Water network pumps control reducing the energy cost

Jan Studzinski¹, Marek Kurowski²

Abstract

Two algorithms for pumps control reducing the energy cost in the communal water networks are presented in this paper. The energy saving in water and wastewater networks is, beside the reduction of water and wastewater leaks, one of the main operational tasks in the waterworks. As a result an essential cutting of the exploitation costs can be achieved. In the presented algorithms an heuristic method of multi criteria optimization is applied. Both algorithms are parts of the ICT system for complex management of communal waterworks that is under development at the Systems Research Institute of Polish Academy of Sciences. All calculations done during testing these algorithms were made with the real data from Polish waterworks.

1. Introduction

The last years are the time of intense implementation of IT solutions in waterworks. GIS (Geographical Information System) and SCADA (Supervisory Control And Data Acquisition) systems as well as hydraulic models of water and wastewater nets are already regarded as standard ICT tools. They are used as data bases and sources of information for network operators about the work state and work quality of the nets which they are managing. But still the applications dealing with optimization problems that arise in the networks are rather rare among the programs used in the waterworks. There are a lot of such problems: hydraulic models calibration, SCADA systems planning, water and wastewater nets hydraulic optimization, water and wastewater nets planning, networks control etc. [5]. Data stored in data bases of GIS and SCADA systems and results produced by hydraulic models can be used to solve these problems and the received solutions can improve the quality of the network work and reduce operational costs.

At the Systems Research Institute an integrated ICT system for complex management is under development for a couple of years [6]. Its two algorithms for controlling the work of pump stations in water networks by means of a multi-criteria optimization are described in this paper. These algorithms were tested using real data coming from the Polish waterworks in Rzeszow. The aim of the algorithms is the reduction of energy used in the waterworks and the resulting decrease of enterprise operational costs.

The ICT system as the whole is presently introduced in the Upper Silesian Waterworks in Katowice [10].

2. ICT system

The ICT system under development is shown in Fig. 1. It consists of 4 functional modules and of 33 applications in total. The module regarded as data source for all calculations consists of a GIS system for generating the numerical map of the considered water net and for exporting the water net hydraulic graphs to water net hydraulic model, of a SCADA system for measuring the flows and pressures in all pipes and nodes of the water net and of a CIS (Customer Information-Billing System) system for recording the water amounts supplied to the water net end users.

¹ Systems Research Institute of Polish Academy of Sciences, studzins@ibspan.waw.pl
² Windsoft Microenterprise, makur@xl.wp.pl
Water network pumps control reducing the energy cost

Figure 1: Structure of the ICT system under consideration with 4 functional modules

Figure 2: Module with simulation and optimization algorithms of the ICT system
The remaining 3 modules include programs for mathematical modeling of the water net hydraulic load [7], applications for designing the distribution maps for some water net parameters like water flows or pressures using the algorithms of kriging approximations [1], and the applications for hydraulic calculation of a water net and its optimization [5, 8]. Two of these applications destined for pumps and pump stations control and algorithms applied in them are described below.

3. Algorithms description
The first algorithm has been adapted from the REH program of Straubel [4] and implemented into ICT system. In this algorithm the pump stations installed in the water net are considered to be indivisible units and the principal optimized parameter is their output pressure. The best suited pressure for each of the pump stations is calculated using multi-criteria optimization algorithm with four objective functions:

1. Maximum deviation from individual target pressure for customer nodes.
2. Total power of all pump stations.
3. Maximum output pressure among all pump stations.
4. Actual (simplified) cost of drink water produced.

All objective functions are to be minimized. User can turn off some objective functions from optimization process. The power of a pump station is calculated as the product of the water flow and the pressure (the head supplied) on its output. The efficiency of each pump station is considered to be 100%. The cost of production of 1 m$^3$ of drink water is known (done) for each pump station. At each iteration of optimization algorithm the hydraulic model of the water network is solved and the values of all objective functions are determined.

The multi-criteria optimization algorithm allows the user to execute several different, though connected, tasks:

- Utopian optimization – separated one-criterion optimization run for each objective function in turn.
- Pareto optimization with objective ranks – gives only one solution. Optimization process is performed for each objective function in turn, in diminishing rank sequence. The ranks of objective functions can be changed by user beforehand.
- Pareto compromise set – finding the set of not-dominated solutions. The not-dominated solution is the one for each there are no other solution with all objective functions having better value.
- Pareto compromise set with objectives constraints.

As a result the user can choose the solution that meets best all his demands reducing at the same time the energy cost. The algorithm of optimization is heuristic and each optimization run requires a huge number of hydraulic model calculations.

The second algorithm for pumps control has been developed at IBS PAN. It assumes that each pump station can consist of several parallel working pumps with different work parameters. Each pump has its known head-versus-flow and efficiency-versus-flow characteristics. The idea of the algorithm was inspired by Waterworth who shown in his papers that some combinations of parallel working pumps can consume less energy than 1 pump producing the same water pressure on the pumps station output [9].
The goal of the multi-criteria optimization algorithm is to find the best steering sequence (schedule) for each pump where for consecutive time unit (usually one hour) the pump can be turn on or turn off. There are three objective functions in the algorithm:

1. Cost of electric energy used by pumps (twenty four hours).
2. Number of “pump switches”.
3. Maximum deviation from individual target pressure for customer nodes.

All criteria are to be minimized. The cost of electric energy depends on efficiency of actually working pumps as well as on different energy cost at different day period – especially when water reservoirs (tanks) are present in the water network. Number of “pump switches” is a surrogate measure of pump maintenance cost - a pump’s wear can be indirectly measured through the number of times it has been switched on.

The valid schedule should fulfill some additional constrains:

- At each time unit (hour) the water reserve in the reservoir tanks cannot be lower than the minimum value set by the user.
- At the end of twenty four hours the summarized water reserve in the tanks cannot be lower than the reserve at the beginning of this period.

The optimization run gives at its end the pump work schedule that minimizes overall operational cost of the water network.

4. Exemplary calculations

In Fig. 3 the investigated water net is modeled while in Figures 4, 5, 6 and 7 some exemplary pictures illustrating the process of performing the first control algorithm are shown.

![Figure 3: Calculated water network with 2 pump stations (at bottom left)](image)

In the water net two pump stations are installed whose output pressures are to be minimized in the third objective function (Fig. 4). Additionally the possibility of installing a new pump station on a given pipe is considered. For all pump stations their lower and upper pressure values are fixed. While controlling the output pressures of the pump stations the water pressures on the output nodes
of the water net have to be secured according to the values determined beforehand. The water net investigated consists of 280 nodes and 398 pipes.

**Figure 4:** Given limiting values of output pressures for the considered pump stations and the calculated objective functions

While performing the task of utopian optimization the separated one-criterion optimization runs for all objective functions are done (Fig. 5). As a result the optimal values for all criteria are calculated that can be regarded as reference values by the following Pareto optimization tasks. Some exemplary results of the solution of the Pareto optimization task with objective ranks are shown in Figures 6 and 7.

**Figure 5.** Results of the utopian optimization for the first control algorithm

**Figure 6.** Objective functions for the Pareto optimization task with the objective ranks given and the resulted control parameter values for 3 pump stations considered.
Water network pumps control reducing the energy cost

One can see by the comparison of the tables in Figures 5 and 7 how big are the differences between the optimal and quasi-optimal results received for the utopian and Pareto optimization tasks respectively (Table 1). Although the results obtained for the first three criteria while solving the Pareto optimization task are acceptable then the water production cost are much too high. The reason for it is placing this criterion at the end of the criteria ranking list what results in a very limited area of steering values while searching for the criterion optimal point. Now in the management of the water net operator is to decide what is more important for the waterworks: to pay less for the water production or to secure right water pressures on the end nodes of the water net or to take care about the rational operation of the pump stations. Depending on his decision the sequence of the objective functions can be change in the rank list.

<table>
<thead>
<tr>
<th>Objective function</th>
<th>Utopian task</th>
<th>Pareto task</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>FUN(1)</td>
<td>0.00</td>
<td>2.96</td>
<td>m WC</td>
</tr>
<tr>
<td>FUN(1)</td>
<td>26.4</td>
<td>648.9</td>
<td>kW</td>
</tr>
<tr>
<td>FUN(1)</td>
<td>173.0</td>
<td>181.8</td>
<td>m WC</td>
</tr>
<tr>
<td>FUN(1)</td>
<td>87.5</td>
<td>2,219.9</td>
<td>PLN/h</td>
</tr>
</tbody>
</table>

Table 1: Comparison of the results for utopian and Pareto optimization tasks

While calculating the second algorithm only the task of Pareto optimization with ranks has been tested. For the calculation the following assumptions have been made:

- In the calculation only control of two pump station installed in the water net is considered.
- One of the stations has only 1 pump and the other one has 2 pumps which are to be controlled.
- For all pumps their characteristics of output pressure in [m WC] depending on water flow in [l/s] and of efficiency in [%] depending of water flow are set (Fig. 8).
- The time step of pump work equals to 2 h what means that in the period of 24 hours there are 12 time periods in which each pomp can be switched on or off.
The hydraulic load of the water net for 24 hours is set in advance (Fig. 9).
The control schedule being the result of the calculation will show the operation cycles for 3 pumps in 2 hour time steps.

In this algorithm a singular calculation of the criteria values requires the multiple run of the hydraulic model (24 times) considering the water consumption in the network end nodes for each hour. However in the first algorithm the hydraulic model was run only once for singular calculation of the criteria values.

Figure 8: Exemplary working characteristics for 1 pump

Figure 9: Objective functions given for the second control algorithm and the function of the hydraulic load of the water net

Figure 10: Given lower and upper limiting values for pump schedules and the resulted control schedules for calculated objective functions
The results of calculation are shown in Figures 10 and 11. One can see from the table in Fig. 11 that the first two criteria have got their quasi optimal values acceptable but in third criterion the difference between the required and calculated pressures in the end nodes of the water net seems to be quite big (2.018,8 m WC = 202 atm.). But it is the sum of pressure differences for all output nodes, and the value for each node is the total for each of 24 hours. As in case of the first algorithm the improvement of the results could be achieved by changing the sequence of the objective functions in the rank list. The decision for such the action is on the side of the water net operator.

5. Conclusions
A central production and distribution of water for cities realized by waterworks creates a complex of research problems consisting of water network control belonging to technical tasks and of water network management belonging to organizational tasks. The main goal of each waterworks is the production of drink water that will be provided to the individual or collective consumers in amounts needed, in a good quality and with a possibly small price. The implementation of the presented ICT system in waterworks shall cut down the operational costs of the water net, boost its reliability and ensure a high and homogeneous quality of the water. The integrated ICT system shall also improve and make easier the job of water net operators and planners and of the management staffs of waterworks. In case of operators the improvements will concern the operational control of the water network, in case of planners they will concern better and faster planning of the investments regarding repairs, modernizations and expansions of water networks and in case of management staffs the improvements will concern the complex and more effective waterworks management. The implementation of the ICT system shall be especially important and useful for city agglomerations running complex and wide spread water networks. Such the networks are characterized usually by great exploitation costs resulted from water losses caused by water net damages and from the great costs of the energy used [3, 9]. The last trend in development of complex ICT systems is to include the IT systems concerning the management of waterworks into wider systems prepared for Smart City management [2]. In such cases the waterworks systems are integrated with other systems dedicated to traffic, persons and streets monitoring, air pollution forecasting, flood threat modeling, rescue management etc.
Aknowledgement

The paper presented has been realized in frame of the research project of the Polish National Center for Research and Development (NCBiR) co-financed by the European Union from the European Regional Development Fund, Sub-measure 1.3.1. "Development Projects"; project title: “IT system supporting the optimization and planning of production and distribution of water intended for human consumption in the sub-region of the central and western province of Silesia”; project ref no POIG.01.03.01-14-034/12.

References


Water network pumps control reducing the energy cost