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The effect of the intelligent emplacement of pressure reducing valves in reducing leakage in real water distribution networks

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ABSTRACT: Due to the special topography of Kaleybar city, the water distribution network of this city has 7 pressure-reducing valves that have been experimentally installed in different locations to manage the extra pressure in the network. In this research, the effect of the intelligent emplacement of pressure-reducing valves is investigated by using the valve selection index to reduce leakage and increase network reliability. The aim is to minimize hourly leakage by determining the optimal location and setting of valves, In addition to the minimization of leakage as the objective function, the minimum pressure restriction in three cases of no pressure restriction (0 meters), water supply at the entrance of the building (10 meters) and water supply for a four-story building (26 m) is considered as a penalty function. For this purpose, a combination of the Ant Colony Optimization Algorithm with the EPANET simulator in MATLAB has been used. The results show that with the intelligent emplacement of pressure-reducing valves in Kaleybar City, the leakage of the network has been decreased by 15.9 percent and the reliability of the network has been increased by 15. 5 percent, which shows the effect of the proposed method in improving the hydraulic performance of water distribution network.

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1- Introduction

Water distribution networks are one of the urban infrastructures that are responsible for transferring drinking water from supply sources to consumption points. Due to the severe shortage of drinking water resources, it is essential to identify the factors affecting water loss from networks in order to preserve and manage water resources. The amount of leakage is directly related to the water pressure. So, by reducing and managing the pressure in the water distribution networks, its amount decreases drastically [1]. In order to manage the pressure in water distribution networks, several researches have been conducted in which various operating methods have been used to control network equipment and facilities, which has led to the improvement of network performance [2-4]. Dini and Asadi investigated the increase of the hydraulic performance of the real water distribution network by optimizing the location and hourly schedule of valves. The results showed that the reliability is increased and the leakage is reduced [5]. Saghebian et al investigated the hydraulic performance of water distribution networks by optimal setting of pressure-reducing valves with the two objective functions of maximizing reliability and minimizing leakage. Comparing the results showed that in the reliability maximization function, the reliability is higher but the leakage is lower than the leakage minimization function [6].

2- Methodology

2- 1- Objective function

The objective function used in this research is the minimization of hourly leakage as shown in equation (1), where MinLeakage is the minimum hourly leakage of the network and Q_j is the hourly leakage in the j_{th} node. Equation (2) is used to calculate each nodal hourly leakage of the network.

$$MinLeakage = \sum_{j=1}^{j=nN} Q_j \tag{1}$$

$$Q = KP^{\beta} \tag{2}$$

where, Q is the leakage flow at each pipe, P is the average pressure value in each node, K is the leakage coefficient that can be calculated separately for each node, and β is equal to 1.18 according to the research conducted 7]].

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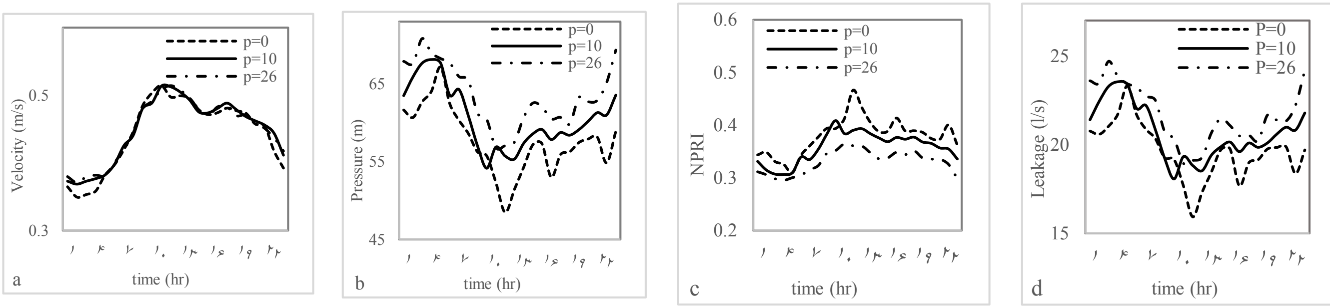

Fig. 1. Leak, reliability, pressure and flow rate changes of Kaleibar water distribution network in the current state

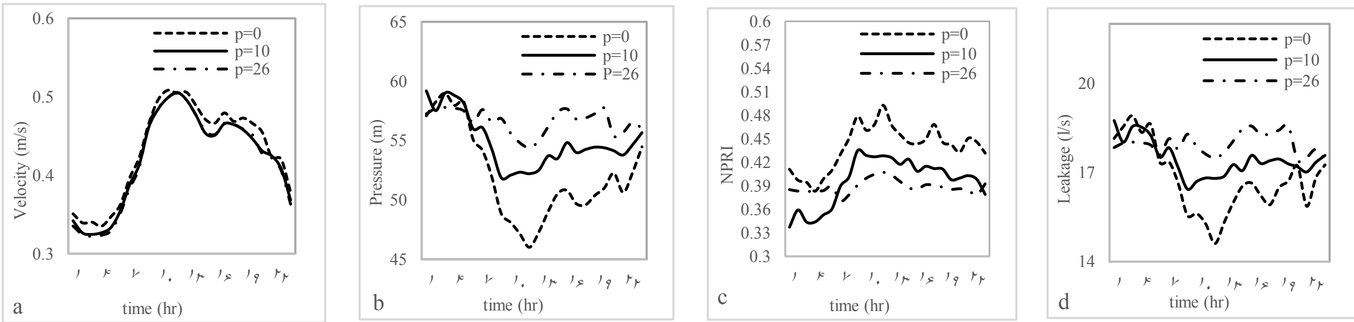

Fig. 2. Leak, reliability, pressure and flow rate changes of Kaleibar water distribution network after placing the new valves

2- 2- Network reliability

To evaluate the performance of the network, the leakage index and the reliability of the network have been used. The reliability index of the network is in the form of equations (3) and (4) [8]

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

where *NPRI(j,t)* is the Nodal reliability index of in the j_{th} node at time *t* and *P* is the nodal pressure in the j_{th} node at time *t*. The network reliability index is obtained by equation4)).

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

where *NPRI* is network nodal pressure reliability index, *NN* is the number of nodes, and $Q_{j,t}^{req}$ is the required demand of the j_{th} node at time *t*.

3- Results and Discussion

In this article, in order to evaluate the proposed method, the water distribution network of Kaleibar has been studied. Due to the special feature of the topography of the city, the Kaleibar water distribution network has 7 pressure-reducing valves that are experimentally installed in different positions of the network. To evaluate the proposed method, two scenarios are defined. The first scenario is in the current state and according to the position of the existing valves, and the second scenario is defined based on the position of the selected valves by the valve location index and is intelligently defined. In both scenarios, the hourly schedule of valve settings has been optimized using the Ant Colony Algorithm in the MATLAB environment.

3- 1- The first scenario

In this scenario, without changing the position of the existing pressure-reducing valves, the outlet pressure of the valves is set as a 24-hour schedule with the aim of minimizing the amount of leakage. The setting schedule for the valves in the Kaleibar water distribution network has been done in three scenarios, 0, 10, and 26 meters. The results show that the reliability of the network has a negative correlation with the variation of leakage and the average pressure. Also, the variation of average velocity in the pipes shows that there is a positive correlation between the average velocity and consumption.

3- 2- The second scenario

In this scenario, the position of the pressure-reducing valves has been re-determined by using the valve location index [9], the pipes with higher index values were selected, and the position of the new valves was determined from among them based on the grouping of the pipes. After determining the position of the valves, the outlet pressure of the valves was adjusted using the Algorithm of the Ant Colony. During the minimum consumption, in all three scenarios, the leakage is high and reliability is low. Also during the maximum consumption, the leakage is low and reliability is high. In this scenario, the pressure values in all three modes are relatively high at times of minimum consumption and relatively low at times of maximum consumption, and there is a positive correlation between pressure changes and network leakage and a negative correlation with network reliability. Also, the average hourly velocity in all three scenarios are similar with little changes.

In general, the comparison of two scenarios shows that in the second scenario, the leakage has improved by 15.9 percent on average, also, the reliability has increased by 15.5% on average compared to the first scenario. Overall, it shows that the intelligent placement of pressure-reducing valves has resulted in an effective improvement in all hydraulic indicators of the network, including leakage, reliability and average pressure of the network.

4- Conclusion

In this paper, the effect of intelligent placement of pressure-reducing valves in reducing leakage from real water distribution networks has been studied. For this purpose, by using the valve location index, 7 current valves have been repointed. The objective function used to optimize the output head of the pressure-reducing valves is to minimize the hourly leakage, which is used to adjust the output pressure of the valves. In order to properly provide network services, in addition to the objective function of minimizing leakage, the minimum pressure restriction in three cases of 0, 10, and 26 meters are considered. Reliability index, leakage, nodal pressure and average velocity of the network have been used to evaluate the performance of the water distribution network. The results show that with the intelligent placement of the pressure-reducing valves and the optimal adjustment of their schedule, all the indicators have increased compared to the base state, so that the leakage, reliability, average nodal pressure and average velocity of pipes have been improved by 15.9, 15.5, 9.9 and 0.6 percent, respectively, which indicates the proper performance of the proposed method in improving the hydraulic efficiency of the real water distribution network.

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