Pressure Control of a Large Scale Water Network using Integral Action

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Abstract: This paper presents a study of the effect of performing different control structures on a large scale water network. The aim is to keep network pressures stable and to their minimum in order to increase network efficiency and reduce leakage loss. One and two actuators pressure control is presented, including split range pressure control, all based on PID family. Simulations are performed using a simulation model of a real network (Demand Management Area situated in Barcelona). Resulting pressures of different control structures are compared. Subsequently, some leakages are introduced to the network to conclude which pressure control structure minimizes best the water loss. Finally, some discussions of the benefits of using each control structure are presented.

Keywords: Pressure Control, PID, Water Networks, Leakage, Control Structures.

1. INTRODUCTION

Working efficiently and reducing costs has become essential in all kind of processes. Efficient water networks offer the same services to the customers, but reduce energy consumption. One of these efficient improvements is to reduce pressures at networks nodes to its minimum, guarantying contracted water supply. Minimizing pressures also helps improving other known problems like leakages. In this paper different pressure control structures will be studied.

1.1 Leakage and pressure

Leakages are a key issue in a good management of water networks (Farley 2003). Pressures within the network are sensible to leakages and this property is used to develop techniques of leakage detection and isolation (Pérez 2011). Looking from the other point of view, the loss assumed to a leakage is pressure dependent (Brdys 1994), as seen in equation (1).

$$q = Fp^{\lambda} \tag{1}$$

Where q is the loss of the leakage, F is the flow coefficient, and p the pressure on the faulty pipe or node, raised by a pressure coefficient λ.

Some leakages are not expected to be found because they are too small but a good pressure control may minimise their size (Ulanicka 2001). If some pressure sensors are present in the network (Pérez 2009) closed loop techniques combined with simple control actions may produce good pressure behaviours.

1.2 DMA and pressure reduction valves

All the simulations have been done in a DMA (Demand Management Area) situated in Barcelona network. This DMA has two water inputs (Àlaba and Llull). Fig. 1 shows the location of the water inflows.

These two control points are provided with pressure, flow and chlorine sensors. The pressure can be controlled using pressure reduction valves (PRV).

The idea in this paper is to improve the management of the DMA manipulating the pressure at these two points. This manipulation will control the pressure on the nodes with the maximum (p_M) and the minimum (p_m) pressures. These nodes are detected using the simulation in a day. The location of these two critical points is signalled in Fig. 1 too.

The inputs of the model are pressures at the control points and demands of network nodes. The demands are kept the same in all the tests while the pressure will be manipulated in order to improve the performance of the DMA. If the pressure within the network is controlled manipulating the input pressures, the leakages can decrease while the service keeps its quality (minimal pressure). If no pressure peaks appear the durability of the assets increases too.

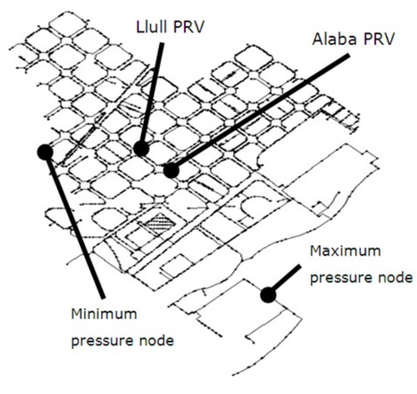

Fig. 1. Location of PRVs in the DMA

2. CONTROL

The control objective is to keep the maximum and minimum pressure in acceptable values that minimize the leakage while assuring the service. Some control structures are presented and the results are analysed. All the structures use a control of the PID family.

Pressure reduction valves have an internal control loop which controls the pressure on their output. The pressure of a distant node can be controlled as a consequence of modifying the set point of the PRV if it is fixed depending on the error among the desired pressure on a node and the real pressure of the same node. The structure of this control is shown in Fig. 2.

2.1 Integral action

The intuitive control is based on the correction of the pressure at control point proportional to the error of the pressure at the controlled point. This results in an *integral* control. The system adjusts with no delay as the pressurised network is treated as a static model. Thus the stability is not menaced by the introduction of the integral action by itself. Equation (2) shows the control law that is applied in different structures.

$$p_{sp}(k+1) = K_i e(k) + p_{sp}(k) \quad (2)$$

Where p_{sp}(k) is the pressure set point in the input at sample k, K_i is the constant of the integrator and $e(k)$ is the error of pressure at the controlled point. Samples are taken every 10 minutes. Parameters K_i are taken 1 because dimensionally set point and manipulated actions are the same (pressures) and there is no dynamics in the network (pressurised network) for tuning the parameter.

2.2 Control structures

The most important control objective is to keep the lowest pressure node at the minimum limit during all day. This control will be performed using only one actuator. The actuator is selected based on the sensibility of the pressure in the controlled node to the change in the pressure at the input. Fig. 3 shows the control structure.

Next approach consists on split range control of this lowest pressure node. This time the two actuators will be used, dividing the control action between them. Fig. 4 shows this split-rage control.

Third approach is equivalent to the previous one, but controlling the node with the maximum pressure of the network. The aim is to keep this node pressure to its daily minimum.

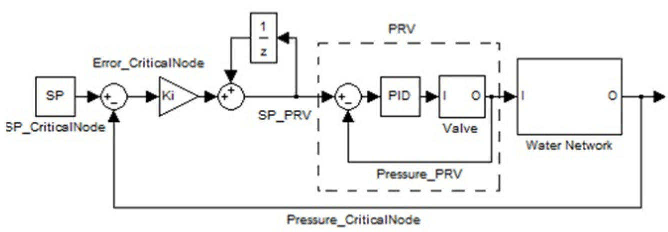

Fig. 2. Pressure control using Pressure Reduction Valves

Pressure at the rest of the nodes will be compared on second and third controls.

Finally, a double loop control will be performed. The two actuators will control the pressures of the nodes with the minimum and the maximum daily pressures at the same time. Fig. 5 shows the decoupled control of the multivariable system where the pairing of input-output has to be selected.

3. RESULTS

Initially, pressures of all network nodes are observed. As shown in Fig. 6, the network pressures are located between 42 and 53 m, being higher during night time, when demands are lower.

3.1 Monovariable control

After the node with the lowest pressure of the network has been identified, a pressure control is performed to keep this pressure on its minimum during all day (42 meters).

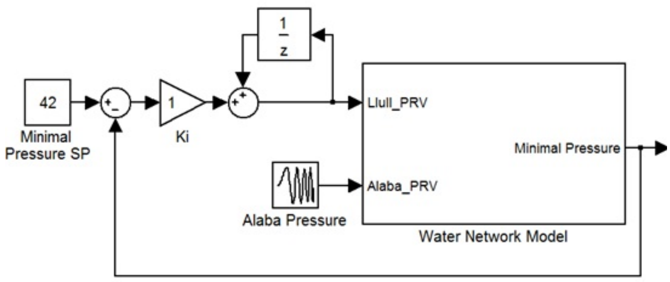

Fig. 3. One actuator control structure

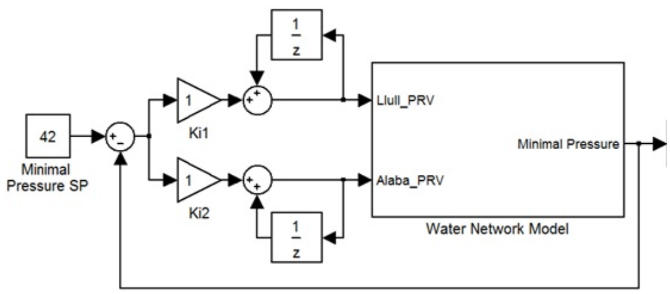

Fig. 4. Split range control structure

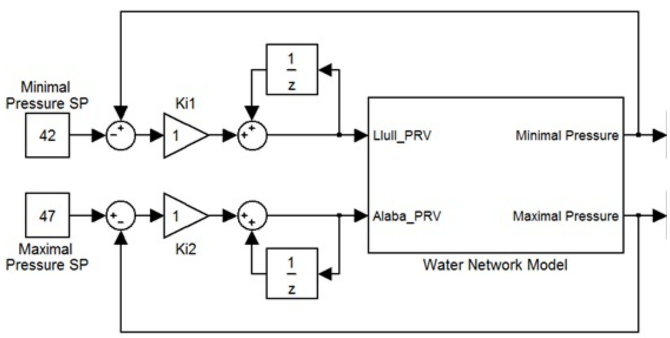

Fig. 5. Double loop control structure

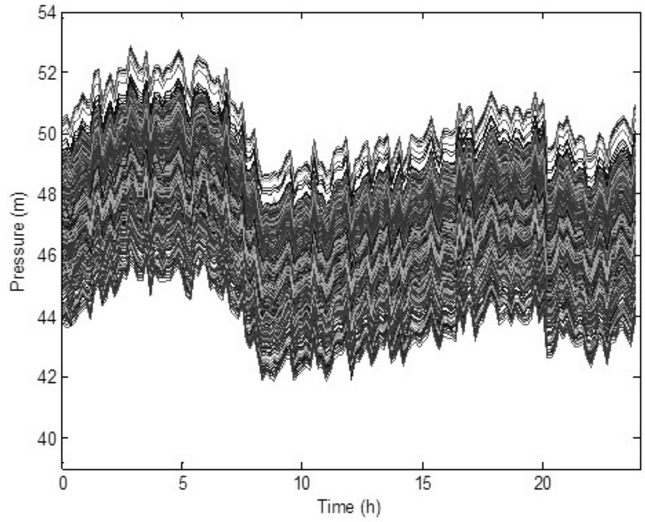

Fig. 6. Pressures with no control

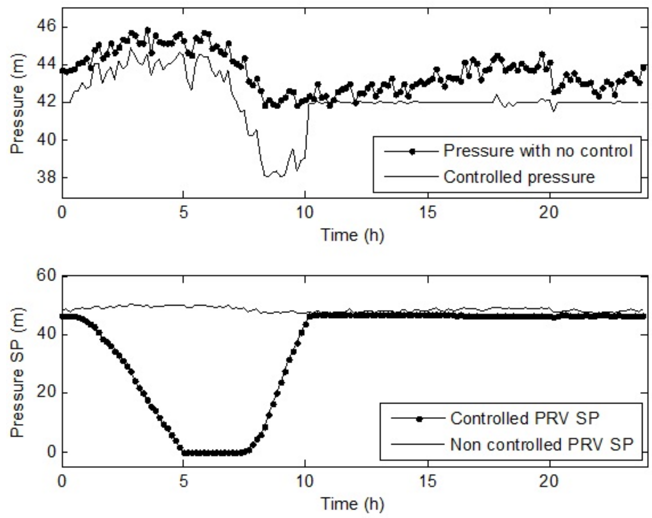

Fig. 7. Results controlling p_m, manipulating Llull PRV

Only one valve is used, while the other keeps its initial states. In Fig. 7 pressures and set points are depicted.

It can be seen that Llull PRV is not able to control this pressure on the first hours. This is due to the high values of the pressures of the node in this interval, along with the fact that Àlaba PRV states are not modified. Llull PRV has closed up to a fully closed state, even this action has not been enough to drop pressure to the specified set point. Wind-up effect can be observed from 7h to 10h. Pressure control modifying Àlaba PRV and keeping Llull valve to its initial states shows worse results.

If the anti-wind-up is introduced the results improve and pressure is controlled at once when the saturation is overcome (7h), Fig. 8.

These results show that the control of the minimum pressure node cannot be done by manipulating only one actuator. In order to solve that, split range control is performed. Control action is divided proportionally among the two actuators. Fig. 9 shows how pressure set point is reached without error.

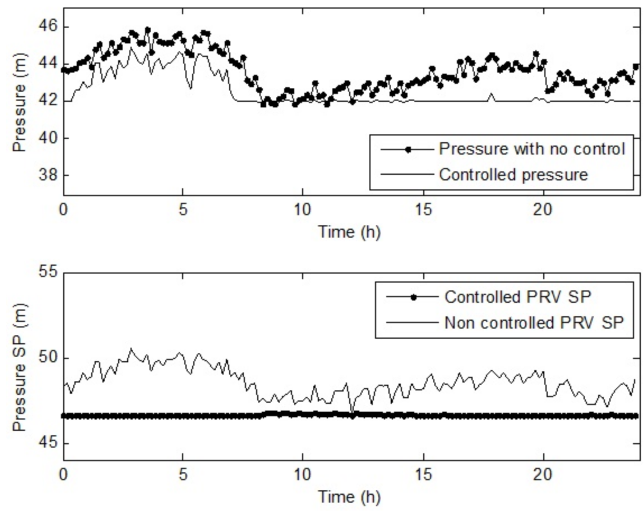

Fig. 8. Results controlling p_m, manipulating Llull PRV (anti-wind-up)

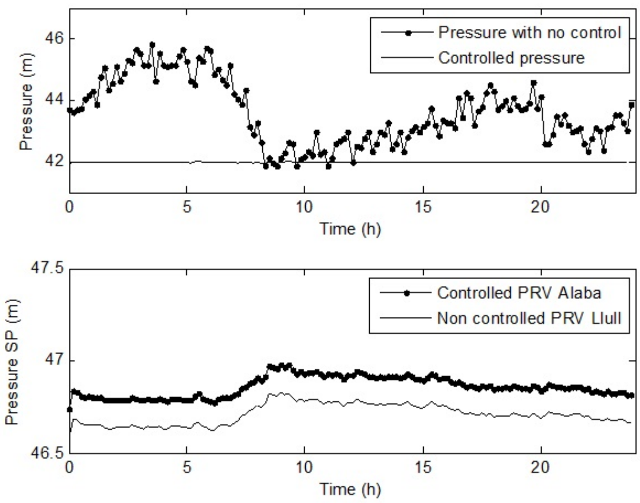

Fig. 9. Results controlling p_m, manipulating Llull PRV and Àlaba PRV (split-range)

Effect of this modification on the network pressures is depicted in Fig. 10. The resulting pressures are located between 42 and 49 meters, and slightly stabilized. This result shows that controlling the node with the minimum pressure of the network, the node with the maximum pressure and all the other nodes suffer reductions on their pressures. Maximum pressure of the network has changed from 53 meters to 49 meters.

Next test consists on controlling the node with the maximum pressure, fixing its set point to 47 meters. Here the split-range control is used directly. As shown in Fig. 11, pressure on the node is controlled without significant error, and valve states are achievable. This control causes stabilization and reduction of other network nodes pressures too (Fig. 12).

Now these pressures are contained between 40 and 47 meters. This satisfies the condition of having a maximum pressure of 47 meters, but the minimum pressure is below the specified one.

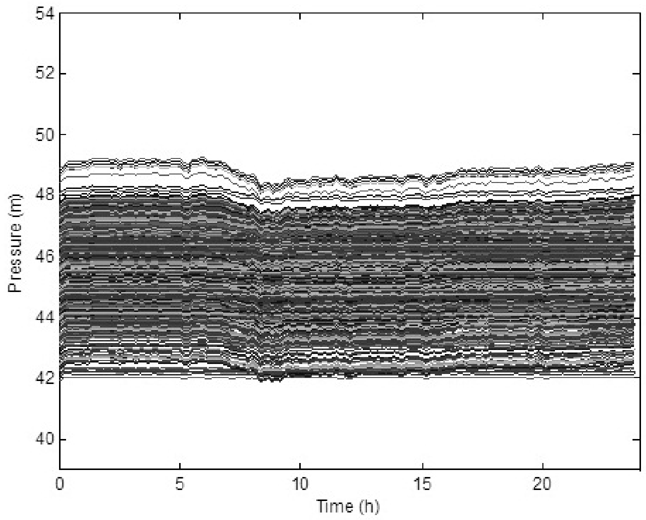

Fig. 10. Pressures with split range control over the minimum pressure node

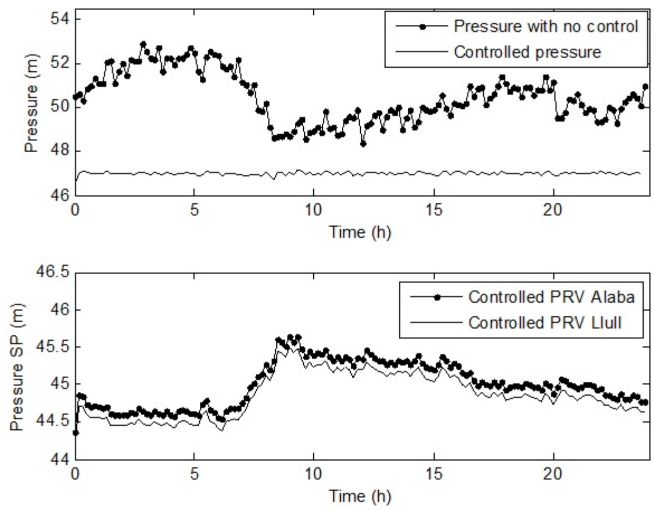

Fig. 11. Results controlling p_M, manipulating Llull PRV and Àlaba PRV (split-range)

3.2 Multiple loop Control

Next step is to control both pressures using single loops. The idea is to control this coupled multivariable system without attending the coupling. The sensitivity of the pressure in the critical points (p_m, p_M) to changes in the input set-points is for the gain analysis:

$$K = \begin{vmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{vmatrix} = \begin{vmatrix} K_{MinLlull} & K_{MinAlaba} \\ K_{MaxLlull} & K_{MaxAlaba} \end{vmatrix} = \begin{vmatrix} 0.95 & 0.08 \\ 0.40 & 0.73 \end{vmatrix}$$

These values were already used for the monovariable control when choosing the manipulated variable. It is presented in this section because the manipulated/controlled pair is more relevant in the double loop control.

Relative gain matrix (Seborg 1989) is generated from the gain matrix K:

$$\Lambda = \begin{vmatrix} 1.05 & -0.05 \\ -0.05 & 1.05 \end{vmatrix}$$

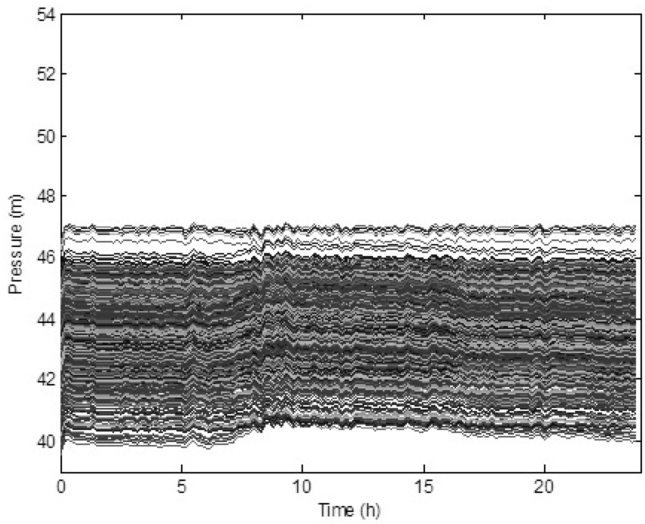

Fig. 12. Pressures with split range control over the maximum pressure node

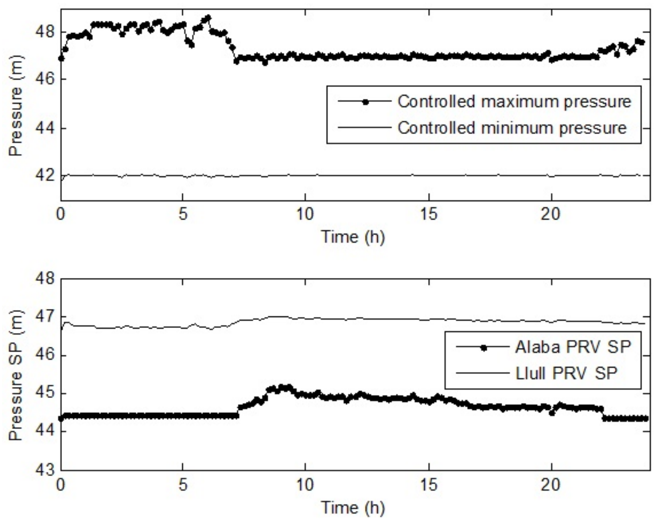

Fig. 13. Pressures p_m and p_M and control actions (Llull and Àlaba) using the two loops control

It is clear that in these conditions the pairing input-output is p_m with Llull and p_M with Àlaba. Using the double loop structure of Fig. 5 the p_m is well controlled and the p_M is kept in its value most of the time (Fig. 13). Nevertheless, now the minimal and maximal pressure may correspond to other nodes thus in Fig. 14 all the pressures are shown.

Comparing Fig. 14 with Fig. 12 and Fig. 10 it can be seen that results are not very much improved. It seems that it is a tradeoff solution between maximal and minimal pressure set-points. This result suggests the idea of using a combination of the outputs as controlled variable so that the coupling of the two loops is overcome. The mean of p_m and p_M is controlled with a single loop with split-range. Results of such intuitive control are shown in Fig. 15 and Fig. 16.

Results with this structure are quite similar to those obtained with two loops.

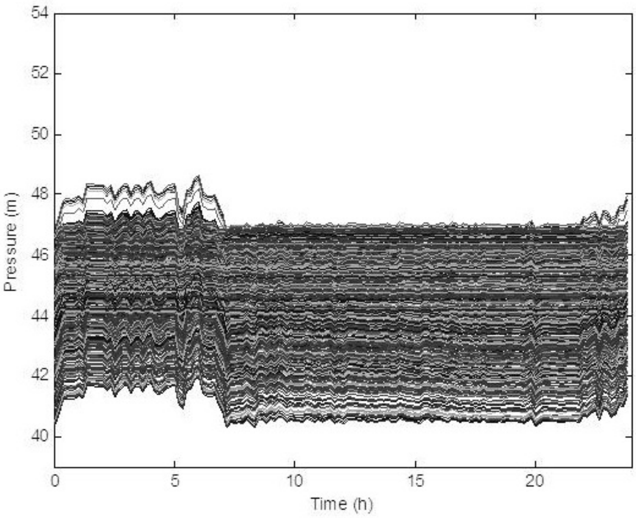

Fig. 14. Pressures using the two loops control

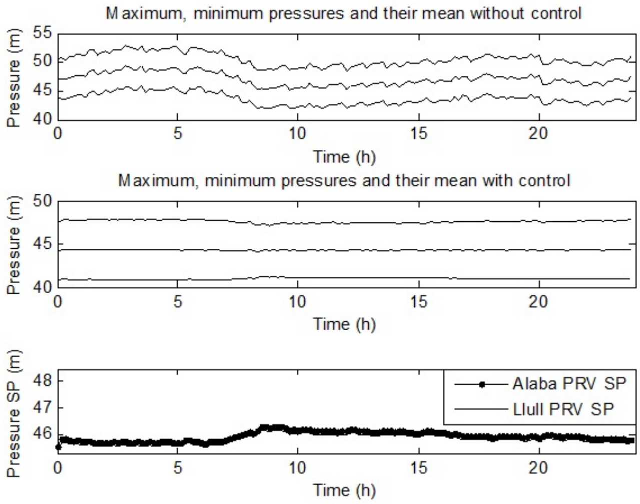

Fig. 15. Control of mean pressure

3.3 Leakage reduction

Once pressure reduction and stabilization is achieved, an analysis of their effect on leakages is performed. As commented in section 1.1, leakages are pressure dependent, so a drop on their loss is expected to appear when carrying out pressure control.

Five leakages have been defined in the simulation model, all of them having approximately a loss of 0.7 l/s under no control conditions. Table 1 shows the daily leakage loss for each type of control. As it can be seen, split range control over the maximum pressure node is the one with higher percentage of saved water regarding to when there is no control. This is due to that the network pressures obtained with this control are the lowest, as seen in Fig. 12, but it affects the minimal pressures that may go out of its desirable limit.

Simulated leakages are spread all over the network. Their loss, as seen in the introduction, depends on pressure so a leakage near the maximum pressure node would be bigger than another one close to the minimum pressure node.

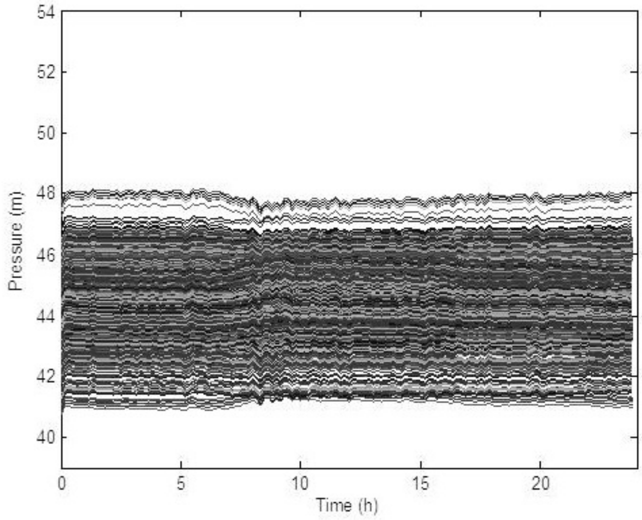

Fig. 16. Pressures in the network with mean pressure control

Although a 3.65 % of saved water could seem insignificant, it is equivalent to 11 m^3 per day for the studied leakage. For a 2 l/s leakage on each of the five nodes, the saved water in one day increases to 33 m^3.

4. CONCLUSIONS

A simple solution for pressure control in a DMA corresponding to a real network is proposed. The use of measures present within the network connected to the control points allows a better pressure behaviour to DMA as a whole. Results presented are on simulation.

First of all an analysis of the critical points in the network is carried out. The sensitivity of the pressure at these points to the changes at the inputs of the network helps to design the different structures of control.

Five different structures are presented and the results obtained are coherent. All the structures use the integral action. No stability problems are present once the anti-wind-up is introduced. Monovariable control works very well for the only variable controlled but in the case that both objectives (minimal and maximal pressure) have to be controlled two loops produce a more equilibrated solution. Finally an intuitive solution based on a monovariable control of a combination of the two outputs (mean pressure) produces a similar result as the multiple-loop one. It has been seen that although pressures have been stabilised, the difference between the lower and higher pressure is always 7 meters. This corresponds to the height difference between the higher node and the lower one, and cannot be improved due to the network topology.

On the other hand, it has been proved that the reduction of pressures on the network decreases the leakages loss. This is due to the dependence of leakages on pressure. The two variable control and the control of the mean allow a high saving than the control of minimal pressure, and scope better the pressure than the control of the maximal pressure. The saving that seems small in percentage should be taken into account as, due to the long life of some leakages, is relevant in absolute numbers.

Table 1. Leakage loss under different conditions

Faulty Node	No Control Loss (m^3)	Control 1 Loss (m^3)	Control 2 Loss (m^3)	Control 3 Loss (m^3)	Control 4 Loss (m^3)
1	58.43	57.38	56.17	56.37	56.78
2	68.08	67.07	65.90	66.35	66.49
3	60.35	59.35	58.16	59.33	58.76
4	59.22	58.18	56.98	57.17	57.58
5	58.46	57.42	56.20	57.42	56.82
Total	304.55	299.42	293.43	296.67	296.44
Saved water (%)		1.68	3.65	2.59	2.66

Control 1: Split range control over the minimum pressure node.
Control 2: Split range control over the maximum pressure node.
Control 3: Double loop control.
Control 4: Split range control over the mean of the maximum and minimum pressure nodes.

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REFERENCES

Brdys, M. A., Ulanicki, B. (1994). *Operational control of water systems: Structures, algorithms and applications.* Prentice Hall International, UK.

Farley, M., Trow, S. (2003). *Losses in Water Distribution Networks.* IWA Publishing, UK.

Pérez, R., Puig, V., Pascual, J., Peralta, A., Landeros, E., Jordanas, L. (2009). Pressure sensor distribution for leak detection in Barcelona water distribution network. *Water Science & Technology*, volume 9, pages 715–721.

Pérez, R., Puig, V., Pascual, J., Quevedo, J., Landeros, E., Peralta, A. (2011). Methodology for Leakage Isolation using Pressure Sensitivity Analysis in Water Distribution Networks. *Control Engineering Practice*, volume 19, pages 1157–1167.

Seborg, D. E., Mellichamp, D. A. (1989). *Process dynamics and control.* John Wiley & Sons, USA.

Ulanicka, K., Bound, P., Ulanicki, B., Rance, J. (2001). Pressure Control of a Large Scale Water Distribution Network with interacting Water Sources - A Case Study. *CCWI*, pages 41–53.