SOME OPTIMIZATION METHODS FOR INCREASING THE ENERGY EFFICIENCY OF THE WATER SUPPLY SYSTEMS

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Abstract: *We are witnessing the rapid growth of the energy prices and there are expectations that they will continue to grow in the future. Consequently, there is a constant need of energy efficiency improvements that could be achieved by decreasing of energy losses, smart and efficient energy utilization and conservation of energy resources.*

The water supply systems are large energy consumers. So, the investments in the increasing of their energy efficiency will not only have an economic dimension, but also they could have large positive effect on the environment protection. In this paper, an analysis of the degree of efficient usage of the energy and the appropriate techno-economic analysis of the energy consumption for a real water supply system is presented. Few methods for increasing the energy efficiency of water supply pump stations and an analysis of the potential benefits of this method are proposed and discussed too.

Keywords: WATER SUPPLY, ENERGY EFFICIENCY, OPTIMIZATION, ECONOMY

1. Introduction

The water supply systems consume electric power at each of the stages of the water production and supply chain: starting from pumping the water to the water treatment plant, along the water treatment process and during distribution of the water via the water supply network.

Energy losses in these systems are generally conditioned by a several reasons: inefficient pump stations, poor system design, installation and/or maintenance, old pipes with high network losses, bottlenecks in the supply network as well as inefficient operation strategies of the various supply facilities [1].

This paper proposes a few measures for increasing the energy efficiency of a typical water supply system, and a further analysis of a possible technical and economic benefits of these measures are defined. Several appropriate proposals for the modernization of this water supply system are given, with application of some contemporary computer techniques and procedures.

2. Analysis of a Typical Water Supply System

The investigated water supply system is the water supply system of the Municipality of Radovish, which operates through mixed gravitation/pumping mode, where gravitational system is used from three existing water catchments: "Ambari", "Stara Kaptaza" and "Filter Stanica", on one side, and water pumping system from the two pumping systems: "Industrija" and "Raklish", on the other side. Both pumping systems are connected with drawn pool which is filled with water from ten existing water wells [2].

The amount of water consumption is a time-variable function with the amounts that significantly varies annualy, monthly, daily and even hourly. These variations are generally implied from climate condition changes, the work of the major industrial plants, the number of inhabitants, the standard of the population, etc. However, usually there is larger water consumption during the summer period compared to the winter period [3].

The average daily water consumption during winter was 89 l/s, while in the summer the water consumption goes as high as 122 l/s [2]. This difference indicates a possibility of introducing two separate operational modes for the water supply system, the summer operational mode and the winter operational mode. This was the firstly suggested activity among the others for increasing the energy efficiency of the whole water supply system [2].

In order to analyze the characteristics of the water supply system of the Municipality of Radovish, a real simulation of the system was made using the LabView simulation package.

3. Annual Electricity Consumption

To determine the measures for energy efficiency improvement of the system, the analysis of the electricity costs for the last 6 years was done. The results of this analysis are shown on Fig. 1.

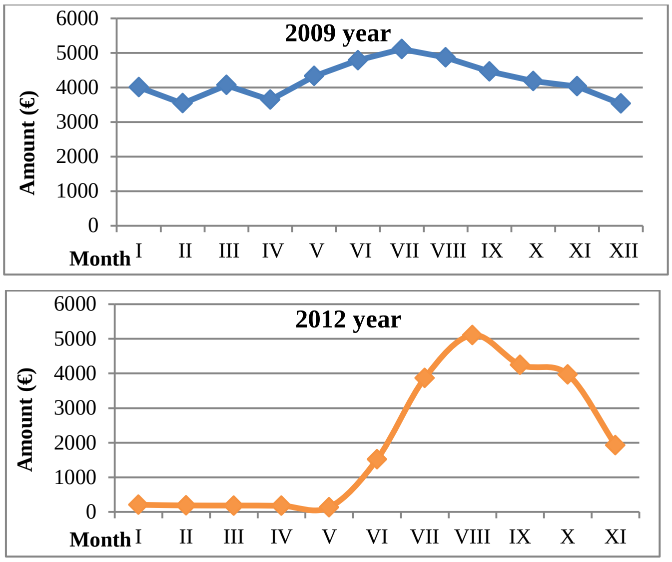

Fig. 1 *Cost paid for electricity consumption for 2009 and 2012 year*

It can be noticed that in 2009 the company had large electricity cost consistently all year around. Surging water consumption during the summer months is the main reason for larger cost in this period of the year. In 2012, the company significantly reduced electricity cost, mostly as a result of disconnection of the pumping stations during the winter i.e. the introduction of only the gravitational mode at the end of 2010 during the winter period.

Additionally, an analysis of the cost for the consumed reactive power for the period between 2008 and 2013 was made. The results are shown in Fig. 2, where it can be seen that in those 6 years the company had really high cost for consumed reactive power.

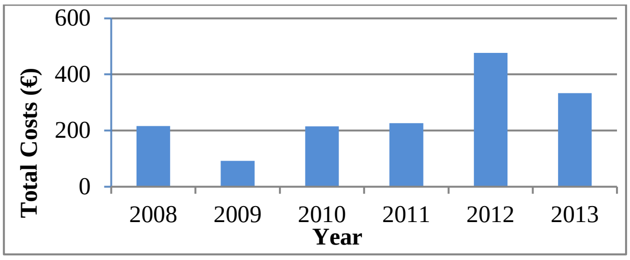

Fig. 2 *Reactive power cost paid for the period between 2008 and 2013.*

4. Problems and Weaknesses in the Water Supply System

From the analysis of the current state of the system and the reference annual consumption we realized that by the end of 2010, successful effort for increasing the energy efficiency in the system was made i.e. the introduction of the zonal water supply brought significant economic benefits for the company.

Additionally, from the analysis of the reactive power consumption we realized that this typical water supply system is using two types of electric motors which use excessive reactive power directly from the power grid, i.e. they have low power factor. This, so-called ***reactive power*** used by some power devices for creating an electromagnetic energy as a medium for conversion of the energy from one to another form, is not converted into useful work [4], therefore brings only additional energy cost to the company.

From the analysis of the pumps operation mode of the pump station "Industrija", we realized that except the turning off mode for the winter months, there is no other way to regulate its work during the summer months. According to received information, turning on and off is performed manually by the operator. This was considered as another subjective reason for increased electricity cost.

5. Research Results

During the research, beside reorganization of pump operation for winter and summer regimes, a set of additional measures to overcome the perceived weaknesses in the system were investigated and proposed, among which the most significant were the following two measures:

- the improvement of the power factor of the pumping systems, i.e. decrease the amount of reactive power taken from the grid and replace it with locally generated one, and
- the development of a system for automatic regulation of the three main parameters in the water supply system: pressure, water flow and the amount of water in the reservoir.

5.1. Measure #1: Reorganization of the Pumps Operation

This measure provided electricity cost reduction and some technical benefits:

- Reduced work of the motors and pumps,
- Increased motors and pumps efficiency,
- Extended “working life”,

The main disadvantages of this measure were low water supply quality or reduced pressure and water flow during the summer months, and consistently the same cost for water supply services for that period of the year. Because there were no additional investments for this measure and there was saving of around 67.5%, we could conclude that this measure was a highly cost-effective measure.

5.2. Measure #2: Reactive Power Compensation

With the application of adequate reactive power compensation generated locally by installed capacitor banks, additional increase of the energy efficiency of the whole system could be expected. In such case, the installed capacitor banks could provide only a part of the requested reactive power, leading to a reasonable increased value of the power factor at least to a level of 0.96. This is because only a power system that have power factor less than 0.95 are required to pay additional cost for taking the excessive reactive power from the electric power grid [5].

Calculation of the required reactive energy for compensation and selection of the type of compensation are two most important steps to achieve optimal cost-benefit of the proposed activity.

The amount of added reactive power could be calculated using well-known formula:

$$Q_c = Q_1 - Q_2 = P * (\tan\varphi 1 - \tan\varphi 2) \quad [VAr]$$

Based on the analyzed data, we made a calculation of the required reactive power used by both types of motors which are used in this particular water supply system. Thus, the calculated amount of reactive power that should be additionally provided by the capacitor banks was 4.9 [kVAr], and 12.9 [kVAr] for each type of the electric motor, respectively. Therefore, to achieved a full reactive power compensation for the whole electricity supply system (both pumping stations and all five motors) to the desired value for the power factor cosφ=0.96, a total amount of 40.5 [kVAr] reactive power was required [6].

Because of the power supply stability and continuous load factor, as well as the short distance between the pumping stations and the supplying transformer substation *(less than 10 meters)*, the central compensation system was proposed. The capacitor banks should be installed at the same bus bar as the pumping stations next to the power transformer, to provide enough reactive power for the whole installation. Using the layout shown in Fig. 3, one could eliminate tariff penalties for excessive consumption of reactive power from the grid on one side, and on the other, relieve the supply transformer from unnecessary reactive load, increase its efficiency and prolong its operational life [4].

The main disadvantage of this central compensation mode is the fact that the reactive current generated by the capacitor banks would still flow through the supply cables towards the pumping stations, generating additional power losses. However, due to the very short distance between the power transformer and the pumping stations, increase of the power losses should be insignificant [6].

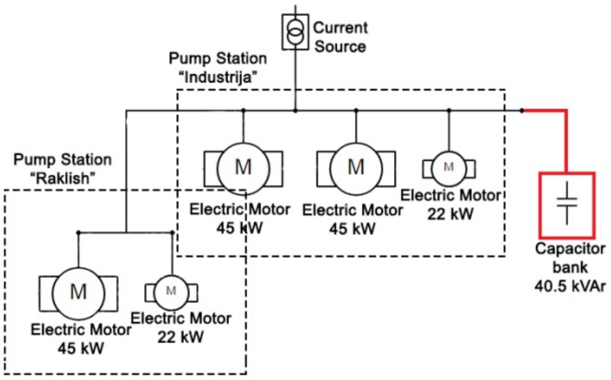

Fig. 3 *The pump stations with central reactive power compensation system [6]*

Speaking about the economic benefits of this measure, the total financial resources spent for procurement of the reactive power for the period between 2008 and 2013, (Fig. 2), were estimates at 1,559€, i.e. an average of 259.83€ per year, while the total investment for purchase and installation of the proposed compensation equipment and the realization of this improvement method was estimated at 326.5€. This investment could be also estimated as a cost-effective measure because the full investment in this kind of capacitor banks would be paid off for approximately 1 year and 3 months. To be precise, one could conclude that only with the implementation of the proposed measure this company could decrease the existing operational electricity cost for at least 1.7%.

5.3. Measure #3: Pumping System Operating Mode Optimization of the Depending on the Needs and Electricity Prices

The pumping system operating mode is a very complex process for large water supply systems. In our research the various operation modes of pumping system were investigated in order to find the one that will provide reduced power consumption and reduced cost for pump station maintenance. The increased electricity consumption during the months from May to November shows that it is necessary to activate both pumping stations.

To determine the electricity savings which can be achieved with the implementation of this measure, the real simulation of the system using the LabView simulation package was made. For this purpose, the data for the maximum hourly water consumption for the different parts of the city had to be known and used in the process simulation. For simulation purposes, the parts of the city which are water supplied using the pump station "Industrija" were only considered. Fig. 5 shows a graph with the values for the maximum hourly water consumption connected with this pump station.

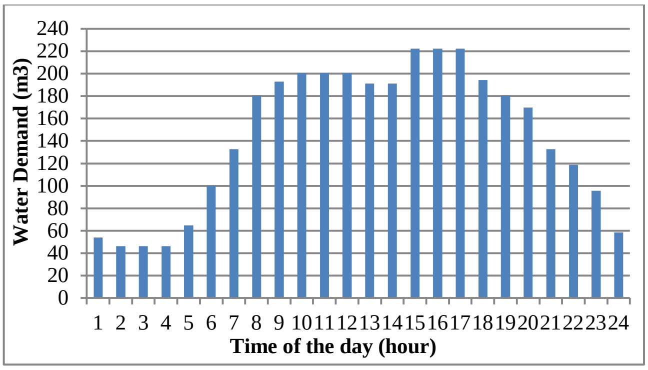

Fig. 4 *Maximum hourly water consumption*

Amount of Water Regulation

With the regulation of the amount of water in the reservoir, the costs optimization can be achieved only in respect of the company. The first step of the implementation of the proposed measure was to put into service the reservoir "Industrija". The optimization was achieved by determining the optimum upper and lower level of the water in the reservoir. Initially 900 m^3 for upper amount of water was considered i.e. the maximum capacity of the tank. Filling the reservoir to the maximum level through the night was planned.

The simulation is run for two periods: day-time and night-time.

- the period between 7:00 and 22:00, or the period of high tariff and accordingly, the high electricity prices, and
- the period between 22:00 and 7:00, or period of low tariff and accordingly, the low electricity prices.

Tab. 1 shows the results of the simulation when only one parameter is regulated (amount of water in the reservoir), i.e. the target function are total amount of money which the company would spend if the proposed measure is realized.

Table 1: *Costs of various optimization parameters*

Hysteresis		**7:00 h – 22:00 h**		
		200 m^3 & 300 m^3	200 m^3 & 500 m^3	200 m^3 & 900 m^3
7:00 h – 22:00 h	800 m^3 & 900 m^3	37.74 €	38.33 €	44.24 €
	500 m^3 & 900 m^3	41.45 €	39.90 €	47.32 €
	300 m^3 & 900 m^3	41.58 €	41.51 €	47.53 €

From the table can be seen that there is the lowest electricity consumption when the values of the upper and the lower level of the water during the period between 07:00 and 22:00, would be 200 m^3 and 300 m^3, and while for the period from 22:00 to 07:00 would be 800 m3 and 900 m3.

Water Pressure Regulation

The second set of optimization methods which use the same cost function - minimization of the company costs, is realized with the introduction of one additional optimization criteria: the amount of the water pressure in the water supply system. In this case, we "maintain" the pressure for the whole operational time to optimal value for water pressure in the water supply systems, at the value of 5 bar, without considering the amount of water in the reservoir. In this case, the optimal solution for 24 hour operation gives the following optimal values: consumption of 720 kWh during the high tariff period and 241 kWh during the low tariff period, or 44.24€ for whole operational period of 24 hours, or monthly (30 days period), the company could spend approximately 1327.32€ for pumping purposes.

Amount of Water and Water Pressure Regulation

Finally, optimization was realized using both optimization criteria jointly: (i) the amount of water in the reservoir, and (ii) the value of the water pressure in the water distribution system. The same optimization target function – the minimization of the energy cost was used. In this case, besides providing reduction of the operational cost for the water supply company, the obtained optimized operational mode results with rising of the quality of the water supply services for all customers connected to the system, mostly due to ensured minimum water pressure in the distribution network as requested by the water supply standards.

The optimization results for this two-parameter optimization procedure shows that for 24 hour operation the company will spend 685 kWh during the high tariff period (day-time) and 244 kWh during the low tariff period (night-time), or a total of 42.50€ per day, or monthly cost could be estimated at the amount of 1275.12€.

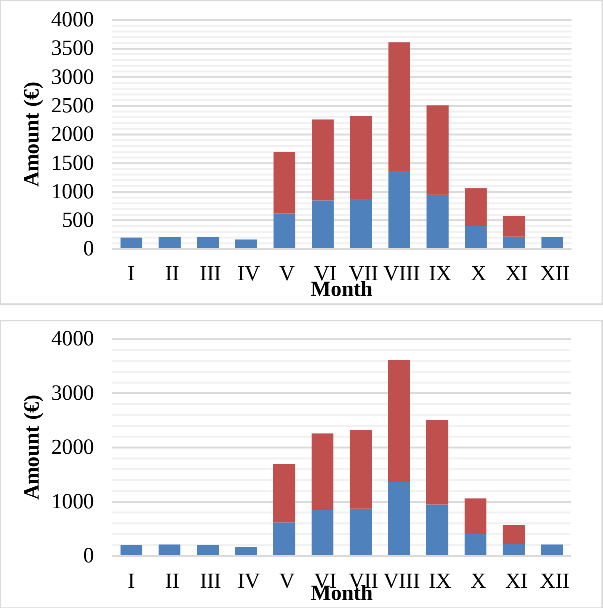

Fig. 5 *Monthly savings with optimization of the amount of water in the reservoir (above), and monthly savings with optimization of the amount of water in the reservoir and the water pressure (below)*

According to the simulations one could come to the conclusion that the largest energy savings could be obtained when the pumping station "Industrija" works in the optimization mode only for the amount of water in its reservoir. The savings per month that would be obtained with the implementation of this measure are given in Fig. 5, graph above. The amounts of money that the company will save only by the implementation of this measure are shown with red color on the above graph on Fig. 5. The results show that with usage of this optimization mode only, the company annually could save approximately 9 275€.

However, this optimization mode does not provide the improvement of the water quality supply services, i.e. sometimes, especially during the summer months the users are "receiving" the water with extremely low pressure (below 5 bar). Therefore, the optimization mode must include the quality of water supply services, i.e. one should definitely include the second optimization parameter, the value of the water pressure at the point of the last consumer in the water distribution system. This solution could be optimal not only for the water supply company but also for all customers connected with this water supply system. The savings per month in such optimization mode, are presented in Fig. 5, graph below. The results show that with usage of this optimization mode only, the company annually could save approximately 8 681€.

This optimization mode could not be achieve without implementation of appropriate SCADA system for on-line monitoring and control of the whole water supply system. As part of our research, the investment cost for purchase and installation of such SCADA system was also analyzed. The investment cost according the regional prices for purchasing and installation of middle range SCADA system was estimated at about 21 700€.

Having into account the cost for additional SCADA investment and the annual savings that the company could achieve by implementation and utilization of that SCADA system, one could calculated that the pay-back period in the first case of the optimization (only the water level in the reservoir) could be approximately 2.3 years. In the second case of the optimization (water level and water pressure combined) the expected pay-back period could slightly increase, but even in that case it could be around 2.5 years. Both pay-back periods are acceptable and show very high cost effective measures that could be quickly and efficiently implemented in such water supply systems.

6. Conclusion

According to the aforementioned results, the type and the essence of the proposed measures for operational cost reductions and energy efficiency improvements, in Table 2 the economic benefits of each of the proposed measures are summarized:

Table 2: *Investment value and repayment time of the proposed measures*

Proposed Measures	Investment value	Repayment time
Reorganization of the Pumps Operation	/	/
Reactive Power Compensation	326.5 €	1 year & 3 months
Pumping System Operating Mode Optimization	21 700 €	2 years & 4 months or 2 years & 6 months

According to the summarized results shown in Tab. 2, for this typical water supply system, we suggest:

1) Further improvements of zone-based water supplying method in order to improve the quality and the quantity of the water supply services.
2) Procurement and installation of adequate equipment for reactive power compensation for elimination of the unnecessary financial costs due to excessive reactive power consumption.
3) Activation of "Industrija" water reservoir for optimization of the water supply mode for the whole city.
4) Investment in the adequate SCADA system for monitoring and management of the water supply system, especially for the amount in the water level in the reservoir, optimization of the pumps operating mode with the respect of the water needs and electricity prices.

This ranking list of measures is proposed to the responsible persons in the company in order to decide which of the proposed measures are technically and economically viable for implementation by the company.

7. References

[1] M. Feldman, Aspects of Energy Efficiency in Water Supply, Proceedings of the 5th IWA Water Loss Reduction Specialist Conference 26-30 April Cape Town South Africa pp. 85-89, 2009

[2] ЈП “Плаваја, Снабдување со вода за пиење и одведување на урбани и отпадни води во Општина Радовиш 2010 година”, April, 2011

[3] L.K Reynolds, S. Bunn. Integrating Water Systems - Boxall && Maksimovic (eds): Improving energy efficiency of pumping systems through real-time scheduling systems, Taylor & Francis Group, London 2010

[4] Schneider Electric. Reactive Energy Management – Low Voltage components, January 2013

[5] Свет на енциклопедиски знаења. Реактивна моќност, 21 April 2015 г. http://mk.swewe.net/

[6] S. Kostadinova, V. Cingoski, S. Gelev, R. Golubovski, Increasing Energy Efficiency of Water Supply Systems with Pump Systems Power Factor Improvement, Zbornik radova sa XX međunarodnog naučno - stručnog skupa INFORMACIONE TEHNOLOGIJE - sadašnjost i budućnost, Žabljak, Crna Gora, 23 - 28 februari 2015.