Journal of Electrical Engineering, Electronics, Control and Computer Science – JEEECCS, Volume 7, Issue 23, pages 33-42, 2021

Appraising the Impact of Critical Pipes on Water Loss Volume in WDNs considering Valve Effect

Appraising the Impact of Critical Pipes on Water Loss Volume

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***Abstract* – Water loss through leaking pipes is inexorable in water distribution networks (WDNs). A certain level of water losses cannot be avoided from technical point of view. This means that not all the losses in the WDN can be reduced. Due to the increasing level of background losses in the WDNs, water loss is recognized as a major challenge facing the operation of municipal water services. Background leakage (a form of water loss) are diffuse flow, overtime, it causes significant loss of volume of water in WDNs. Nevertheless, the leak flow can be managed by adjusting the pressures along the pipe or at the pipe end nodes through the installation of pressure reducing valves (PRVs). In most cases, the average pressures in some specific areas where these pipes are located are adjusted. However, due to the installation cost of PRVs it will be wise to select those pipes where the background leakage is high, as well as their location within the network, and suggest them for pressure reduction. These pipes are regarded as critical pipes. Thus, this paper presents an algorithm for selecting critical pipes in WDN and most importantly, the effect of these pipes in WDN water losses analysed. In addition, the impact of pressure reducing valves on the water loss level is discussed. The results presented indicate that the impact of the critical pipes on the overall network leakage water flow is huge. Consequently, by adjusting the pressure at the end nodes of the critical pipes will reduce the water loss level within the network.**

Keywords-background leakage; critical pipe; pressure reducing valve; water distribution network; water loss.

I. INTRODUCTION

Water loss is inexorable in water supply networks and mainly occur along all distribution piping networks. Even a newly installed distribution piping network still experience some level of losses which may occur at the pipe joints or fittings. These losses can be categorised as reported and unreported leaks. The former are pipe burst and represents the major water outflow occurring due to structural deformation, high pressure or third party damage. This type of leak can be detected using appropriate leakage detection methodology. Because it causes sudden and evident pressure drop along the water system, its occurrence is easily noticed and localised. The unreported leaks are background losses due to small cracks and deteriorated joints or pipe fittings attached to the pipe [1, 2]. They are usually diffuse in nature, consequently, they do not cause evident pressure drop unlike the reported ones. Therefore, they run continuously along the pipes that makes up the distribution networks which causes the loss of huge volume of water after some times. The background leaks cannot be detected using measuring instrument due to their flow characteristics. Nevertheless, they can be modelled and evaluated to report their impact in water supply networks.

Several modelling and experimental validations [3-9] have shown that leak flow is sensitive to pressure. In [3], a technical note in the inclusion of pressure dependent demand and leakage terms in water supply network models. Lambert [4] presents a modelling approach to leak flow and revealed that leak flow is strongly related to pressure. It rises as the pressure along the pipe increases. In [5], an experimental investigation into the pressure-leakage relationship of some failed water pipes was presented. These studies have shown that water losses can be reduced by reducing the pressure within the network. Thus, controlling the pressure at some nodes (connection points between two or more pipes) in the network will minimise the leakage level in the network. The problem becomes a serious one as it is necessary to consider meeting and maintaining the required pressure to satisfy consumer demand at each node. Thus, it is crucial at this point to determine some strategic points in the network, where such pressure control could be carried out. Therefore, by localising the leaky pipes, one may have an idea of these points. It is interesting to note that it's practically impossible to reduce the entire losses in the network but rather reducing the water loss ratio. Thus, the idea of localising critical pipes, which are pipes with a relatively high background leak rate, is conceive.

In the past, several research efforts under leakage detection framework have been conducted and can be found in the literature [2, 10-13]. In [10], pressure measurements were analysed, thus, anomalies in these measurements report the presence of leak. In [11], acoustic sensors are installed along the pipes to harness acoustic signal, which are analysed using wavelet transform. The research study in [12] repots the use of water balance and automated minimum night flow for leak detection. In this work, the water inflow and outflow within the network during night hours is metered. The water loss is the estimated by finding the difference between the system input volume and that due to night hourly flows. Lately, geographic information and supervisory control systems is increasingly used by water utilities. This allows water utilities to explore hydraulic models for analysing the state of WDNs near real-time. Among others, these analyses have been utilised for leakage analysis [2, 13-16], vulnerability and water quality assessment [17, 18], and pressure control for leak reduction [19-22]. Leakage analysis involves studying the behaviour of leak flow and developing methodologies for detecting water losses in the network. Vulnerability assessment is to analyse the consequence of water network element failures [23] while water quality assessment is to perform routine check on the water quality parameters by analysing samples obtained from the WDNs for conformity with standard values.

Pressure control is usually achieved by controlling the operation of pressure reducing valves installed along the network (either at one or the two end nodes of the pipe or along the pipe itself). However, due to the installation cost of PRVs it will be wise to select those pipes where the background leakage is high (the critical pipes), as well as their location within the network, and suggest them for pressure reduction. Thus, this paper presents an algorithm for selecting critical pipes in WDN and more importantly, the effect of these pipes on WDN water loss level is analysed. Strictly speaking, research studies on background leakage localisation is very limited. Also, studies that pinpoint where pressure control could be carried on the network is rare. Nevertheless, Adedeji et al. [2] proposed an algorithm that permits the estimation and localisation of background leakages in WDNs. The proposed system was demonstrated on several WDNs to see its potential and capability in handling different water network topology and configuration. However, the effect of PRVs was not considered. In this paper, an improvement in the algorithm for localising critical pipes while considering the effect of pressure reducing valves (PRVs) is presented. More importantly, the algorithm presented in the current study helps to determine critical pipes and areas where they could be found within the network. This will assist in pressure reduction purpose. The improved algorithm is based on the use of graph-based integrated hydraulic model for the WDN and tested on a WDN case network derived from real scenario. The paper is organised as follows. The next section presents the methodology used which entails the hydraulic model formulation and the leak localisation algorithm. In Section III, the results of its demonstration on the WDN is presented while Section IV concludes the paper.

II. RESEARCH METHODS

This section discuss the methodology used for the critical pipes identification. At first, a WDN is modelled and formulated using link-node hydraulic model. Thereafter, an algorithm presented for achieving this process.

A. *Mathematical Model*

I. WDN Hydraulic Model and NR-based Solution

Theoretically, a non-compressible fluid flow within a pipe network is described by mass continuity and energy conservation. Consider a WDN with n_p pipes, n_j junction nodes (nodes with unknown heads), and n_f number of fixed-head nodes (nodes with known heads), with a total nodes n_t, which equates to $n_t=n_j+n_f$. The flow in the WDN is described by the following system of partly linear and partly non-linear equations [24] for looped water distribution networks as

$$\begin{bmatrix} E & -A_s^T \\ A_s & 0 \end{bmatrix}\begin{bmatrix} q \\ h \end{bmatrix}+\begin{bmatrix} -A_f^T h_f \\ d \end{bmatrix}=0 \tag{1}$$

where $q \in \Re^{(n_p \times 1)}$ denotes the vector of the pipe flow rate, $h \in \Re^{(n_j \times 1)}$ is the vector of the unknown heads at the junction nodes, $h_f \in \Re^{(n_f \times 1)}$ is the vector of the known head at the fixed-head nodes, $d \in \Re^{(n_j \times 1)}$ is the demand at the junction nodes. Also, $A_s \in \Re^{(n_j \times n_p)}$ and $A_f \in \Re^{(n_f \times n_p)}$ are the incidence sub-matrices obtained from the topological incidence matrix A, with A_s relating to pies that are connected to the junction nodes while A_f relates to pipes connected to the fixed-head nodes. The matrix A has an element of 1 if the flow in the pipe is enters the node connected to that pipe or -1 if the flow in the pipe leaves the node connected to such pipe or 0 otherwise. Also in (1), $E \in \Re^{(n_p \times n_p)}$ is a diagonal matrix whose elements are derived from

$$E = diag\left(r\left|q\right|^{\alpha} + k_m\left|q\right|\right) \tag{2}$$

where $k_m \in \Re^{(n_p \times 1)}$ is the vector of the minor loss factor as a result of valves or other fittings connected to the pipe, $r \in \Re^{(n_p \times 1)}$ denotes the vector of the pipe hydraulic resistance, and α is an exponent. The value of α depends on the choice of head-loss model adopted. According to [25], α is 1.85 when head-loss model is considered and 2 for both Darcy-Weisbach or Chezy-Manning.

II. Integrating the Pressure-dependent Leak Model

In WDNs, leak flow occurs at the pipe nodes and along the pipes. Since leak flow is pressure-dependent, therefore, this relationship is defined in the vector $q_{leak} \in \Re^{(n_j \times n_j)}$ which denotes the nodal leak flow. If the pressure-dependent leakage model is integrated, (1) may be rewritten as

$$\begin{bmatrix} E & -A_s^T \\ A_s & 0 \end{bmatrix}\begin{bmatrix} q \\ h \end{bmatrix}+\begin{bmatrix} -A_f^T h_f \\ d+q_{leak} \end{bmatrix}=0 \tag{3}$$

Using the topological incidence matrix, the elements of q_{leak} may be estimated from the pipe leak model Q_{j-leak} as

$$q_{leak}=\frac{1}{2}\varphi\left[Q_{j-leak}\right]=\frac{1}{2}\varphi\begin{bmatrix} Q_{1-leak} \\ \cdot \\ \cdot \\ Q_{n_p-leak} \end{bmatrix} \tag{4}$$

where φ is the absolute of A. The vector of the leak flow in the pipe may be expressed as

$$Q_{j-leak}=\begin{cases} \beta_j L_j\left(h_j\right)^p & if\ h_j>0 \\ 0 & if\ h_j\le 0 \end{cases} \tag{5}$$

where β_j and L_j denote the leak discharge coefficient and the length of the j^{th} pipe, while p is the exponent of the leak-pressure relationship. The value of p is reported as 1.18 for background leakage [3]. Also, h_j represents the pressure-head vector in pipe j estimated as

$$h_j=\left(1/2\right)\varphi^T h \tag{6}$$

Therefore, the expressions in (3) may be conveniently written as (7) and can be unravel using Newton-Raphson (NR) method.

$$f(x)=f\begin{pmatrix} q \\ h \end{pmatrix}=\begin{pmatrix} E & -A_s^T \\ A_s & 0 \end{pmatrix}\begin{pmatrix} q \\ h \end{pmatrix}+\begin{pmatrix} -A_f^T h_f \\ d+q_{leaak} \end{pmatrix} \tag{7}$$

During each iteration "t", the NR method is expressed as

$$x^{(t+1)}=x^{(t)}-J^{-1}f\left(x^{(t)}\right) \tag{8}$$

$$J(q,h)=\begin{pmatrix} \frac{\partial}{\partial q}f_1(q,h) & \frac{\partial}{\partial h}f_1(q,h) \\ \frac{\partial}{\partial q}f_2(q,h) & \frac{\partial}{\partial h}f_2(q,h) \end{pmatrix}=\begin{pmatrix} N & -A_s^T \\ A_s & N_{lk} \end{pmatrix} \tag{9}$$

wher $N\in\Re^{\left(n_p\times n_p\right)}$ is a diagonal matrix whose elements are the partial derivatives of the head loss equations as

$$N=diag\left(\alpha r|q|^{\alpha-1}+2k_m|q|\right) \tag{10}$$

Also, N_{lk} is a diagonal matrix of size (n_j by n_j). Its elements are determined from the derivatives of the nodal leakage vector q_{leak}. Therefore, the elements of N_{lk} are computed from derivatives of Q_{j-leak} with respect to h_j. For a node i, N_{lk} is;

$$N_{lk(i,i)}=\frac{1}{2}\varphi\left[\frac{d}{dh_j}Q_{j-leak}\right]=\frac{1}{2}\varphi\begin{bmatrix} \frac{d}{dh_j}Q_{1-leak} \\ \cdot \\ \cdot \\ \frac{d}{dh_j}Q_{n_p-leak} \end{bmatrix} \tag{11}$$

$$\frac{d}{dh_j}Q_{j-leak}=\begin{cases} p\beta_j L_j\left(h_j\right)^{p-1} & if\ h_j>0 \\ 0 & if\ h_j\le 0 \end{cases} \tag{12}$$

Substituting these expressions into (8), then

$$\begin{pmatrix} N & A_s^T \\ A_s & N_{lk} \end{pmatrix}\begin{pmatrix} q^{(t)}-q^{(t+1)} \\ h^{(t)}-h^{(t+1)} \end{pmatrix}=\begin{pmatrix} E & -A_s^T \\ A_s & 0 \end{pmatrix}\begin{pmatrix} q^{(t)} \\ h^{(t)} \end{pmatrix}+\begin{pmatrix} -A_f^T h_f \\ d+q_{leak} \end{pmatrix} \tag{13}$$

By further simplifications, the estimate of the nodal head and the flow for iteration "t" with pressure-dependent leak model integrated may be obtained as

$$h^{(t+1)}=\left(B+N_{lk}\right)^{-1}\begin{bmatrix} -\left\{A_s q^{(t)}+\left(d+q_{leak}\right)\right\}+N_{lk}h^{(t)}+ \\ A_s N^{-1}\left(Eq^{(t)}-A_f^T h_f\right) \end{bmatrix} \tag{14}$$

$$q^{(t+1)}=q^{(t)}-N^{-1}\left[Eq^{(t)}-A_s^T h^{(t+1)}-A_f^T h_f\right] \tag{15}$$

where $B=A_s N^{-1}A_s^T$ is a symmetric positive definite matrix.

B. Critical Pipes Identification Algorithm

The pseudo code in Fig. 1 describes how the algorithm operate. The algorithm was written and compiled using MATLAB R2013a software on a hp Elite Book 8560p computer with a 6 GB RAM and 64-bit operating system. It entails hydraulic analysis of the water network and leak computation. The algorithm load WDN network data which are the base demand, fixed-heads, pipe length and diameter, among others. It then performs water network analysis using the set of equations presented in the mathematical model. One of the results of this analysis is the computation of the leak flow in the pipes as well as the leak threshold. The threshold is computed as the mean of the leak flow along the pipes. If the leak flow in each pipe is below the threshold, the algorithm reports no leaking pipe. Otherwise, it reports leaking pipe and tag such pipe as a critical pipe. It also reports the critical pipe number (ID) as well as the node number where those pipes are attached. Thereafter, it creates a new set of pipe leak flow vector where the critical pipes still retain their Q_{j-leak} value and those with leak flow below the threshold holds a value of zero. By this, it is easy to select the critical pipes from the vector. This is achieved by removing those with zero value from the vector remaining the critical pipes only. As may be observed in the algorithm, the identification and selection of potential critical pipes which are well above a pre-defined background leakage threshold is possible. Also, nodes of the network where such pipes are located may be determined since each pipe has two end nodes. It is conceived that if pressure adjustment is performed along the critical pipes or at one or two end nodes where such pipes are connected, water loss within the network will be minimized.

Figure 1. The algorithm pseudo code

```
Algorithm:
1: Begin{
2: Load WDN network parameters
3: Read the parameters and initialise
4: for node i=1:n_s,
5: for pipe j=1:n_p,
      Run network analysis and compute nodal leakage vector q_leak
      Compute the nodal leakage threshold q_leak-thresh
     % q_leak-thresh is computed as the mean of the leak flow in the network nodes.
      if q_leak<q_leak-thresh
         Print "No leaking node"
      else
         i: Print "Leaking node ID"
         ii: Search for pipes connected to this node
         iii: Compute the pipe leakage flow vector Q_j-leak
         iv: Compute the background leakage threshold (Q_j-leak-thresh) at the pipe level
         if Q_j-leak<Q_j-leak-thresh
             Print "No leaking pipe"
         else
             i: Print "Leaking pipe ID"
             ii: Tag leaking pipe as a critical pipe and report critical pipe ID
             % Select critical pipe from the leakage flow vector
             iii: Create a new set of (n_p by 1) pipe leakage flow vector where the critical pipes are
                  assigned their Q_j-leak value and the non-critical pipes assigned a value of zero..
             iv: if y denotes the number of pipes with Q_j-leak<Q_j-leak-thresh, then;
             v: Create a set of (n_p-y) vector of the critical pipes flow rate
             vi: Display "Pressure control recommended in nodes where the critical pipe with ID...is
                 attached"
         end if
      end if
      %: Assessing the leakage status of the network
      i: Compute the network leakage ratio (NLR) at the node and pipe level
      ii: Compare the percent NLR to the acceptable water loss benchmark
      iii: Comment of the leakage level of the network
end for j
end for i
8: End}
```

C. Case Study

The algorithm was validated on a WDN having the layout shown in Fig. 2. The network has a total of 300 nodes. A node is the connection point for two or more pipes and this is where water demand or consumption takes place. Out of the 300 nodes, 3 are fixed-head nodes where the nodal head is given/known. The fixed-head nodes has a total head of 400 *m*. Also, there are 297 junction nodes where the nodal heads are unknown. The fixed-head nodes are nodes 1, 164 and 300 while the junction nodes indexes from nodes 2 to 163, and nodes 165 to 299 as shown in Fig. 2. These nodes are linked by a total of 447 pipes. A pipe has two end nodes. The pipes and nodes are labelled according, and thus assigned an identity (that is, pipe and node ID). In Fig. 2, only the nodes number are shown for clarity sake. The length and diameter of the pipes vary between 100 *m* to 2000 *m* and 100 *mm* to 750 *mm* respectively. It also has two pressure reducing valves (PRVs) with PRV1 attached to pipe 242 (between nodes 169 and 298) while the PRV2 is attached to pipe 415 (between nodes 285 and 299). The two PRVs have a minor loss coefficient of 3.6. The base demand at the junction nodes varies between 0.0 *l/s* to 10.0 *l/s*. Hazen-William's model is utilised for the head loss estimation. For simplicity and modelling sake, it is assumed that the pipes are of the same material with Hazen-William's friction loss coefficient of 120. The necessary data related to this network may be found in [26].

III. Results And Analysis

Fig. 3 relays the leak flow occurring at the network nodes. Fig. 3 shows that nodes 2, 11, 75, 102, and 113 has the highest leak flow while node 166 to 297 has the least. The highest leak flow occurs in node 11. It is observed that the nodes with the highest leak flow are due to the total cumulated length of pipes connected to these nodes. Consequently, the threat posed by the presence of high leak flow in these nodes will affect consumer connections as the volume of water that is expected to be withdraw will be less.

In Fig. 4, the flow rate along the network pipes is illustrated. This shows both the required discharge and the leak flow along the network pipes. The figure demonstrates the variability in the background leak flow that exist among the pipes. Three pipes with IDs 1, 172 and 237 have the highest leak flow while pipes 238 to 447 have the least flow. This is because the pressure-head at the end nodes of pipes 1, 172 and 237 is relatively high. Consequently, the computed average pressure-head in the pipes increases. It was also noticed that the longer length exhibited by pipe 1 (1500 *m*), pipe 172 (2000 *m*) and pipe 237 (2000 *m*) as against the 200 *m* and 300 *m* for pipes 238 and 447 respectively is another factor. Looking at Fig. 4, it is obvious that the leak flow in some other pipes is also relatively high. For example, pipes 23, 163, 167, and 228 should be monitored as their leak flow is also relatively high. This will be explain further while looking at the critical pipes selections for this network. Nevertheless, the leak flow in most of these pipes is relatively low compared to the estimated required flow in the pipes.

For critical pipe selection and to analyse the impact of the critical pipes on the network flow, the leak flow rate across the pipes is plotted against the background leakage threshold for the network as illustrated in Fig. 5. One can see that majority of the pipes have their leak flow below the threshold. Thus, the algorithm identifies and selects those whose leak is far above the threshold and tagged them as critical pipes. The Fig. 5 shows that the leak flow in pipes 1, 23, 163, 167, 172, 228, and 237 is far above the threshold. Consequently, they are selected as critical pipes for this network. Analysing the effect of the critical pipes, for this network, the estimated total required flow in all the pipes amounts to 15,671 *l/s* while the corresponding estimated leakage level amounts to 5821.3 *l/s*. Therefore, the estimated network leakage ratio at the pipe level amounts to 0.3715. This indicates that almost 37.2% of the total flow through the pipe is lost to background leakage flow at the pipe. Moreover, the estimated leakage level due to the critical pipes alone amounts to 2968.2 *l/s* with a network leakage ratio (due to critical pipes) of 0.1894. Comparing this to the leakage ratio due to all the pipes, it was noticed that about 51% of the total leakage flow in the pipes is due to the critical pipes. The critical pipes are just 7 in number out of a total of 447 pipes.

Figure 2. The layout of the WDN considered

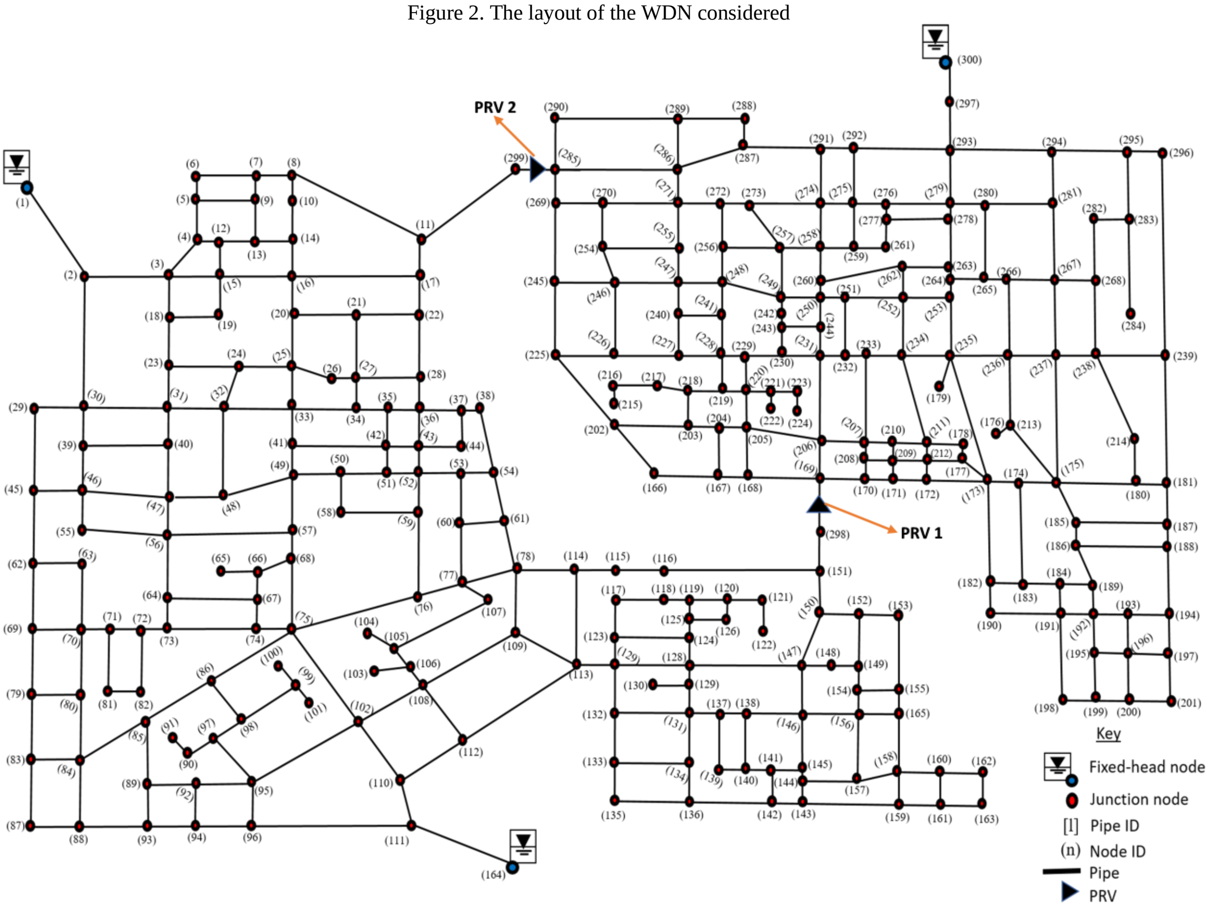


Figure 3. Nodal leakage outflow

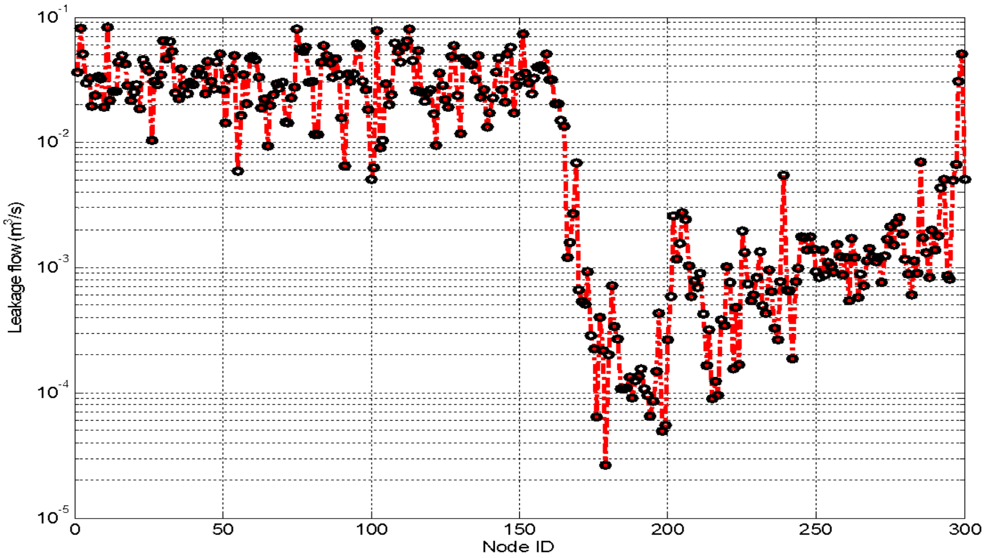


Figure 4. Flow rate along the network pipes

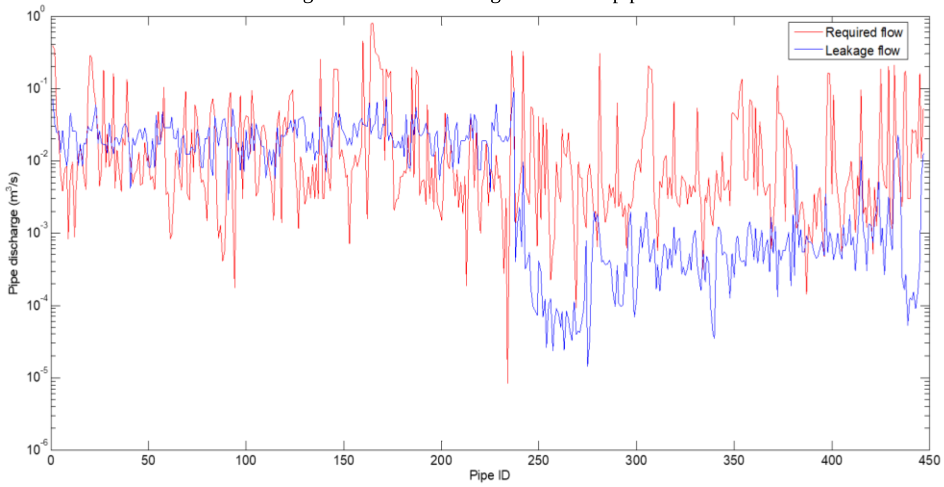
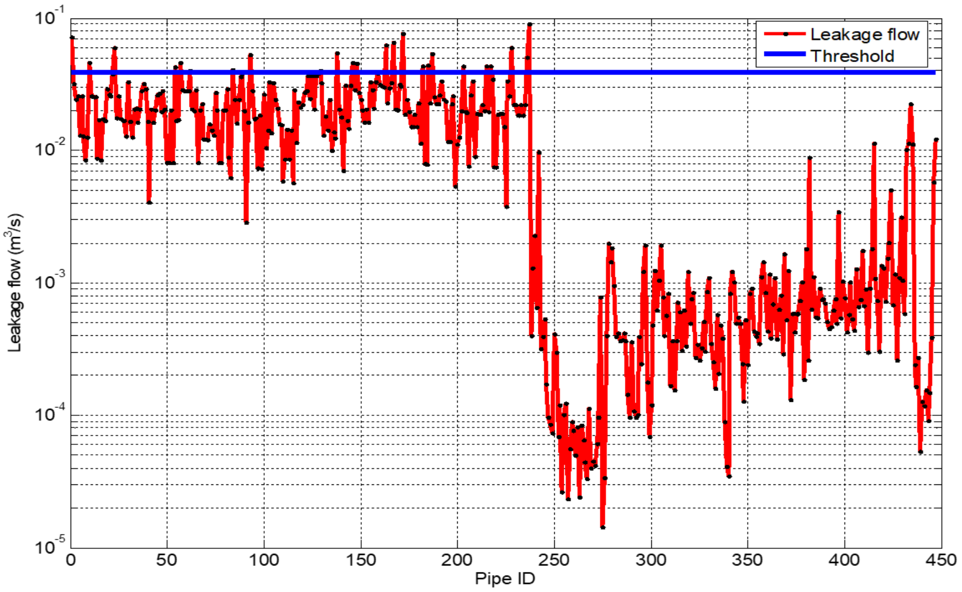


Figure 5. The pattern of the pipe leak flow against the leak threshold



One can see that the critical pipes have significant impact on the network water flow. Since each of this pipe has end nodes with its own nodal identification, thus, the algorithm suggest pressure management at these nodes or along the critical pipes (pressure management at the pipe level). However, the implementation of pressure management methodologies depends on the cost of implementation. Thus, optimising the operation of PRVs for pressure adjustment is essential.

Fig. 6 reports the estimated water loss volume in each pipe. As expected, the critical pipes with pipe ID 1, 23, 163, 167, 172, 228, and 237 have the highest water loss volume. Although, the leak flow rate in the critical pipes is relatively low when compared to the estimated required flow, these pipes posed the biggest threat to water loss volume in the network. With an estimated total loss volume of 349.3 m^3 in all the pipes, the loss volume due to the critical pipes alone amounts to 178.1 m^3 which is half of that due to the total pipes. This shows that the water loss volume due to the critical pipes is significant. It is conceived that reducing the loss volume due to the critical pipes through pressure adjustment will reduce the overall network leakage ratio.

Now analysing the impact of the two PRVs in the pipes 242 and 415 on the network flows. The results of the network behaviour when the PRV is included and when removed from the pipes is presented in Table I. In the inclusion of the valves, the local head loss generated by the valves is estimated using its minor loss coefficient and the flow in the pipe where the valve is located. When the minor loss coefficient was set to zero, the valve was considered to have been removed from the pipe. As may be observed in Table 1, the estimated flow in the pipe 242 when the PRV is not included amounts to 364.6 *l/s*. However, with the inclusion of the PRV, the estimated flow in the pipe 242 reduces to 326.8 *l/s*. The same applies to pipe 415 as may be observed in Table I. This shows that the inclusion of the PRVs reduces the flow level a bit. Since flow rate is sensitive to pressure, the flow in each pipe is expected to reduce with the inclusion of the PRVs as the pressure head at one of the end nodes reduces (the downstream node). Also, the head loss in the pipes is also considered under the same condition. The head loss in each pipe is observed to increase when the PRVs are present on the two pipes. This is expected as the PRVs introduce local head loss which is added to the head loss due to the pipes.

When the overall network performance is considered, the total estimated flow in the pipes is also affected. With the inclusion of the valves, the total estimated flow in the pipes amounts to 15,671 *l/s*. However, when the PRVs are removed, the total estimated flow in the pipes amounts to 16,575.5 *l/s*. The network leakage level and the volume of water loss (or water loss volume) are also influenced by the presence of the PRVs. The network leakage level with the inclusion of the PRVs amounts to 5,802.3 *l/s* out of which 2,821.8 *l/s* are due to the critical pipes. However, when the PRVs are removed, the estimated network leakage level amounts to 5,821.3 *l/s* out of which 2,968.2 *l/s* is due to the critical pipes. Considering the water loss volume, the estimated total water loss volume with the inclusion of the PRVs amounts to 348.14 m^3 out of which 169.31 m^3 are due to the critical pipes. However, when the PRVs are removed, the estimated total water loss level amounts to 349.3 m^3 with 178.1 m^3 due to the critical pipes.

Figure 6. Water loss volume through the pipes

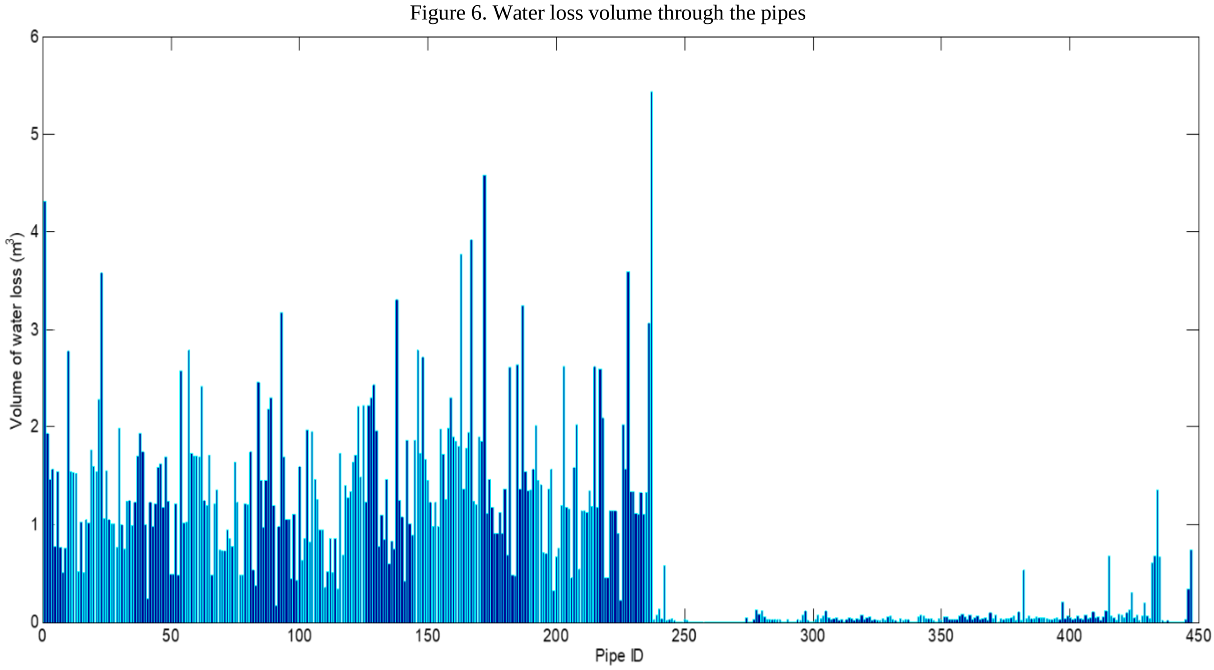


TABLE I. IMPACT OF THE PRVS ON THE NETWORK BEHAVIOUR.

PRV No	Pipe ID	Pipe flow with PRV (*l*/*s*)	Pipe flow without PRV (*l*/*s*)	*Δh* with PRV	*Δh* without PRV	*NLL* with the 2 PRVs (*l*/*s*)	*NLL* without the 2 PRVs (*l*/*s*)	*WLV* with the 2 PRVs (m^3)	*WLV* without the 2 PRVs (m^3)
1	242	326.8	364.6	133.61	93.31	5802.3	5821.3	348.14	349.3
2	415	96.61	109.5	138.67	128.75				

Δh: Head loss; *NLL:* Network leakage level; *WLV*: Water loss volume.

IV. CONCLUSION

Lately, the fear over the financial loss and environmental pollution caused by leaking pipes has intensify. These have steered the development of efficient algorithms which can identify leaky pipes in small to large-scale WDNs. It is well established that adjusting the pressure along the pipes or at the pipe end nodes with the installation of PRVs, will greatly reduce the water loss level within the network. However, due to the installation cost of PRVs, it will be wise to select those pipes where the leak flow is high (the critical pipes), as well as their location within the network, and suggest them for pressure adjustment. Thus, the identification of critical pipes in WDNs is key to reducing water loss level in the network. This paper presents an algorithm for selecting critical pipes in WDN with more focus on the effect of these pipes on WDN water loss level. Also, the impact of pressure reducing valves on the water loss level is discussed. The results presented indicate that the impact of the critical pipes on the overall network leakage water flow is huge. In severe situations, where there are large numbers of critical pipes in the network, significant volume of water is loss and network service disruption will be experience. Nevertheless, the inclusion of PRV along the pipe has significantly reduce the water loss level in the network as may be noticed in the results presented.

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