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NUMERICAL QUANTIFICATION OF ENERGY CONSUMPTION FOR THE “TEIUL DOAMNEI” PUMPING STATION

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The paper presents the methodology used for computing the energy consumption of the “Teiul Doamnei” pumping station in Bucharest, Romania. A numerical model of the pumping station and it’s serviced water network is created in EPANET and the operating algorithm of the pumping station is implemented via control statements. An analysis over a 24 h period is performed with variable water demand derived from the data recorded at the pumping station in the previous year. Energy consumption results for the existing situation are in good agreement with recorded values in the pumping station.

Keywords: water network, EPANET, variable speed driven pumps.

1. Introduction

In our paper, we present a methodology for computing energy consumption for a modern pumping station within a water distribution network upon a variable water demand. 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.

The study-case is performed for the water distribution network of “Teiul Doamnei” district in Bucharest.

2. Computational methodology

The input data are the functioning parameters of the pumping station during the year 2008. From the recorded values we derive the variation pattern of the water consumption in the district area serviced by the pumping station. This variation pattern is used in the sequel as control parameter for the pumping station

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numerical model in order to compute energy consumption. These values are compared to the energy consumption recorded in 2008.

As the variation pattern of the flow rate was already discussed in [2] we will focus on the differences between the variation steps of the rotation speed of the pumps. In fact, EPANET can only simulate discrete values of the rotation speed of the pumps. This is not the case for the real functioning of the pumps which is continuous. In order to verify how the start/stop algorithm of the pumps can adjust the flow in the water distribution network we exaggerated the maximal and minimal picks of the water demand curve without changing the daily mean value. The variation pattern of the consumption is presented in figure 1.

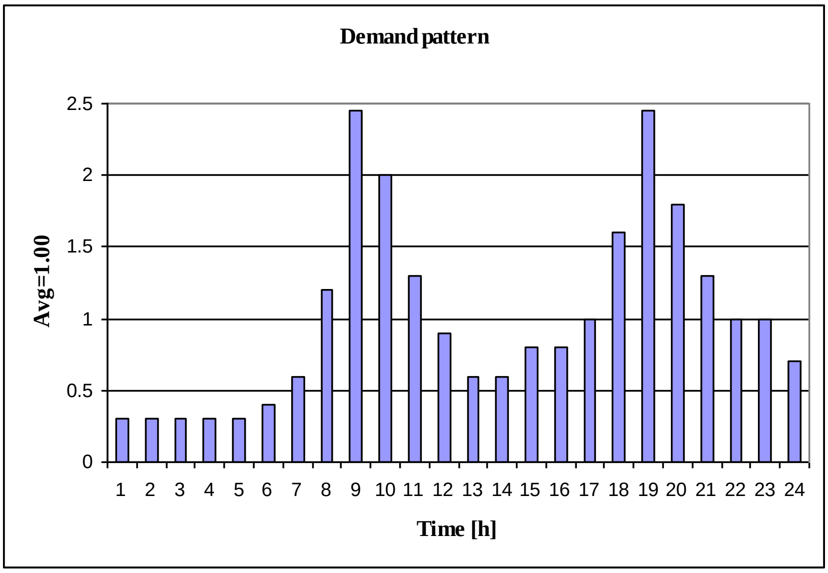

Fig. 1. Variation pattern of the mean daily consumption

3. Water distribution network model

The water network model consists of 259 pipes, 1 reservoir (that represents the main water distribution network of the town), 215 node junctions and 4 identical pumps. The roughness of the pipes was considered to be 2 mm for all the pipes in the model. All the junctions of the network are considered to be using water. The base water demand values for each node were set in accordance with the mean daily value registered by the water distribution company for each consumer in the area and was considered to vary hourly based on the pattern presented above. Diameters and lengths of the pipes were introduced based on the information existing in the water distribution company. Junctions elevation were introduced according to the actual elevation of the terrain plus the height of the supplied consumer (either houses or blocks of flats of 4, 8 or 10 floors high).

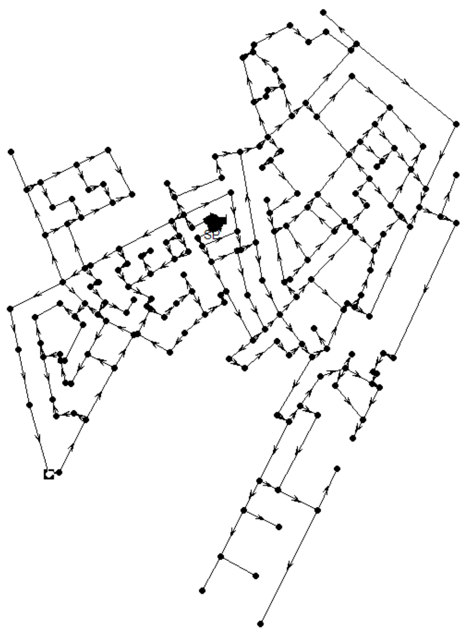

Fig. 2. “Teiul Doamnei” water distribution network configuration

4. Pumping station model

The pumping station consists of 4 parallel coupled pumps that discharge water in a common pipe connected at both ends to the “Teiul Doamnei” network (see fig. 3). On the suction side water comes from the main water distribution network of Bucharest. The suction side was modelled by a reservoir set at an elevation that includes the actual elevation of the network plus the piezometric head available in the main water distribution network. Existing pumps head and efficiency curves were introduced in the model.

The pumping station numerical model also includes 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 [3]. Of course, in our case, we must specify to the program, exactly which pump to start and which one to close. For the "Teiul Doamnei" pumping station model we implemented 2 such algorithms: the first one that modifies the rotation speed of the pumps in steps of $0.05n_0$ and the second one that modifies the rotation speed of the pumps in steps of $0.02n_0$. In order to compare the results we also used a simpler algorithm that does not modify the rotation speed of the pump but only starts or stops an extra pump is the minimum or maximum pressure levels are reached [3]. The first algorithm resulted in a set of 26 ruled base controls while the second resulted in a set of 62 ruled base controls.

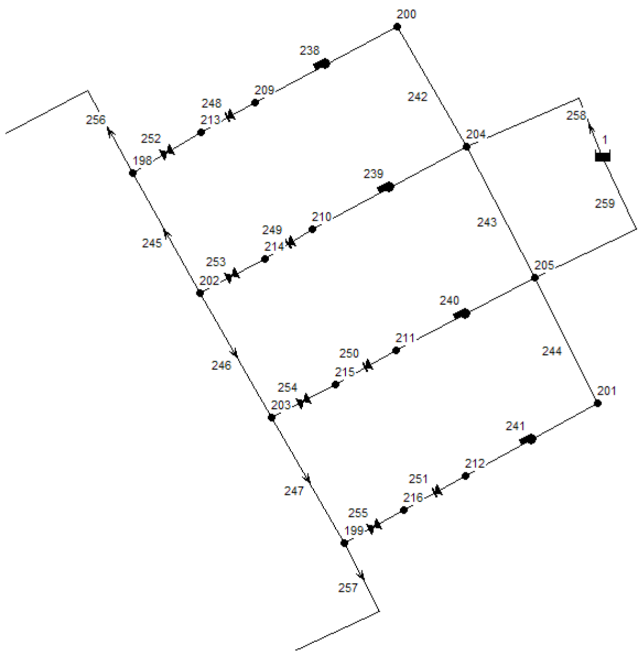

Fig. 3. The "Teiul Doamnei" pumping station model

For example, the 20th rule associated to the first algorithm is: *RULE 20*; *IF junction 202 pressure below 49*; *AND pump 240 status is opened*; *AND pump 239* *setting is 0.75*; *THEN PUMP 240 status is opened*; *AND pump 239 setting is 0.80,* meaning that at the outflow node of the pumping station (a node with the ID number 202), if the pressure value is less than 49 mH_2O, and the 3rd pump (240) is opened, and the 2nd pump (239) is working at 0.75 of its nominal speed n_0, then the 3rd pump should stay opened and the 2nd pump should increase its speed at $n = 0.8n_0$. 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.

5. Numerical results

A hydraulic analysis over a 24 h period has been performed for the described numerical model of the distribution network of “Teiul Doamnei”, with variable water demand derived from the data recorded during 2008. The hydraulic computation time step was set at 2 minutes and reporting time step at 2 minutes.

To exemplify the results, we present in Figure 4 the flow distribution through the network at 8:20 a.m. for the second algorithm. 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). In Figure 4 we represented the velocity for the pipes and pressure for the nodes.

As a first preliminary result we must state that the values of the water demand have decreased significantly with respect to 2002 [2]. This is probably due, on one hand to water price that increased in the last years and on the other hand to water consumption metering at the users that was completed. The remaining fact, verified at the “Teiul Doamnei” pumping station, is that in the last 2 years only one pump was sufficient to insure the water demand of the network.

Occasionally a second working pump was needed only for a limited period of during winter holydays and Easter period.

In Figure 5 we present the pressure variation at the node exiting the pumping station for the 3 studied cases, i.e. no variation of the rotating speed of the pumps, variation in increments of $0.05n_0$ and variation in increments of $0.02n_0$.

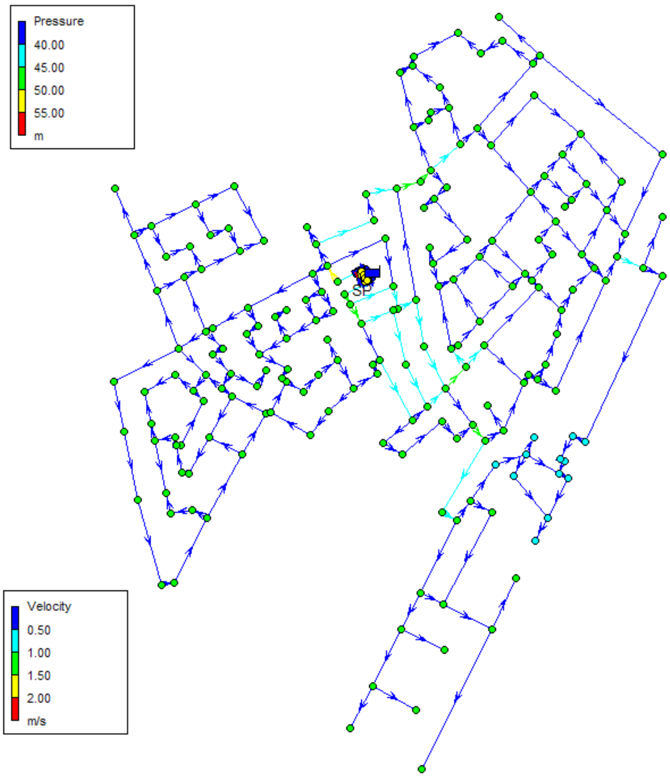

Fig. 4. The "Teiul Doamnei" water distribution network results for 8:20 a.m.

For the first case, the pressure at the exit of the pumping station varies from 51 meters of water column up to 62 meters of water column exceeding by far the prescribed pressure of 49-50 meters of water column. For the second case, the pressure at the exit of the pumping station varies from 47 meters of water column up to 52 meters of water column exceeding again the prescribed pressure level of 49-50 meters of water column. For the third case, the pressure at the exit of the pumping station adjusts for almost all variations of the flow rate within the prescribed pressure level of 49-50 meters of water column. We must also notice the variations that appear exactly at the times when flow rate changes are steeper.

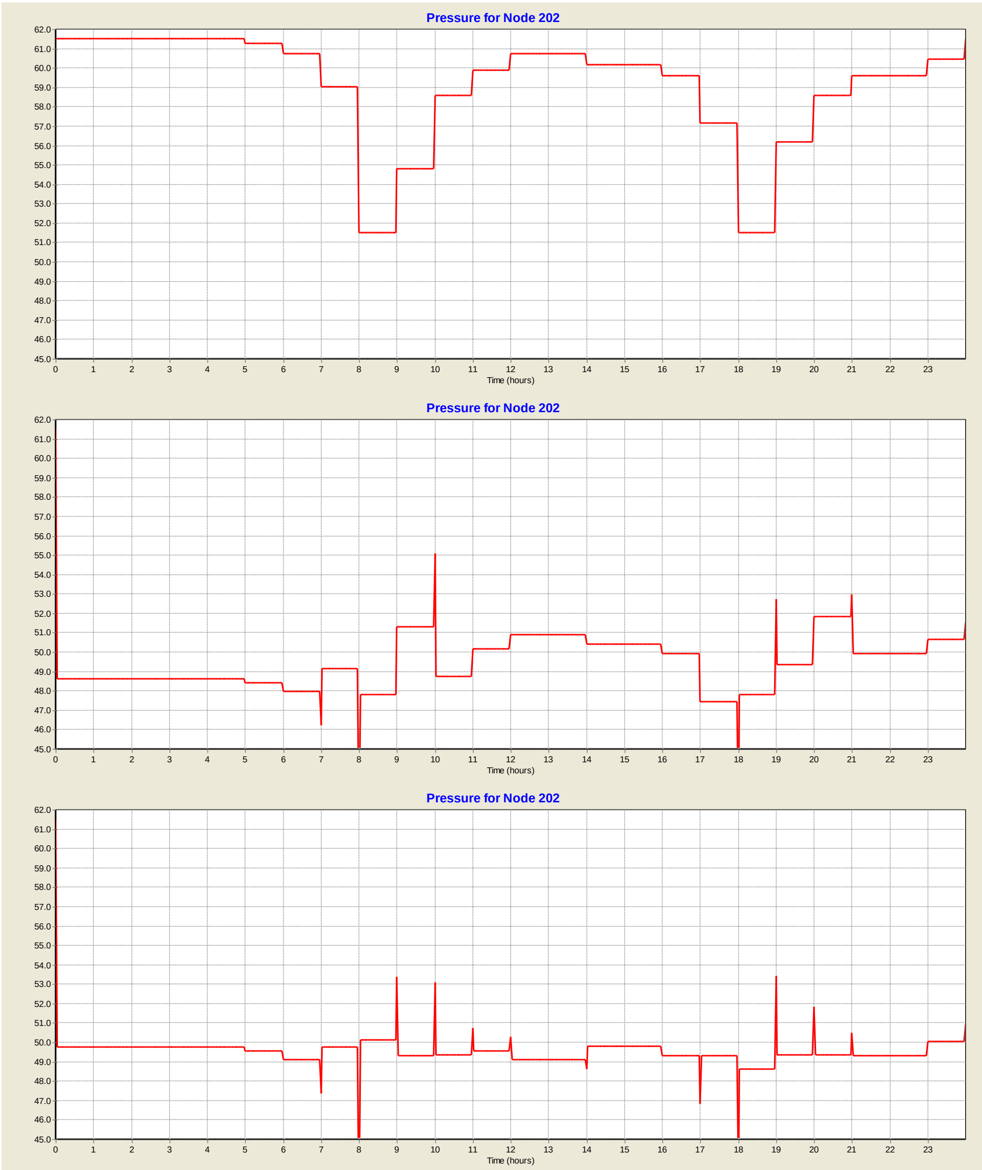

Fig. 5. Pressure variation at the junction that exits the pumping station (upper panel, no rotation speed variation algorithm; middle panel, rotation speed variation in decrement of 0.05 n_0; lower panel, rotation speed variation in decrement of 0.02 n_0)

This is entirely due to the way in which EPANET computes the hydraulic calculations and evaluates the conditions in the ruled-base controls, as presented in the former chapter of this article. Those changes are of no consequence to the functioning of the network and pumping station. In Figure 6 we present the results obtained for the energy consumption of the pumping station in the 3 studied cases.

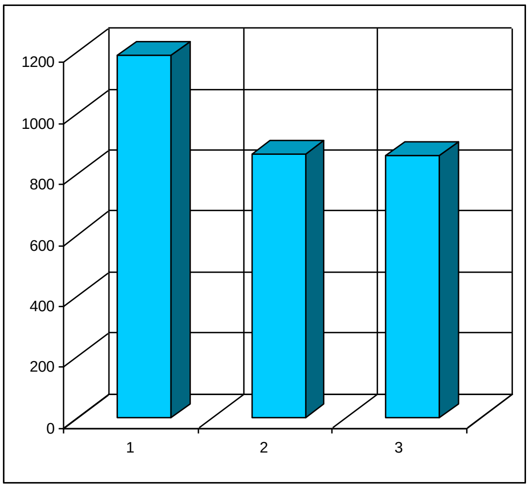

Fig. 6. Energy consumption for the 3 studied cases in kWh/day

6. Conclusions

By analysing the values of the pressure at the exit node of the station it is obvious that the smaller decrement of the rotational speed produces the best result, i.e. almost constant pressure in the network. As long as the energy consumption is concerned the 2 cases using a rotational speed variation algorithm display a significant decrease in this consumption, in which the value of the decrement of the rotation speed plays a minor role.

This result is also consistent with values recorded at the pumping station over 2008, where the average daily energy consumption was of about 800 kWh. The model we created can prove useful in performing other analysis in order to assess the functioning of variable rotation speed driven pumps in a water distribution network.

R E F E R E N C E S

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