PUMPING STATIONS OPERATING PARAMETERS UPON A VARIABLE DEMAND, DETERMINED NUMERICALLY FOR THE WATER DISTRIBUTION NETWORK OF ORADEA

Andrei-Mugur GEORGESCU[1], Sanda-Carmen GEORGESCU[2],
Tudor PETROVICI[3], Magda CULCEA[4]

The paper presents a methodology for computing the pumping stations operating parameters upon a variable demand. The study-case is performed for the complex water distribution network of Oradea (Romania), which incorporates 5 interconnected pumping stations, three tanks and a source of water. Oradea's water distribution network is modelled within EPANET through a main emitter, and the variable water demand is implemented by adjusting the throttle control valves (TCV) placed on 7 main pipes, upstream of the emitter. A TCV simulates a partially closed valve by adjusting the minor head loss coefficient of the valve, using simple controls. The numerical model of the pumping stations is created in EPANET and the operating algorithm of each pumping station is implemented via control statements (rule-based controls). Such an operating algorithm is created for one variable speed driven pump, in each group of pumps coupled in parallel. A hydraulic analysis over a 48 h period is performed with variable water demand derived from the data recorded at the pumping stations in August, 2006.

Keywords: pumping station, water demand, throttle control valve, EPANET.

1. Introduction

In our paper, we present a methodology for computing the pumping stations operating parameters upon a variable demand, within a water distribution network. The numerical model is built using EPANET 2.0, a free of charge software for hydraulic network computations, provided by the U. S. Environmental Protection Agency [1]. That software allows the use of variable consumption flow rates over a specified period of time, as well as variable speed driven pumps. It also allows the use of command sets that can simulate the operating algorithm of the pumping station.

[1] Associate Prof., Hydraulic and Environmental Protection Department, Technical University of Civil Engineering Bucharest, Romania
[2] Associate Prof., Hydraulics and Hydraulic Machinery Department, University "Politehnica" of Bucharest, Romania
[3] Senior Researcher, Hydraulics and Hydraulic Machinery Department, University "Politehnica" of Bucharest
[4] Student, Faculty of Building Services, Technical University of Civil Engineering Bucharest

The study-case is performed for the complex water distribution network of Oradea, one of the main cities in North-Western Romania. There are 1287 relevant pipes within that network (Figure 1), with a diameter $D \geq 150$ mm [2].

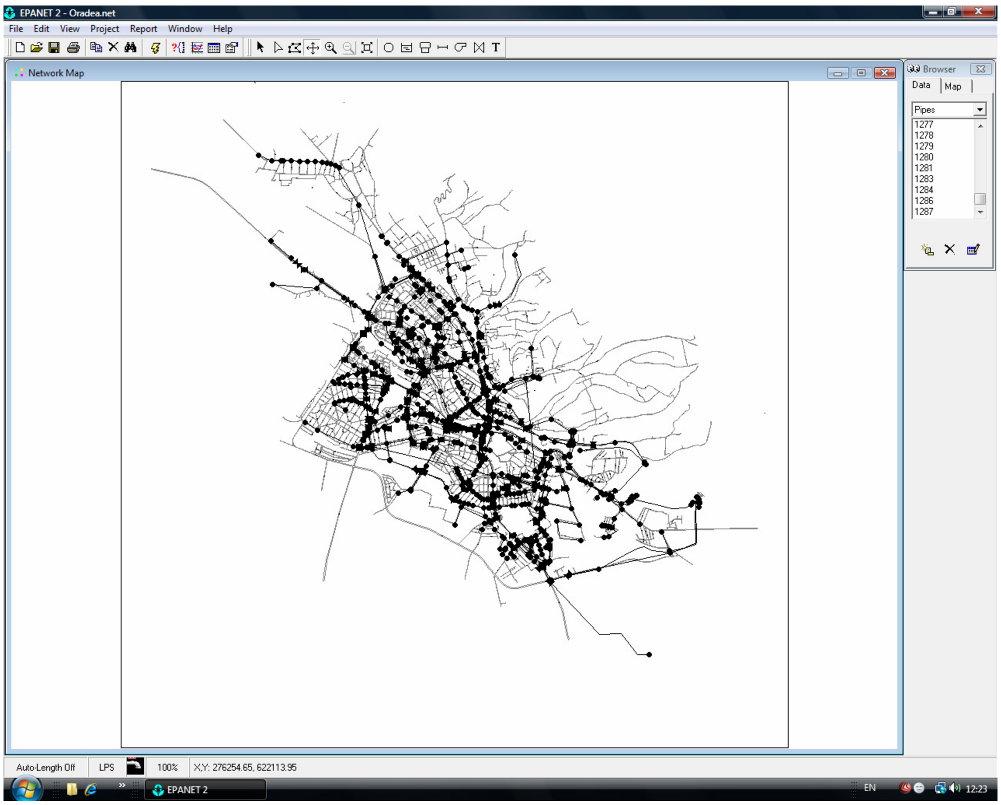

Fig. 1. Oradea's water distribution network.

Oradea's water distribution network model incorporates 5 pumping stations, three tanks, and one source of water. That complex network can be modelled using EPANET, by replacing the pipes that ensure the water distribution within the city, through a main emitter, labelled E in Figure 2. The variable water demand is implemented by adjusting the throttle control valves (TCV) placed on 7 main pipes, upstream the emitter. The TCVs (labelled from TCV1 to TCV7 in Figure 2), simulate partially closed valves, by adjusting the minor head loss coefficient of each valve through simple controls.

In Figure 2, the pumping stations are labelled from PS1, to PS5. The operating algorithm of each pumping station is implemented in EPANET via control statements (ruled based controls). Such operating algorithms are created for one variable speed driven pump, in each group of pumps coupled in parallel.

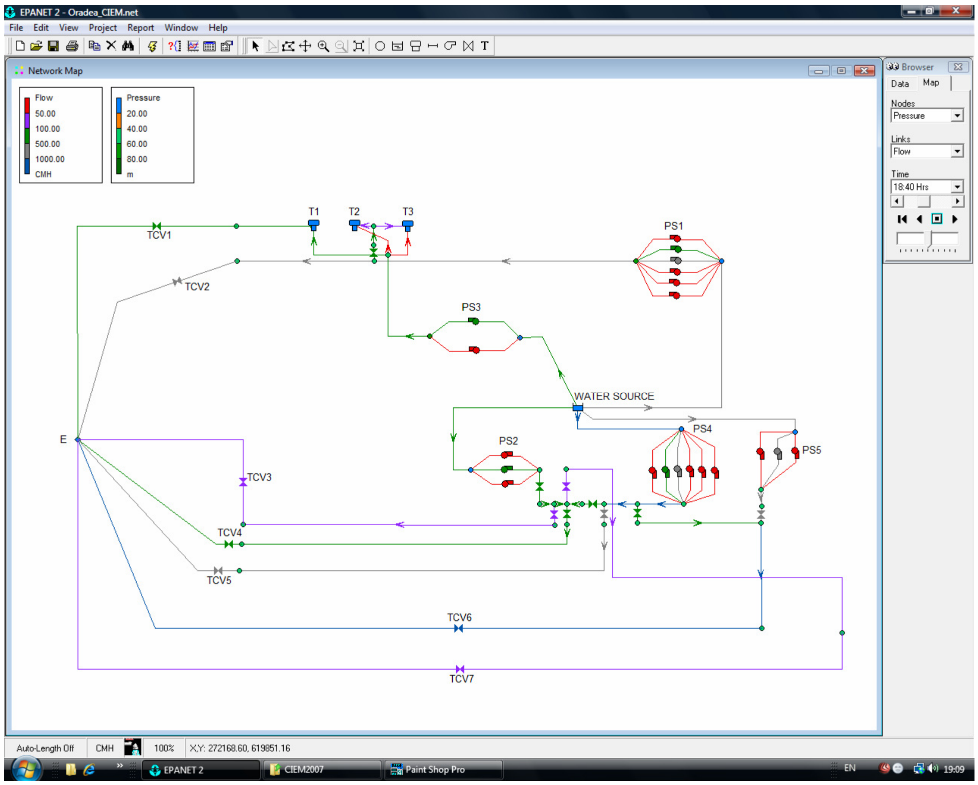

Fig. 2. Scheme of the interconnected pumping stations.

The tank T1 has a capacity of 2000 m^3, while each of the tanks T2 and T3 have a capacity of 10000 m^3. The tanks ensure the water demand during the night, when the pumps are working at their minimum capacity. During the day, the pumping stations ensure both the water demand within the network, and the filling of the tanks.

A hydraulic analysis over a 48 h period (starting from midnight) is performed for the described numerical model of the distribution network, with variable water demand derived from the data recorded at the pumping stations of Oradea in August 2006 [3]. Further work will focus on modelling the whole water distribution network from Figure 1, by replacing the main emitter and the 7 TCVs in Figure 2, with the pipes that ensure the water distribution over the city area.

2. Numerical model

The data available for the realisation of the numerical model consisted of:

- ➢ data for the pumping stations, i.e. pump type, pump characteristic curves, and number of pumps;

➢ functioning algorithm of the pumping system, i.e. tanks are filling during the day and emptying during the night; at PS1 there are maximum 2 pumps working during the day (one with variable speed), and only the variable speed one during the night; at PS2 and PS3 there is always one pump functioning regardless of the variable demand; at PS4 there are maximum 2 pumps functioning during the day (one with variable speed), and only the variable speed one during the night; at PS5 there is only one pump functioning during the day;
➢ mean hourly consumption recorded in Oradea during August, 2006.

A quick glance at the functioning algorithm suggests that there are mainly two flow regimes: one with important flow rates during the day, and another with smaller flow rates during the night.

By adding throughout 24 hours the average hourly discharge, we obtained the average daily discharge. As the available data was recorded for August, a summer month, we considered the day regime to start at 6 a.m., and end at midnight, while the night regime to start from midnight to 6 a.m. The next assumption was that the day regime is close to the optimal operating point of the pumps (the flow rate was considered to be 1.1 of the flow rate given as the optimal operating point of the pump). We were thus able to compute also the night regime flow rates, such that the daily discharge of the numerical model matched the one recorded in the network.

Then, we adjusted the head losses through the 7 throttle control valves (TCV1 to TCV7), in order to obtain the two flow regimes. The changes in the head losses were implemented via Simple Control statements, as a function of time of the simulation. For example, the simple control statements at the second valve, TCV2, are: *link 2 20506 at time 0*; *link 2 6199 at time 6*; *link 2 20506 at time 24*; *link 2 6199 at time 30*, meaning that on the pipe (link) having the ID number 2, the minor head loss coefficient of the valve has the value $\zeta = 6199$, at time $t = 6$ h and $t = 30$ h from the beginning of the simulation, while $\zeta = 20506$, at time $t = 0$ h and $t = 24$ h (at midnight over the 48 hours period).

The above problem was to be able to let the demand flow adjust freely at the emitter, view as an end node of the numerical network model. Emitters are devices associated with nodes that model the flow through a nozzle or orifice. In these situations the demand (i.e. the flow rate through the emitter) varies in proportion to the pressure at the junction raised to the power 0.5. The constant of proportionality is termed as the "discharge coefficient". Emitters are used to model flow through sprinkler systems and irrigation networks. They can also be used to simulate leakage in a pipe connected to the junction and compute the flow available at some minimum residual pressure. In the latter case one would use a very high value of the discharge coefficient (e.g., 100 times the maximum flow expected) and modify the junction's elevation to include the equivalent head of the pressure target [1, 4, and 5].

Each pumping station numerical model consists of a number of pumps coupled in parallel, each pump with its characteristic curves, and an operating algorithm identical to the one used in reality, implemented within EPANET through Rule-Based Controls.

Rule-based controls allow link status and settings to be changed based on a combination of conditions that might exist in the network over an extended period simulation. Rule-based controls are statements of the form: *RULE ruleID; IF condition_1 AND condition_2 OR condition_3, etc; THEN action_1 AND action_2 OR action_3, etc; ELSE action_4 AND action_5 OR action_6, etc*, where *ruleID* represents an identification label assigned to the rule, *condition_n* represents a condition clause and *action_n* represents an action clause.

For the existing situation, the parameter that starts/stops a pump is the value of the pressure at the exit node of the pumping station, i.e. if that pressure is less than a minimum value, the speed of the functioning pump is adjusted up to the maximum level, or if this level is reached, another pump is started; if that pressure exceeds a maximum value, the speed of the functioning pump is adjusted up to the minimum level, or if this level is reached, another pump is stopped [6]. Of course, in our case, we must specify to the program, exactly which pump to start and which one to close. For the 5 pumping stations and the above mentioned operating algorithm, we obtained a total of 55 rule-based controls.

For example, the 20th rule associated to the first pumping station (PS1) is: *RULE 20*; *IF junction 12 pressure below 62*; *AND pump PS1_3 status is closed*; *AND pump PS1_2 setting is 1*; *THEN PUMP PS1_3 status is opened*; *AND pump PS1_2 setting is 0.70*, meaning that at the outflow node of PS1 (a node with the ID number 12), if the pressure value is less than 62 mH_2O, and the 3rd pump (PS1_3) is closed, and the 2nd pump (PS1_2) is working at its nominal speed n_0, then the 3rd pump is opened and the 2nd pump reduces its speed at $n = 0.7n_0$. The speed *setting* refers to the ratio between the pump speed *n* and the nominal speed n_0. The rotating speed of a pump varies between $n = 0.7n_0$ and $n = n_0$, by increments of $0.05n_0$. Pumps with constant rotating speed should be opened or closed only if the rotating speed of the variable speed driven pump reaches the nominal rotating speed n_0, or $0.7n_0$ respectively.

It is important to observe the way in which EPANET evaluates the rules. At a time step, EPANET computes the hydraulic quantities of the network then, with the results evaluates the conditions from rule one and takes the specified actions if the conditions are met, goes to rule 2, evaluates the conditions with the same computed data set and takes the specified actions if the conditions are met, goes to rule 3 and so on and so forth, up to the last rule. When all the rules have been evaluated, EPANET passes to the next time step and performs a new hydraulic calculation. Now, it is obvious that, as long as there is no hydraulic calculation after each action, the order in which the rules appear in the program is crucial.

3. Numerical results

A hydraulic analysis over a 48 h period has been performed for the described numerical model of the distribution network of Oradea, with variable water demand derived from the data recorded in August, 2006 [3]. The hydraulic computation time step was set at 10 minutes, and reporting time step at 20 minutes.

To exemplify the results, we present in Figures 3 and 4 the flow distribution through the network at 3:20 a.m. (night flow regime) and at 6:40 p.m. (day flow regime). EPANET allows plotting different hydraulic parameters of the network, i.e. the pressure, head, and base demand at the network nodes (junctions), or the flow, velocity, unit head loss, and friction factor on the pipes (links). The variation of the water demand at the emitter E, over the 48 h simulation period, is presented in figure 5. The variation of the flow rate at the 2nd pump (labelled PS1_2) and 3rd pump (labelled PS1_3) of the first pumping station PS1, over the simulation period of 48 h, is presented in figure 6.

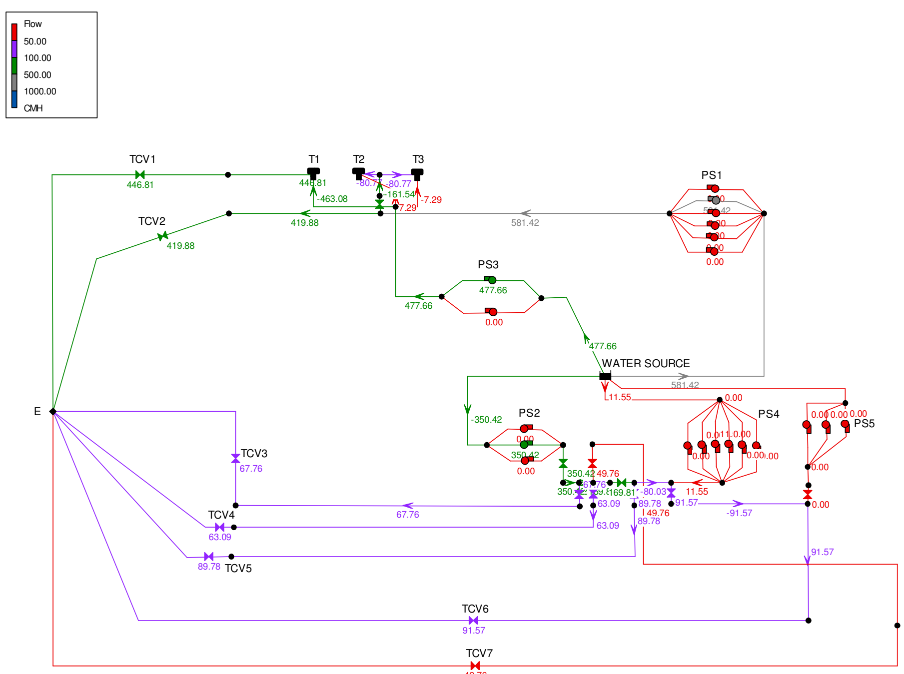

Fig. 3. Flow distribution at 3:20 a.m.

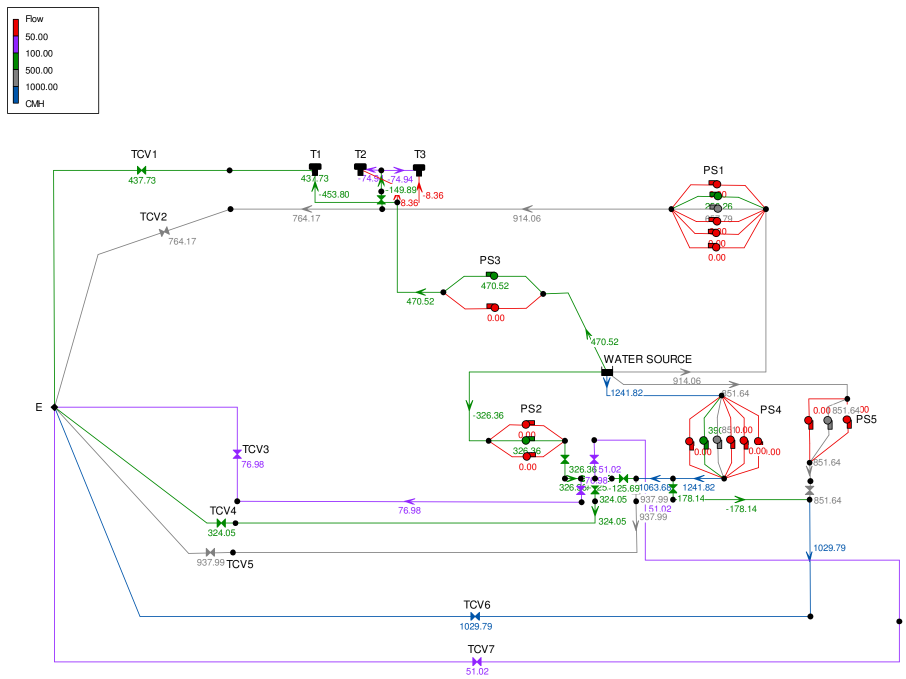

Fig. 4. Flow distribution at 6:40 p.m.

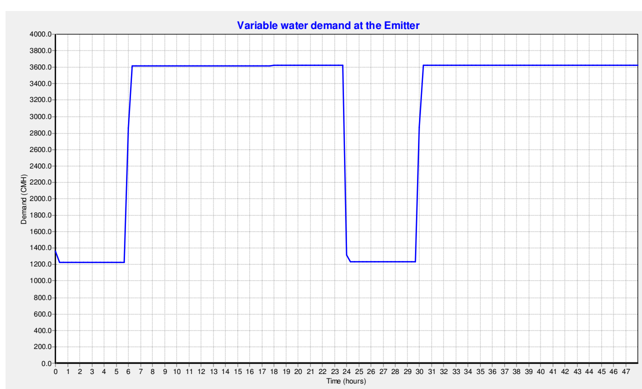

Fig.5. Variation of the water demand at the emitter E, over the 48 h simulation period.

4. Conclusions

We presented a methodology for computing the pumping stations operating parameters upon a variable demand, using EPANET 2.0. The study-case was performed for the water distribution network of Oradea. The complex network of Oradea has been simplified within the numerical model, by replacing the pipes that ensure the water distribution within the city, through a main emitter (see Figure 2). The variable water demand has been implemented by adjusting the throttle control valves placed on 7 main pipes, upstream the emitter.

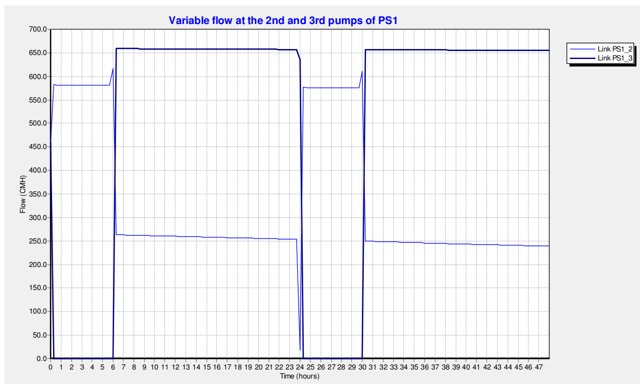

Fig.6. Variable flow rate at the 2nd and 3rd pumps of PS1, over 48 h simulation period.

A hydraulic analysis over a 48 h period has been performed for the proposed numerical model of the distribution network of Oradea, with variable water demand derived from the data recorded in August, 2006. The numerical results match very well the available recorded data.

The numerical model will be developed further, in order to perform a hydraulic analysis through the complex water distribution network of Oradea, by simply replacing the main emitter and the 7 throttle control valves, with the pipes that ensure the water distribution over the city area (as in Figure 1).

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