Reducing energy consumption and leakage by active pressure control in a water supply system

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Abstract: WTP Gruszczyn supplies drinking water to a part of the city of Poznań, in the Midwest of Poland. For the optimal automatic pressure control of the clear water pumping station, nine pressure measuring points were installed in the distribution network, and an active pressure control model was developed and installed. This model is a hybrid form of a predictive controller and a feedback controller: The model predicts the pressure at the off-line measuring points, based on the adaptively learned relation between distribution flow, and pressure drop between pumping station and measuring point. The predicted pressure is used to derive the set-point for the pumping station. The active pressure control resulted in a reduction of pump energy consumption of 31% (237,200 kWh per year, or € 14,300 per year) and a reduction of the water losses of 20%.

Key words: energy reduction; leakage; dynamic pressure control; water distribution

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Introduction

A water supply system is designed to produce drinking water of good quality, and to supply this water to the customers under sufficient pressure. The goal in the operation of the system is to supply the water with a high reliability at the lowest operational costs. Initially, the water supply systems were operated manually by operators, but since the mid 1970's water utilities started automating the systems (Bunn, 2007). At first, the control loops in the automation systems were rather straightforward which led to sub-optimal performance with respect to energy efficiency (Bakker et al., 2003).

To improve the performance of water supply systems, advanced control software is available. Especially, pressure control can be very effective, for it not only reduces pump energy consumption, but it also reduces background leakage. Bunn and Reynolds (2009) showed a reduction of energy cost of 12% at optimally controlled water supply systems in the United States. A case study ofGirard and Stewart (2007) showed a 21% reduction of water loss as a result of reducing the pressure only. And Colombo and Karney (2005) showed that the reduction of the water losses led to a significant reduction of the system's energy consumption.

In this paper, a case study of the implementation of advanced control software for pressure management is presented.

Methods

Case study

Water company Aquanet S.A. is responsible for the water supply in the city of Poznań (550,000 inhabitants), in the Midwest of Poland. The lay-out of one of Aquanet's systems is shown in Figure 1.

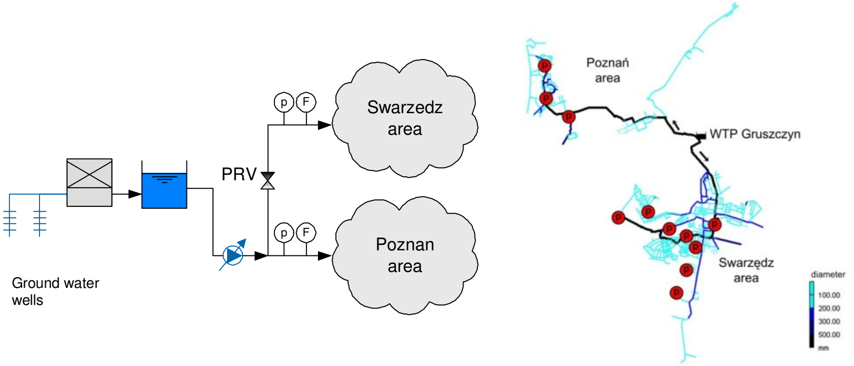


Figure 1 Schematic drawing of the water supply system of Gruszczyn, including nine new and two existing pressure measuring points

Like most water supply companies in Poland, Aquanet manually operated the water treatment and pumping facilities by operators. In 2011 Aquanet decided to fully automate the control of one of their water supply systems (Water Treatment Plant (WTP) Gruszczyn) and to run the system unmanned. The goal of the automation project was to run the water supply system unmanned, and to optimize the control of the system. Optimized control should result in a reduction of operational costs.

Pressure control

The distribution pumping station of WTP Gruszczyn consists of five identical pumps all equipped with variable speed drives (VSD). The pumps are operated as one group at a fixed pump pressure. The clear water is pumped in two directions towards individual supply areas. Initially the two areas were separated from each other by a Pressure Reducing Valve (PRV) in order to reduce the pressure in one zone while keeping a higher pressure in the other zone. The operators chose a relative high pressure set-point for the clear water pumping station, because of a lack of information about the pressure in the entire network during flow variations.

In the automation and optimization project, nine new pressure measuring points were installed in the distribution network (see Figure 1). The measured pressures showed that there was no need to separate the two pressure zones, and that the existing PRV could be removed. After removing the PRV, the pressures in both zones were more equalized. For the control of the clear water pumping station, the dynamic pressure control module (DPCM) of the OPIR software was installed.

In the conventional control, the pressure set-point was a static value chosen by the operator. The DPCM is a feedback control model, which calculates a set-point for the pumping station by comparing all measured pressures at the measuring points with their individual lower bound values. The measuring point with the lowest measured pressure in relation to its lower bound value is the master in the control loop. The DPCM changes the set-point as follows:

- If $p_{mp,master} < p_{lower,\ master}$ → increase set-point
- If $p_{mp,master} > p_{lower,\ master}$ → decrease set-point

Where $p_{mp,master}$ [kPa] is the measured pressure of the master pressure measuring point, and $p_{lower,\ master}$ [kPa] is the lower bound value of the master pressure measuring point. The DPCM uses a proportional-integral-derivative (PID) control mechanism to derive a pressure set-point for the pumping station, based on the desired (lower bound) and measured pressure value of the master pressure measuring point.

Using off-line pressure measuring points

The nine new installed pressure measuring points are equipped with a local logger and GSM modem. The measured pressures are buffered locally and sent to the SCADA system of WTP Gruszczyn once per day. This implies that the measured values were not in real-time available. However, the DPCM estimates the real-time pressure p_i for each pressure measuring point i as a function of the real-time measured pressure at the pumping station p_{ps} and distribution flow to the area F_{dist}:

$$p_i = p_{ps} + a + b \cdot F_{dist}^2 \quad [kPa] \tag{1}$$

The values of a en b were derived by the model, by applying a least squares fit of measured pressure drop between pumping station and pressure measuring point as a function of the flow to the area. By this functionality, the DPCM is a feedback control model using a predicted value as input, and can therefore be considered to be a hybrid form of a predictive controller and a feedback controller as described by Ulanicki et al. (2000).

Consequences of changed pressure

The background leakage q_{leak} depends on the average pressure in the area p [kPa] (Gomes et al., 2011; Araujo et al., 2006; Vairavamoorthy and Lumbers, 1998):

$$q_{leak} = K_f \cdot p^{\beta} \quad [m^3/h] \tag{2}$$

Where K_f [-] is a leakage coefficient for the area, and β [-] is pressure exponent. According to Gomes et al. (2011), the pressure component β varies between 0.5 and 2.5. As proposed by May (1994) and adapted by Araujo et al. (2006) we will use 1.18 for β in this paper. If the pressure in the area changes, the background leakage in the area will change according to:

$$\frac{q_{leak,1}}{q_{leak,0}} = \left(\frac{p_1}{p_0}\right)^{\beta} \quad [-] \tag{3}$$

The overall energy savings due to the implementation of dynamic pressure control software consist of:

1. Savings due to lower pump pressure of clear water pumps (dE_{pump})
2. Saving due to reduced water losses (dE_{loss}).

$$dE_{pump} = \frac{\rho \cdot V \cdot dp}{1000 \cdot 3600 \cdot \eta} \quad [kWh] \tag{4}$$

$$dE_{loss} = dV_{loss} \cdot E_{spec} \quad [kWh] \tag{5}$$

Where ρ is the specific mass of water (1,000 kg/m^3), V is the pumped volume of water, dp is the difference in pump pressure, and η is the total efficiency of pump + motor of the clear water pumps (estimated to be constant at 0.60).

Results and discussion

Compared periods

To evaluate the results of the project, the operational data (flows and pressures) of a period with conventional control were compared with a period of dynamic pressure control. The implementation of the dynamic pressure control software was done in several phases, and after initial implementation a period of tuning followed. Therefore, no contiguous period with a sharp transition from conventional control to dynamic pressure control was available. For a good comparison, we compared for both control strategies a three weeks period in November: conventional control in November 2011 and dynamic pressure control in November 2012.

Pressure control

Figure 2 shows trends of the water demand, the outlet pressure at the pumping station and the average pressure in the area of both examined periods (Swarzędz area).

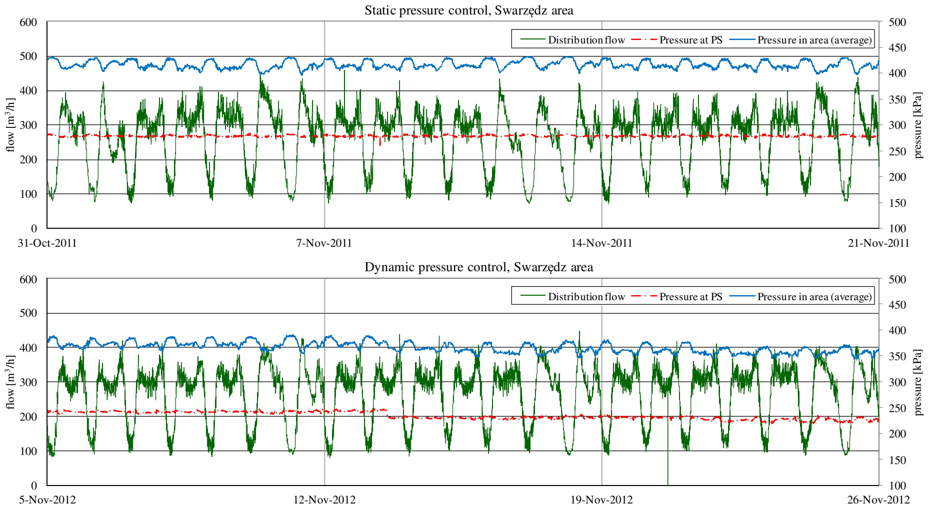
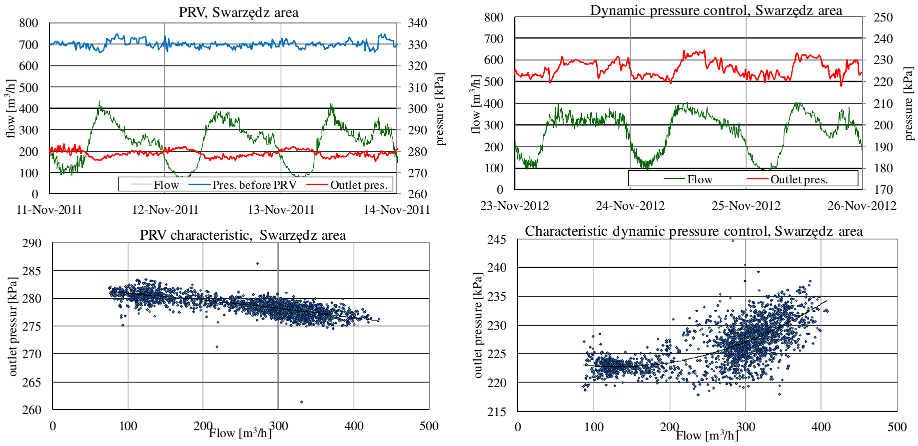


Figure 2 Difference between static (upper graph) and dynamic (lower graph) pressure control, Swarzędz area

In the initial setup of the water supply system, a PRV was reducing the pressure to one of the two supply areas (Swarzędz area, see Figure 1). The pumps were operated at a fixed pressure (330 kPa), and the fixed outlet PRV was set to reduce the pressure to the Swarzędz area to 280 kPa. The installed PRV was a medium driven automatic control valve Cla-val NGE9001, DN250. Prescott and Ulanicki (2003) used this type of valve to develop their dynamic model of PRV's. According to this model, the PRV shows a limited flow dependence, as was also observed in the flow and pressure values of the PRV in the examined system (see Figure 3, left graph).


PRV, Swarzędz area

Dynamic pressure control, Swarzędz area

PRV characteristic, Swarzędz area

Characteristic dynamic pressure control, Swarzędz area

Figure 3 Outlet pressure in the water main to Swarzędz area with initial PRV (left graphs) and with dynamic pressure control (right graphs)

The DPCM worked as a flow modulated PRV, which is also available as integrated medium controlled device, like the AQUAI-MOD® hydraulic controller (Abdel Meguid et al., 2011). The advantage of the DPCM over a flow modulated PRV, is that the DPCM can be tuned easier, and that the DPCM adapts automatically to changing hydraulic or demand characteristics. A potential drawback of the DPCM is that it needs power and functioning communication infrastructure, which is not necessary for a medium controlled device. In the considered case study, this was not an issue because the pressure was controlled at the treatment facility which has a permanent and failsafe power supply and communication infrastructure.

The implementation of the DPCM led to a pump pressure reduction of 97 kPa (29%), and a pressure reduction in the distribution network of 100 kPa (23%) in the Poznań area and 50 kPa (12%) in the Swarzędz area (see Table 1). The reduction in the Swarzędz area was lower, because in the initial setup of the system the pressure was already reduced in this area with a PRV.

Table 1 Difference between static and dynamic pressure control

	Static control	Dynamic control	Difference
Poznań area: Flow [m^3/h]	214	306	+43%
PS pressure [kPa]	330	233	-29%
MP1-3 [kPa]	*444*	*344*	*-23%*
Swarzędz area: Flow [m^3/h]	261	267	+2%
Outlet pressure [kPa]	279	233	-16%
MP4-9 [kPa]	*417*	*367*	*-12%*

A reduction of the pressure in the area resulted in a reduction of the water losses in the distribution network. By applying equation (3), the reduction of the background leakage in the Poznań area was calculated at 26%, and in the Swarzędz area at 14% (average reduction 20%). The total water losses of the Gruszczyn system in 2011 were estimated at 565,000 m^3 per year, based on the average water loss of Aquanet of 11.3% (Aquanet, 2012). The water loss in 2012 was estimated at 450,000 m^3 per year (water loss reduced from 11.3% in 2011 to 9.0% in 2012, difference 113,500 m^3).

The energy savings were calculated by using equations (4) and (5), where V is 5 million m^3 per year, and dp is 97 kPa (see Table 1). This resulted in a dE_{pump} of 225,000 kWh per year (€ 13,550). dV_{loss} is the difference in water loss in the water distribution system (113,500 m^3 per year, see above), and E_{spec} is the specific energy consumption for distribution (0.108 kWh/m^3). This resulted in a dE_{loss} of 12,200 kWh per year (€ 750). The energy savings are listed in Table 2.

Table 2 Energy savings due to the implementation of dynamic pressure control

	Energy [kWh/year]	Energy costs [€/year]	Difference
1. lower pump pressure	225,000	13,550	
2. reduced water loss	12,200	750	
Total	237,200	14,300	31.1%

Conclusions

The implementation of the dynamic pressure control module of the OPIR software at WTP Gruszczyn resulted in a reduction of the pump pressure of the clear water pumps and a reduction of the water losses (20%) in the distribution network. The project has led to considerable savings in the operational costs because of the reduction of energy consumption (31.1%, 237,200 kWh per year, or € 14,300 per year). The project has shown that extra information from the distribution network (from nine new pressure measuring points) in combination with dynamic pressure control software led to a more efficient water supply system.

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