Available energy assessment in water supply systems

Helena Ramos[1], Dídia Covas[2], Luiz Araujo[3], Maria Mello[4]

[1] *Professor*, Civil Eng. Dept., Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisbon, Portugal (Tel: +351 218418151, Fax: +351 218418150, e-mail: hr@civil.ist.utl.pt)
[2] *Assistant Professor*, Civil Eng.Dept., Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisbon, Portugal (Tel: +351 218418152, Fax: +351 218418150, e-mail: didia@civil.ist.utl.pt)
[3] *PhD student*, Civil Eng. Dept., Instituto Superior Técnico, Av. Rovisco Pais, 1049-001 Lisbon, Portugal (Tel, Fax: +351 218418150, e-mail: araujols@civil.ist.utl.pt)
[4] Manager of Hidropower Company, Lisboa, m.mello@hidropower.pt

Abstract

Within European Union priorities, the problematic of available water sources have paid attention through the development of an integrated policy to reduce and control pressures and consequently leakage. In drinking pipe systems Pressure Reducing Valves (PRV) are used as dissipative devices for pressure control through a localized pressure drop. The use of micro-turbines or pumps operating as turbines (PT) seem to be an alternative and sustainable solution to either control the pressure as well to produce energy. This type of solution generally well accepted within renewable energy sources can be adopted as a mitigation method to control the systems loss, in particular the excess available energy which would be dissipated and the rupture occurrence. The existence of high topographic gradients are favorable to adopt these solutions, avoiding the use of high pressure pipe classes with the consequent minimization of costs and the benefit associated to energy yielding, which although depends on the daily consumptions is always a guaranteed energy.

Experimental research is carried out in the Hydraulic Lab of the Department of Civil Engineering at IST, to analyze the hydraulic system response under steady and transient state conditions, as well as the development of comparative analysis between real PRV and PT.

The problematic of waste available energy must paid attention through the implementation of continuous monitoring systems, in particular in drinking and irrigation systems. Furthermore, an integrated policy of water and energy systems management must be developed by using optimization analyses, as well as to encourage water companies to implement it.

Keywords: drinking systems, pressure reducing valves, pressure control, energy production, pump as turbine.

1. INTRODUCTION

The use of pressure reducing valves in water distribution systems is to uniform and control the pressure by separating water pipe systems in district meter areas (DMA) identified by pressure classes accordingly to the topographic development of the zone where the system is implanted. Generally speaking, each DMA is supplied for a guaranteed pressure range or by interconnected reservoirs or even by using pressure reducing valves in each active DMA entrance. Since water supply and distribution systems have serious problems of leakage, the pressure control is fundamental for an optimised and sustainable system management.

The use of renewable energy sources within drinking system seem to be a valuable alternative solution to profit excess available energy instead of the use of dissipative devices. This is a clean project of energy production without significant environmental impacts, with a guaranteed discharge, which can be used in multipurpose systems, without constraints for consumers, or other water uses.

2. BRIEF BACKGROUND REVIEW

The use of pressure reducing valves (PRV) aim at limiting the downstream pressure by regulation of valve opening which induces a local head loss in the hydraulic grade line. There are several types of PRV (Figure 1), in particular PRV with spring, piston and diaphragm control (COVAS and RAMOS, 1998).

The main operating principle of a PRV consists in acting the lock device whenever the downstream pressure is too high, in order to increase the local head loss reducing the downstream pressure till the required value (i.e. LR-PRV – load reference of each pressure reducing valve); or on the contrary, the downstream pressure decreases above the load reference value, the valve opens diminishing the local head loss, increasing the downstream pressure to the required value. Hence it can be distinguished three types of operation: (i) the valve provokes a local head loss to reduce the downstream pressure – this is the active state of the valve (Figure 2 – i); (ii) when the upstream pressure is lower than the PRV load reference value, then the valve opens completely maintaining at upstream and downstream the same pressure – this is the passive state of the valve (Figure 2 – ii); (iii) If the downstream pressure is higher than the upstream pressure the valve closes totally operating as a check valve avoiding the flow inversion – this is the passive state of the closed valve.

This type of valves can operate for different pressure ranges by electrical or mechanical control in order to obtain a better efficient system management and a higher hydraulic performance. Basically, regarding the load, there are the following active operation status (Figure 3): (i) PRV with constant load – the valve reduces and stabilises the downstream pressure, maintaining the pressure constant and equal to the load reference value for each PRV (HLR-PRV) for any upstream pressure and flow in the system – Figure 3-(i); (ii) PRV with constant head loss – the valve reduces the downstream pressure by a constant local head loss independent of the upstream pressure – so the downstream pressure varies with the upstream pressure - Figure 3-(ii); (iii) PRV with constant load but variable in time – is analogous to a PRV with constant load however the pressure is maintained constant in pre-defined intervals varying along the time – Figure 3-(iii), being the more common situation the use of only two time ranges of pressures – one for daily and other for nightly period; (iv) PRV with constant load fitted to the demand – the valve reduces the downstream pressure as a function of discharge or pressure in critical sections of the network – Figure 3-(iv).

3. MODELLING AND ENERGY RECOVER

The profit of excess available energy in water supply systems, namely water drinking and irrigation systems can be a valorous alternative for energy production within the renewable energy sources, with low cost, clean energy source and with no significant environmental impacts (RAMOS e BORGA, 2000a, 2000b; VALADAS, 2001; VALADAS e RAMOS, 2003). For this propose can be used small or micro-turbines or even pumps as turbines (PT) whenever the power or discharge are reduced that would be economically not viable to install turbines.

Whenever the pipe system presents excess available hydraulic energy in some pipe sections, special favourable conditions are created to install turbo-machines for energy recover, which would be dissipated by pressure reducing valves in order to control the maximum admissible service pressure and avoid eventual leakage or rupture occurrence.

In drinking or irrigation system, the pressure varies along the day and along the pipe profile. The hydraulic grade line principle associated to the effect of a turbine operation is quite similar to a PRV, since the net head profit by a turbine allows also the downstream pressure control.

According with some researchers (JOWITT e XU (1990); REIS et al. (1997); KALANITHY e LUMBERT (1998); TUCCIARELLI et al. (1999); REIS e CHAUDHRY (1999); ULANICKA et al. (2001); ARAUJO et al. (2002a, 2002b, 2003); RAMOS et al. (2004)) the best solution for pressure control corresponds the use of head losses devices, namely pressure reducing valves or other hydraulically equivalent equipment. Figure 4-b and c show the effect of pressure reducing valves (i.e. one PRV and five PRV, respectively) for pressure control proposes when compared with the system without any control system (Figure 4-a).

The simulation of these systems is developed for a period of 24-hour, with intervals of 1 hour. The objective consists to minimise the pressure, but to not let it be lower than Pmin value– pre-defined, in any node of the system. The hydraulic simulator needs, for each time interval, to know the values of variables in the modelling process, namely values of roughness in each branch pipe and head loss coefficients for each valve. A Genetic Algorithm (GA) is used to generate these values and runs the optimisation process as a whole. The hydraulic simulation of the system is developed by using routines based on EPANET 2,0. The choice of this tool is due to be a widely tested robust model and, with a large community of users in all the world (e.g., MARTÍNEZ et al. (1999), HERNÁNDEZ et al. (1999); SAKARYA & MAYS, (2000); PRESCOTT & ULANICKI, (2001); ARAUJO et al. (2002, 2002a,b). Darwinian theory of the natural selection and the paradigm of the survival of the most apt had inspired the development of these relatively recent computational techniques, as artificial intelligence and the evaluative computation. Among these techniques, the developed by Holland (1975) is distinguished and is the well known technique of Genetic Algorithms. This technique is robust and efficient in irregular, multidimensional and complex spaces of search and, according to GOLDEBERG (1989, 1994), it does not require derivatives, operates in a population of points, works on representative form of parameters (normally binary representation), uses non-deterministic rules or, probabilistic, and, for each element of a population, it requires information only on the value of an aptitude-function. These techniques have been commonly used, with sufficient success, in several fields of sciences, inclusively in the resolution of optimisation problems of water distribution systems.

The mathematical formulation, for this component of the optimization, is based on the following aptitude-function to minimise the pressure and the number of PRV to be considered:

$$Optimize \quad f(p_i, nv)\Big|_{t=1}^{T} = nv_t \Bigg/ \left\{ \sum_{i=1}^{N} \left[\frac{\left(P_{cal,i,t} - P_{\min}\right)}{P_{\min}} \right]^2 * nv_t + nv_t \right\}^2 \Big|_{t=1}^{T} \qquad (1)$$

with T the total number of intervals to simulate (normally equal to 24 intervals of 1 hour); N the total number of nodes; $P_{cal,i,t}$ the pressure calculated in the node i for the hour t; Pmin the minimum pressure, pre-established by the user, for any node of the network and n_{vt} the number of valves calculated for instant t (i.e., number of pipes with roughness greater than the original roughness – i.e., small Hazen-Williams coefficients) being, therefore, a conditioning of the formulated problem, in order to have lesser possible number of pipes with Hazen-Williams coefficients below to the real ones (i.e., minor number of possible locations for the valves). The program generates results that can be used by EPANET program in order to propitiate to each user the possibility to define where and how many valves will be used to model the network for pressure optimisation (Figure 5). These type of analyse are used for extended period for a stationary flow regime (i.e. an association of different steady state regimes for each time interval) and the real behaviour of PRV and PT under transient conditions require a specific analysis based on experimental research (RAMOS et al., 2004).

Figure 5 shows two different situations: (i) on the left-top – pressure values along a day by the influence of a PRV to fix the downstream pressure (upper curve – node 12) and the pressure variation at the more distant pipe section (down curve – node 22); (ii) on the right-top – a pump operating as a turbine with small downstream pressure variation (depends on pump characteristic curves) (at nodes 12 and 22). The system typology with pressure and discharge distribution for an instant of a day and the characteristic curve of the selected pump operating as a turbine (at the bottom-right). Figure 6 shows an equivalent effect between PRV and PT for all nodes of the system and along the time. Minimum pressure values obtained in different nodes are limited by PRV regulation or through the characteristic curves of the turbo machine adequately selected.

4. EXPERIMENTAL RESEARCH

The experimental research is developed in the Hydraulic Lab of the Department of Civil Engineering, at Instituto Superior Técnico (RAMOS et al., 2004) and it is composed by a pipe-line, connected at upstream to an air vessel, with a volume of 0.8 m3, and at downstream to an open flow reservoir with a weir which discharges the flow to a constant water level reservoir. The pipe material is HDPE of pressure level PN10, with a length of 200 m, with a diameter of 0.043 m, thickness of 0.0035 m, with a roughness of 0.00005 m and a wave speed of 280 m/s.

In the middle length of the pipe is initially installed a PRV to analyse the operating conditions for steady state and unsteady state conditions and afterwards this valve was replaced by a pump operating as a turbine – PT to allow comparisons of the system responses.

In this type of analysis are considered different flow conditions, namely flow energy at the air vessel (upstream) and flow discharge. Whenever a valve, a turbine or a pump as a turbine is installed in a transmission pipe line the hydraulic grade line can present different configurations, depending on the flow conditions and the head loss values which is a characteristic of each device (Figure 7). In particular in the draft tube of a turbine (or a PT) due to the runner rotation, the pressure can drop till the vaporisation pressure, inducing vortex formation. In these cases the downstream pressures at the valve ($p_{d\text{-}valve}$) are lower than the downstream pressure at the end of the system (pd-end) where is also located the discharge control valve at downstream section.

Different values of discharge and upstream load at the air vessel are considered and a similar system response is obtained for both PRV and PT (Figure 8). New tests are running with other type of PRV with a more sophisticated pressure control and regulation.

However, different tests are carried out for different operating initial conditions (i.e. upstream hydraulic load and discharge values). In the facility former described the valve located at downstream corresponds to the valve manoeuvre which originates transient regimes. This complete valve closure allows one to compare the dynamic response of a PT with a PRV, on the point of view of pressure variation.

For an initial PRV opening adjustment (in this case corresponds to the adjustment of the spring) the response to the discharge variation can present different pressure configuration (Figure 9 b, d and e) depending on the initial system conditions, in particular the upstream load and flow discharge. However, the turbine (or pump as turbine - PT) has a similar response independent on the initial system characteristics (Figure 9 a and c). The transient pass through the runner of the PT presenting an equivalent response for all three measurement pipe sections (middle, upstream, and downstream) with the same wave period.

Experimentally was verified the response of the PRV which depends on several factors. According with Figure 2 this type of valve can operate as a check valve and can isolate the flow between downstream to upstream which is quite visible in Figure 11-b, since the wave period is half of the total length of the pipe (i.e. between air vessel and PRV - sections 1 and 2; PRV and valve manoeuvre at downstream of the system – middle and downstream sections).

For equivalent initial conditions with high values (i.e. in lab conditions) of upstream head, the PRV reacts in different way under transient conditions not always favourable in terms of extreme pressure values for the pipe located at upstream the PRV (Figure 9 b). With the decreasing of the upstream load the PRV response fits much better the PT behaviour (Figure 9 e). In lab conditions there are several scale effects which can influence the comparisons. It was not possible to test PT for the smaller discharge of 0.50 l/s due to the high friction in the runner rotation.

4. CONCLUSIONS

The pressure control in drinking pipe systems has enabled this type of analysis based on the profit of excess available energy that would be dissipated in special head loss devices, such has pressure reducing valves. The use of micro-turbines or pumps as turbines (PT) are alternative solutions to be considered individually, replacing totally a PRV or placed in parallel to a PRV, whenever it is not necessary to fix the downstream pressure constant or when there is a reservoir or a treatment plant at downstream. In alternative a PT can be located in series with a PRV in the middle of pipe systems, when the downstream head must be maintained always constant.

A mathematical model was developed based on EPANET program and in Genetic Algorithm technique to optimise the system performance and to analyse the best solution regarding the valve opening adjustment and the selection of the best characteristic curve of the turbo-machine to be used to control the pressure and to profit excess available energy.

Innovative solutions are required within renewable energy sources for energy production by using water pipe systems with guaranteed daily discharge, without environmental pollution and low cost. Experimental analyse have shown an equivalent behaviour between PT and PRV for steady state regimes and some expected differences under transient conditions that in some cases a PT behaviour can be better than a PRV but in other cases a mixed solution of PT+PRV is certainly advisable, depending on the system characteristics and objectives.

5. REFERENCES

ARAUJO, L. S, RAMOS, H. e COELHO, S. T. (2002a) – "Gestão Integrada de Sistemas de Distribuição de Água para um Melhor Controlo de Perdas", 6º Congresso da Água, Porto, Portugal.

ARAUJO, L.S.; RAMOS, H.M.; COELHO, S.T. (2002b) - "Optimização da Localização de Válvulas numa Rede de Distribuição para a Minimização de Fugas". 10º Encontro Nacional de Sanemamento Básico - 16 a 19 de Setembro, Braga, 2002.

ARAUJO, L.S., RAMOS, H.M., COELHO, S.T. (2003) – "Optimisation of the use of valves in a network water distribution system for leakage minimisation". CCWI (Computing and Control for the Water Industry), Imperial College, UK, 2003.

COVAS, D.; RAMOS, H. (1998) – "A Utilização de válvulas redutoras de pressão no controlo e redução de fugas em sistemas de distribuição de água". 8º Encontro Nacional de Saneamento Básico, Barcelos 27 a 30 de Outubro, 1998.

GOLDBERG, D.E. (1994) - "Genetic and Evolutionary Algorithms Come of Age". Communications of the ACM, Vol. 37, nº 3, pp. 113-119.

HERNÁNDEZ, V. MARTÍNEZ, F., VIDAL, A.M., ALONSO, J.M., ALVARRUIZ, F., GUERRERO, D., RUIZ, P.A.., VERCHER, J. (1999) – "HIPERWATER: A high Performance Computing EPANET-Based Demonstrator for Water Network Simulation and Leakage Minimisation". Water Industry Systems: Modelling and Optimization Applications, Vol. 1, Research Studies Press Ltd., Baldock. Hertfordshire, England. pp.141-153.

JOWITT, P.W. & XU, C. (1990) - "Optimal Valve Control in Water Distribution Networks". Journal of Water Resources Planning and Management, ASCE, July/August. pp. 455-472.

KALANITHY, V. & LUMBERS, J. (1998) - "Leakage Reduction in Water Distribution Systems: Optimal Valve Control". Journal of Hydraulic Engineering, ASCE, November. pp. 1146-1154.

MARTÍNEZ, F., CONEJOS, P. & VERCHER, J. (1999) – "Developing an Integrated Model for Water Distribution Systems Considering both Distributed Leakage and Pressure-Dependent Demands". Proceedings of the 26th ASCE Water Resources Planning and Management Division Conference. July. Tempe, Arizona.

PRESCOTT, S.L. & ULANICKI, B. (2001) - Time Series Analysis of Leakage in Water Distribution Networks. Water Software Systems: Theory and Applications. Vol. 2, Research Studies Press Ltd., Baldock, Hertfordshire, England. pp. 17-28.

RAMOS, H.; BORGA, A. (2000a) – "Pump as Turbines: an Unconventional Solution to Energy Production". Journal URBWAT, Vol. 1, N.º 3, pp. 261-265.

RAMOS, H.; BORGA, A. (2000b) – "Pumps yielding power". Dam Engineering, Water Power & Dam Construction, Volume X, Issue 4, pp.197-217, UK, ISSN 0-617-00563-X, 2000.

RAMOS, H.; COVAS, D.; ARAUJO, L. (2004) – "Válvulas Redutoras de Pressão e Produção de Energia". 7º Congresso da Água, LNEC, Lisboa, 2004.

REIS, F.R. & CHAUDHRY, F.H. (1999) - "Hydraulic Characteristics of Pressure Reducing Valves for Maximum Reduction of Leakage in Water Supply Networks". Water Industry

Systems: Modelling and Optimization Applications, Vol. 1, Research Studies Press Ltd., England. pp. 259-267.

REIS, F.R., PORTO, R.M. & CHAUDHRY, F.H. (1997) - “Optimal Location of Control Valves in Pipe Networks by Genetic Algorithm”. Journal of Water Resources Planning and Management, November/December. pp. 317-326.

TUCCIARELLI, T., CRIMINISI, A. & TERMINI, D. (1999) - “Leak Analysis Systems by Means of Optimal Valve Regulation”. Journal of Hydraulic Engineering, ASCE, March. pp. 277-285.

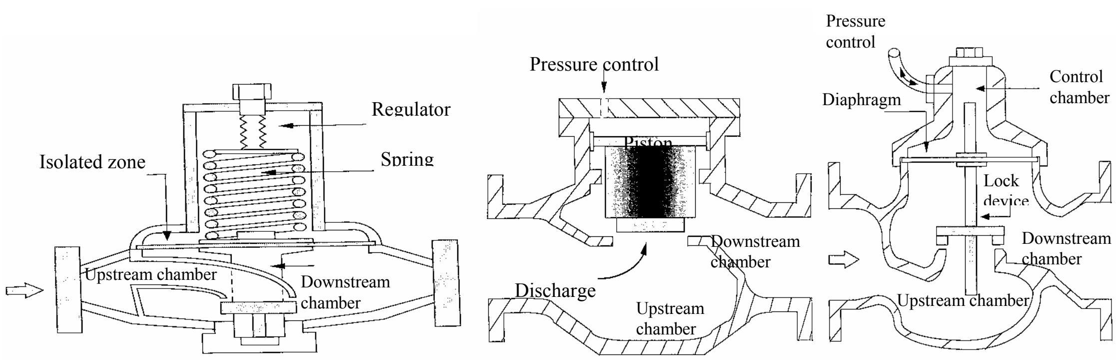
ULANICKA, K., BOUNDS, P., ULANICKI, B. & RANCE, J. (2001) - “Pressure Control of a Large Scale Water Distribution Network with Interacting Water Sources: A Case Study”. Water Software Systems: Theory and Applications, Volume 2, Research Studies Press Ltd., England, pp. 41-53.

VALADAS, M. (2001) - “Uma Solução não Convencional no Contexto das Energias Renováveis para Aproveitamento de Energia em Excesso em Sistemas de Rega”. Dissertação para obtenção do grau de Mestre em Hidráulica e Recursos Hídricos. Instituto Superior Técnico. Universidade Técnica de Lisboa.

VALADAS, M., RAMOS, H. (2003) – “Utilização de bombas como turbinas para o aproveitamento hidroenergético em sistemas de rega”. Revista Recursos Hídricos da APRH. Lisboa. Novembro, Vol. 24, nº3, 2003. pp. 63-76.

ACKNOWLEDGEMENTS

The authors want to thank to FCT through the project POCTI/37798/ECM/2001 and POCTI/58375/ECM/2004, which is partly supported by funding under the European Commission – FEDER, as well as to the Hydraulic Laboratory of Department of Civil Engineering, at Instituto Superior Técnico (Lisbon, Portugal) where the experimental programme is running.



a) b) c)

Fig. 1 - Different types of PRV: a) controlled by a spring; b) piston control; c) diaphragm control

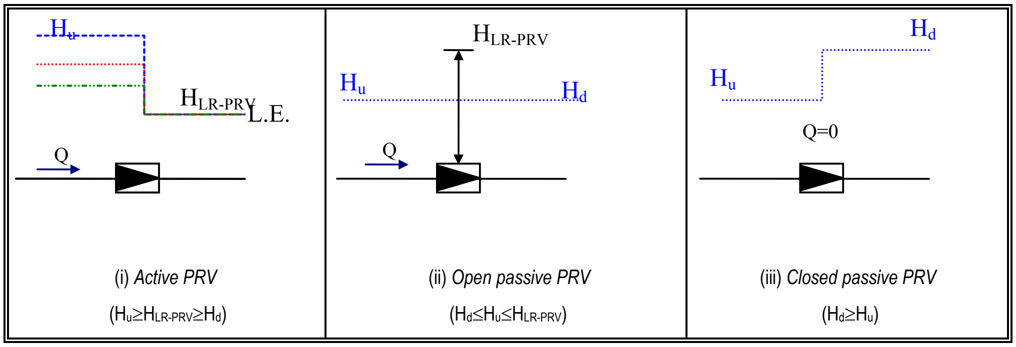


Fig. 2 – Typical operation of a conventional type PRV

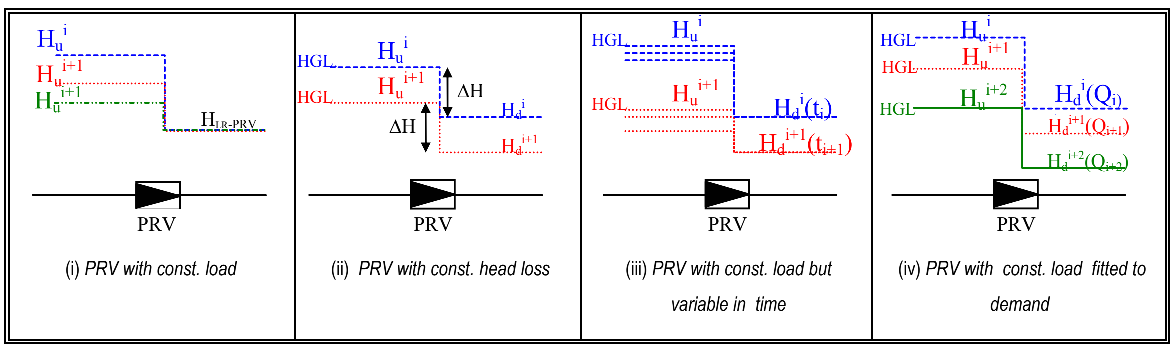


Fig. 3 - Active operation status for different types of PRV

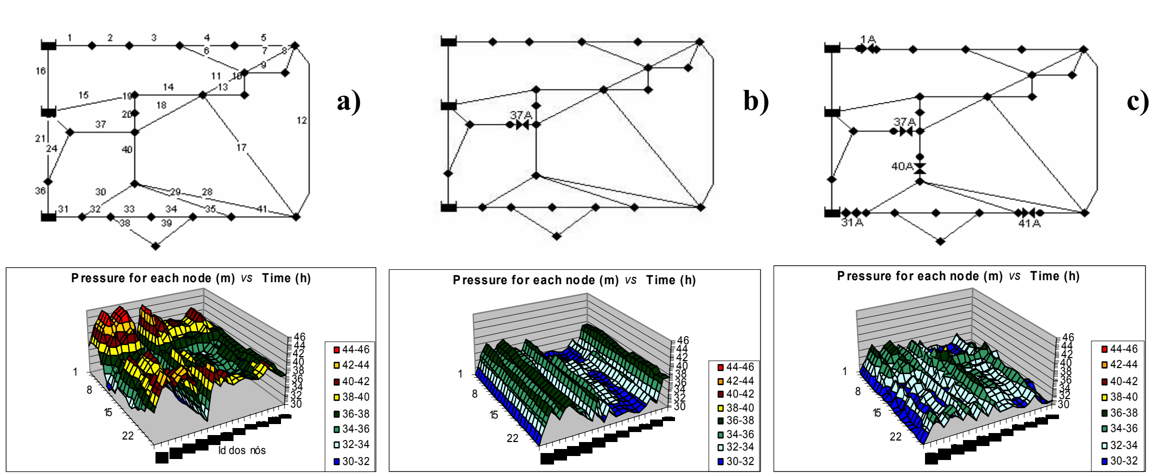


Fig. 4- Pressure control in drinking systems: a) – system without control; b) and c) – effect of 1PRV and 5PRV, respectively, with hour open regulation

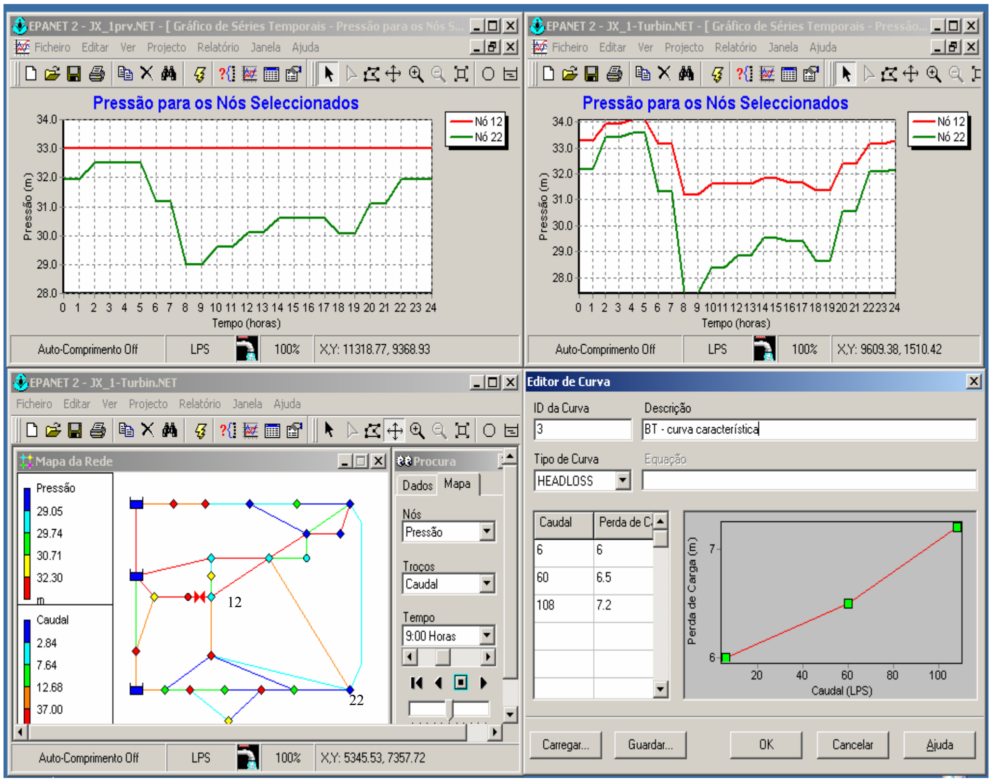


Fig. 5 - Simulation of a PRV operation (left-top) and a Pump/Turbine PT (remaining graphs)

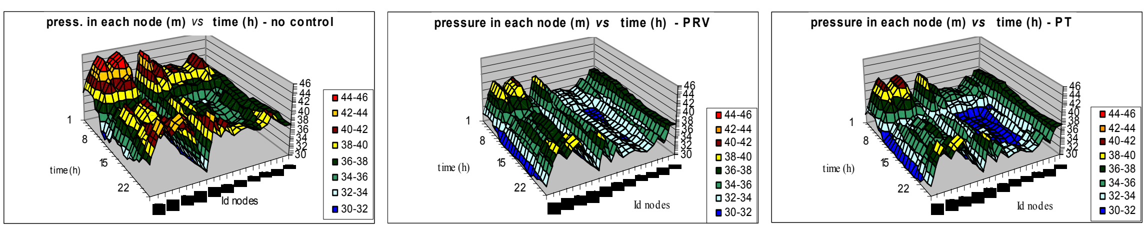


Fig. 6 - System response without and with pressure control by using a PRV and a Pump/Turbine for energy recover

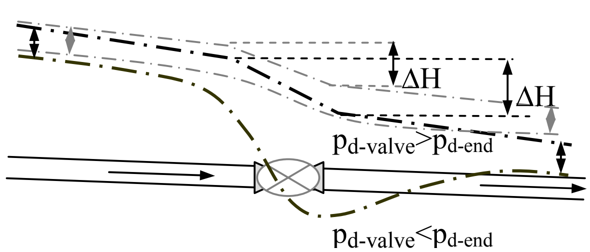


Fig. 7 – Schematic configuration of the hydraulic grade line for different flow characteristics.

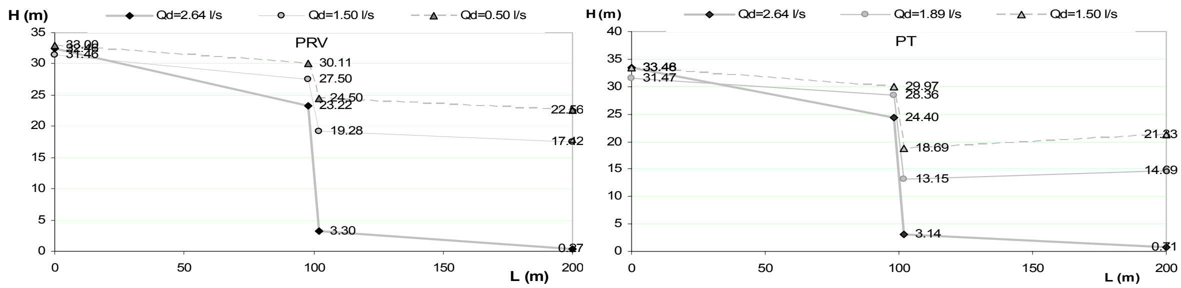


Fig. 8 – Analysis of the behaviour of a PRV and a PT. Values of pressure drop depending on the upstream head and discharge flow

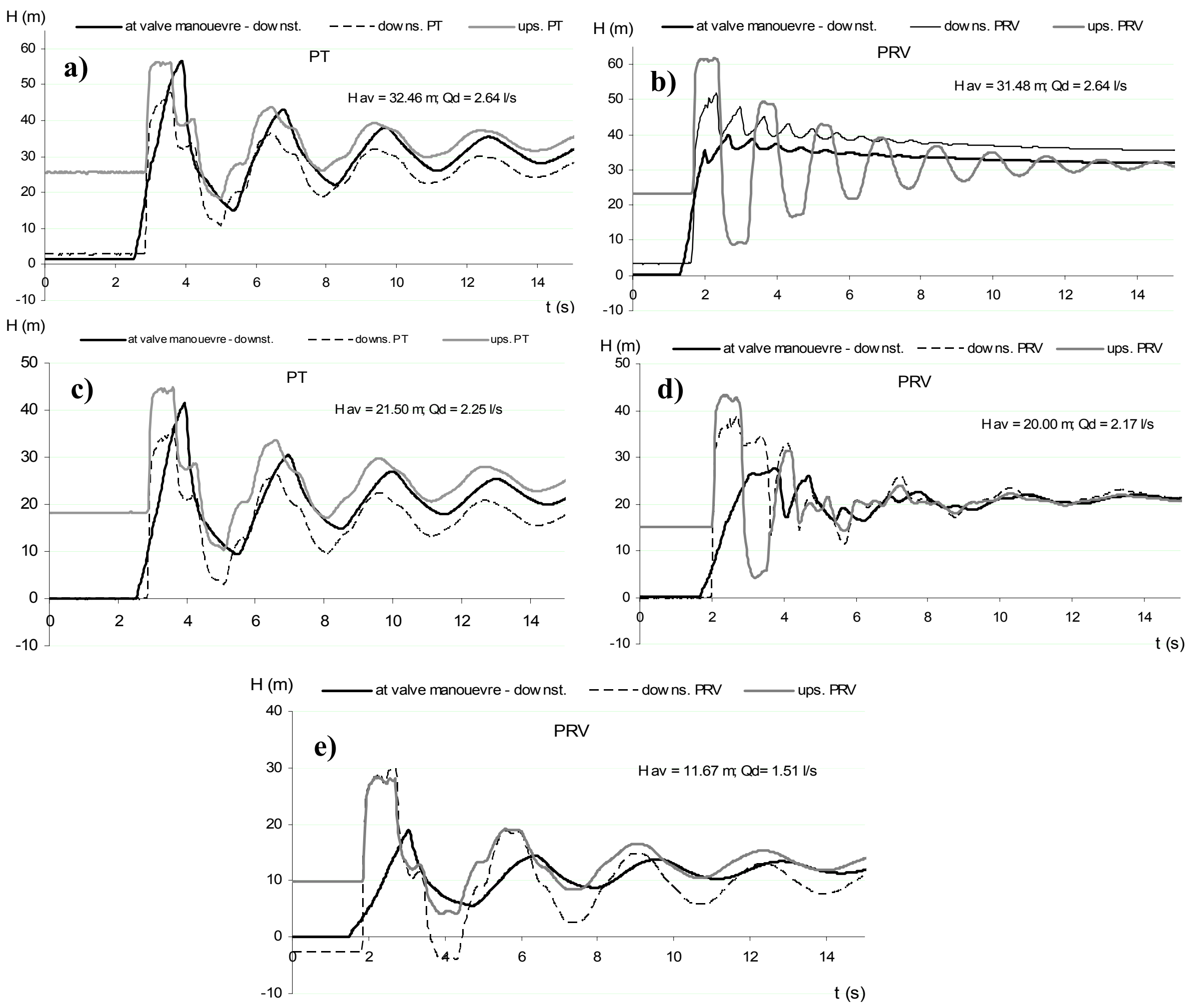


Fig. 9 – Analysis of the dynamic behaviour of a PRV and a PT for a fast closure of a downstream valve.