N_n} \\ V)\, PIV = \dfrac{\sum_{j\in N_m} PIVE_{ij}}{N_m} \\ VI)\, \Delta H_{\max} = \min(H^{\max} - H^{des}) \\ VII)\, PI = w1.PIP + w2.PIV \end{cases} \qquad (2)$$

In relation 1, Di is the diameter of the pipe i, Nm the number of pipes and L is the length of the pipe i. In relation 2, PIP[7]: Total network node pressure performance index, Nn: Number of network nodes, PIPEj: Node performance index j. PIV[8]: Total Pipe Speed Performance Index, Nm: Number of Pipes, PIVEij: Pipe Performance Index ij. PI: Combined

[7] Performance Index of Pressure

[8] Performance Index of Velocity

performance index of node pressure and pipe velocity, w1 and w2 are constant coefficients of 0.5.

3.Discussion and Results

In this problem, pipe diameter as a decision variable, cost and reliability index as objective functions and satisfy the node and energy continuity constraint for the loops and the minimum nodal pressure accepted at all times as the hydraulic constraints of the optimization problem. It was considered. In order to eliminate the probability of achieving local optimal responses instead of the general optimal responses, each problem was optimized 10 times with 1000 iterations and the results of these optimizations were compared to obtain a superior Pareto front Provide answers. Fig. 1 and Fig. 2 illustrate the Pareto fronts obtained from the optimization according to the seven criteria performed on the Hanoi and Pescara sample grids for a sample implementation of the optimization model.

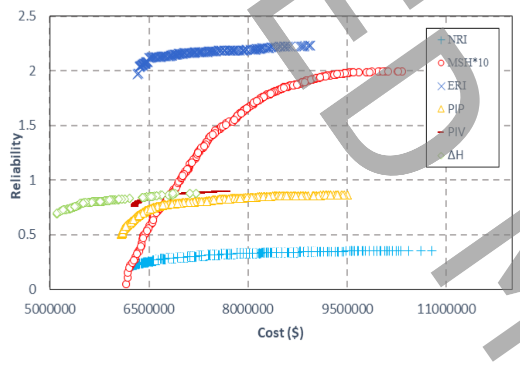

Fig. 1. Pareto fronts obtained for optimal design of the Hanoi water network

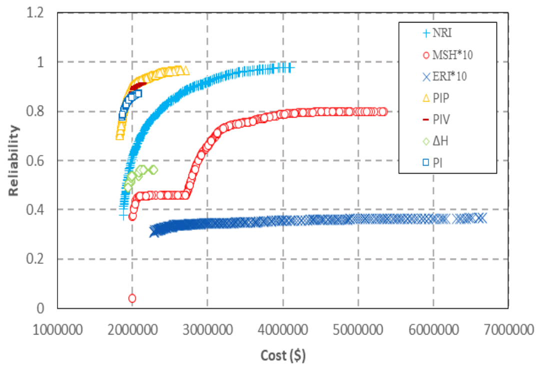

Fig. 2. Obtained Pareto fronts for optimal design of the Pescara water network

The failure scenario (5%, 10%, 20%) is used to better compare the indices. The location of the broken pipes is randomly selected so that the broken pipes are not the same at different times of failure.

4.Conclusions

In a sample of the small water distribution network (Hanoi network), in addition to deriving the optimal network design based on different criteria, it was shown that during the failure of the pipes which may occur naturally or abnormally, the NRI performance index It gives better results than other indices. Also, for a medium-sized water distribution network (Pescara network), in the range of low cost levels, the design based on the node pressure performance index (PIP) and then the NRI index yielded the best results based on the nodal requirement. In the range of high cost levels, the NRI performance index again outperformed other indices. These two indices, in addition to increasing network resilience against pipe failures, also provide the pressure required on the nodes. According to the results generally, the average network pressure based on the NRI index is higher than the network designed with other indices, indicating that there is more surplus energy in the network designed based on this index.

5.References

[1] Tabesh, M. reliability. Advanced Modeling of Water Distribution Networks. Institute of Tehran University Press. 2016. P 394-398.

[2] Todini, E., (2000). Looped water distribution network design using resilience index based heuristic approach. Urban Water 2, 115e122.

[3] Farmani, R., Wright, A. J., Savic, A. D., and Walters, A. G., (2005), “Self-adaptive fitness formulation for evolutionary constrained optimization of water systems.” J. Comput. Civ. Eng., 19(2), 212-216.

[4] Awumah, K., Goulter, I., and Bhatt, S., (1990), “Assessment of reliability in water distribution networks using entropy based measures.” Stochastic Hydrol. Hydraul., 4(4), 309–320.

[5] Tanyimboh, T. T., & Templeman, A. B. (1993). Optimum design of flexible water distribution networks. Civil Engineering Systems, 10(3), 243-258.