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EXTENDED ABSTRACT

Pressure and Leakage Management of Water Distribution Network with Optimal Scheduling of Valves and Pumps

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1. Introduction

Control of water leakage in Water Distribution Networks (WDNs) is important to save drinking water consumption. Pressure management is one of the solutions that directly affected the water leakage and reliability of the WDNs. The leakage rate depended on the nodal pressure, high-pressure increases the leakage rate and failure in the network, and low pressure decreases water supply reliability in WDNs. However, it is necessary to be preserved sufficient pressure throughout the network to ensure that consumer demands are fully provided at all times. Pressure management is one of the effective and cheapest methods for leakage reduction and reliability addition in WDNs. The aim of this paper is to develop a methodology based on maximizing the network reliability by applying an optimized scheduling program for setting flow control valves (FCVs) and pumps at different times of the day, leading to pressure management and leakage reduction in the networks. For this purpose, the particle swarm optimization (PSO) algorithm is used to find the optimal setting of FCVs and pumps. The aim of the optimization algorithm is to maximize the network reliability of the WDN. For this purpose, the network pressure reliability index (NPRI) is used which is proposed by Dini and Tabesh (2017). Also, to determine the optimal location of the valves, the valve selection index (SI) is used which is proposed by Ali (2015). The methodology is verified by an example network (Jowitt and Xu, 1990). Also, it is applied to an example network and Ahar WDN.

2. Methodology

2.1. Leakage rate

In this paper, the leakage in each node of the network is calculated by a function of flow through an orifice (Araujo et al., 2006). They are presented in eq. (1).

$$q_j = (C \sum_{j=1}^{M} 0.5\, L_{ij}) P_j^{\beta} \tag{1}$$

where q_j is the leakage flow at node j, C is the discharge coefficient of the orifice which depends on the shape and the diameter, L_{ij} is the pipe length between nodes i and j, p_j is the service pressure at node j, M is the number of pipe connected to the node j and β is the nodal pressure exponent (β=1.18).

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2.2. Valve selection index

In large-scale WDNs, there are a lot of pipes in the network. So selection of the optimal pipe for installing the valve is difficult. Therefore, before optimization of valve location, all pipes in the network are evaluated by the SI index, which is proposed by Ali (2015).

$$SI = \frac{Q\ L}{C_{HW}\ D} \tag{2}$$

Where SI is the valve selection index, Q is the pipe flow, L is the pipe length, C_{HW} is the roughness coefficient of pipes and D is the pipe diameter.

2.3. Network reliability

The Nodal Pressure Reliability Index (NPRI), proposed by Dini and Tabesh (2017) is used to evaluate the reliability of WDNs. This index is defined as nodal and network reliability indices. In eq. (3) and eq. (4), the utility function of the index is presented for each node and network.

$$NPRI(j,t) = \begin{cases} 0 & P < 10\text{m} \\ \frac{1}{32}(P-10) & 10\text{m} < P < 26\text{m} \\ \frac{1}{10}(P-26)+0.5 & 26\text{m} < P < 31\text{m} \\ 1 & P = 31\text{m} \\ -\frac{1}{38}(P-31)+1.0 & 31\text{m} < P < 50\text{m} \\ -\frac{1}{40}(P-50)+0.5 & 50\text{m} < P < 60\text{m} \\ 0.25 & 60\text{m} < P \end{cases} \tag{3}$$

$$NPRI = \frac{\sum_{j=1}^{NN} Q_{j,t}^{req}(NPRI(j,t))}{\sum_{j=1}^{NN} Q_{j,t}^{req}} \tag{4}$$

Where $NPRI(j,t)$ is the nodal pressure reliability of node j at time t, P is the nodal pressure, $NPRI$ is the nodal pressure reliability of the network, NN is the number of nodes and $Q_{j,t}^{req}$ is the required nodal demand of node j at time t.

2.4. Optimization algorithm

In this paper, the particle swarm optimization algorithm is used to find the optimal setting of FCVs and pumps by maximizing the nodal pressure reliability of the network that is coupled with EPANET (Rossman, 2000). In the PSO algorithms, the position and velocity of each particle (Xi (t) and Vi (t)) are initialized by random vectors. The new position and velocity of the particles (Xi (t+1) and Vi (t+1)) in the PSO algorithm are updated by these equations (Eberhart and Kennedy, 1995):

$$X_i = X_i\ (t) + V_i(t+1) \tag{5}$$

$$V_i(t+1) = C_1 * Rand_1 * \left(P_{i\ .best} - X_i(t)\right) + C_2 * Rand_2 * (P_{g\ .best} - X_i(t)) + W * V_i\ (t) \tag{6}$$

Where $C1$ and $C2$ are called the acceleration coefficients, Rand 1 and Rand 2 are two uniformly distributed random numbers, $P_{i\ .best}$ denotes the personal historically best particle for the ith particle, $P_{g\ .best}$ denotes the best position that the whole swarm has found.

3. Results and discussion

3.1. Verification of the first case study

In this part, the proposed method will be verified in the first case study (Jowitt and Xu, 1990) that was used to find the optimal location and setting of valves by Araujo et al (2006). In Fig. 1, the leakage rate of the example network is compared for the Araujo et al (2006) paper and this paper. A comparison of the results showed that the leakage curve for this paper was in good agreement with the leakage curve for the Araujo et al (2006) paper. So the proposed method and PSO algorithm have a good performance in term of nodal pressure and leakage reduction for the first case study. Therefore, it verifies the performance of the proposed method.

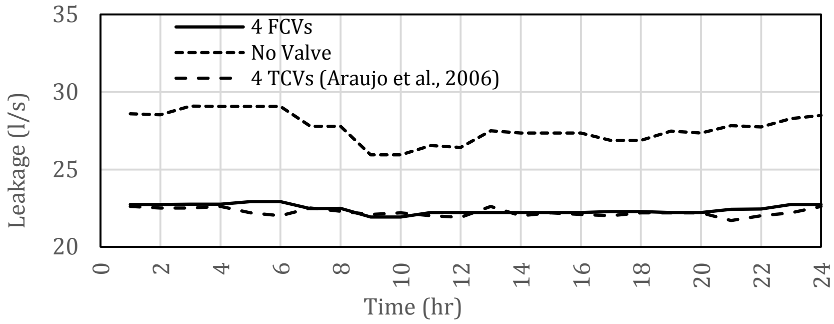

Fig. 1. The leakage rate of the example network

3.2. Application to the Ahar WDN

In this case study, first, the SI index is calculated for the pipes. The 19 pipes from the 192 pipes with the highest SI index are nominated for the installation of valves. After considering the related parameters to the valve selection index, the five pipes (pipes 61, 88, 102, 110, 121) are selected as a final case for installation of valves. In four of them, the flow control valves and in the case adjacent to the pumps, the pumps are considered. For flow control valves, the flow of the valves and for pumps, the relative pumping capacity is assumed as the problem decision variable. The PSO algorithm is used to find the optimal setting of FCVs and pumps.

Fig. 2 and 3 show the variation of NPRI and leakage rate without valves and with optimized valves and pumps for the Ahar WDN. For the case without valves, the average NPRI reliability index and the average leakage rate are 55 percent and 30 l/s respectively. After optimization, they change to 73 percent and 23 l/s respectively. It is clear that by optimizing the setting of valves and pumps in Ahar WDN, the average NPRI reliability index increased about 33 percent and the average leakage rate decreased by about 25 percent in comparison with the network without valves.

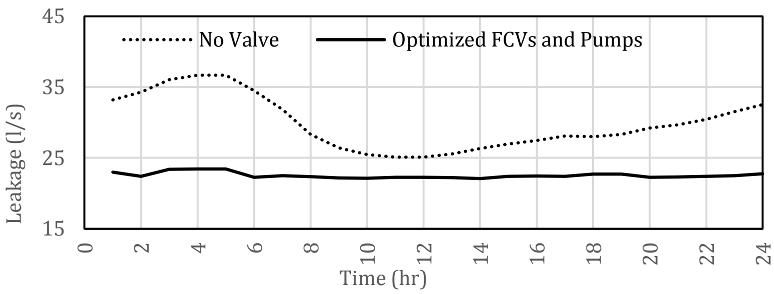

Fig. 2. Variation of leakage rate in the Ahar WDN

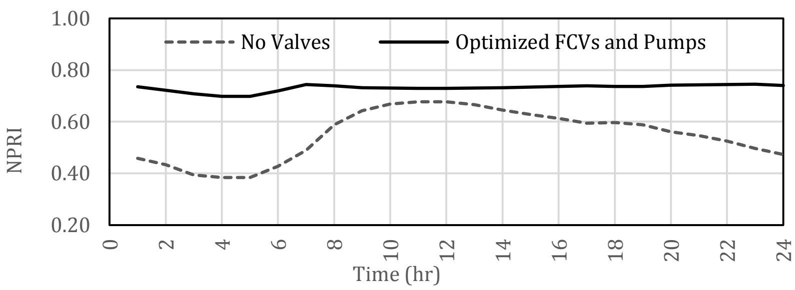

Fig. 3. Variation of NPRI in the Ahar WDN

4. Conclusions

In this paper, the management of pressure and leakage in water distribution networks is investigated by applying the optimal time scheduling of valves and pumps. For this purpose, an optimization model has been developed in which after determining the proper valve location by using the valve selection index, the pressure reliability index of WDNs is maximized by setting the flow in the valves and the relative pumping capacity in the pumps. To create the model, The PSO algorithm that is written in the MATLAB code by the combination of WDN simulator model (EPANET) is used. The proposed method is verified on the Jowitt and Xu, (1990) network and it is used for detailed model examination on Ahar WDN.

The results of verification of the proposed method for the example network in the same condition showed that the leakage rate for this paper was in good agreement with the leakage rate for the Araujo et al (2006) paper, that, it verifies the performance of the proposed method. In Ahar WDN, after considering the related parameters to the valve selection index, the five pipes (pipes 61, 88, 102, 110, 121) are selected as a final case for the installation of valves. In four of them, the flow control valves and in one of them, the pumps are considered. After the optimal setting of valves and pumps in Ahar WDN, the average NPRI reliability index increased about 33 percent and the average leakage rate decreased about 25 percent in comparison with the network without valves which, demonstrates the proper performance of the proposed method to increase the efficiency of the networks.

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