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An Integrated Approach to Optimizing the Energy Efficiency of Water Supply—The Way to Achieve Effective Management †

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Abstract: Escalating energy costs in recent years have spurred an examination of energy cost reduction strategies. Among these, exploring spot markets and building photovoltaic power plants at water facilities have emerged as promising options. This study focuses on the utilization of genetic algorithms to optimize pumping operations. Through simulations and case studies on small and medium-sized water distribution networks in the Czech Republic, the effectiveness of genetic algorithms at reducing operational costs is demonstrated. The integration of neural networks for predictive modeling and real-time decision-making complements the genetic algorithm approach, promising significant operational savings amid evolving energy market dynamics.

Keywords: optimization; pumping plan; water demand forecast; energy management

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1. Introduction

In the current socio-economic landscape, the discussion surrounding the reduction in energy costs has reached fever pitch, largely catalyzed by the unprecedented surge in energy prices in 2022 and 2023. Amid this turmoil, various strategies have been proposed to alleviate the burden of energy expenses. Two prominent avenues are venturing into spot markets and the installation of photovoltaic power plants at water facilities and on their surrounding lands. Nevertheless, the effectiveness of these alternatives hinges on the ability to adapt the production and transport of drinking water over time.

2. The Use of Genetic Algorithms for Pumping Planning

When scheduling water pumping, the problem can be simplified to n time steps of the pump's status when either on or off. In the search for an optimal solution, minimizing the operating cost appears to be the most appropriate objective function. In general, the majority of operating costs stem from the cost of powering the equipment—in the case of water pumps, this is generally related to electricity. Electricity is traded on short-term markets at different prices at different trading hours [1,2]. In the deterministic solution approach, the computational time of the problem grows exponentially as the number of pumps or time steps increases. When trying to find the optimal solution in real time, a different approach is needed. Therefore, the most suitable approach is a heuristic or metaheuristic approach. The metaheuristic approach that appears to be appropriate for this problem is the use of a genetic algorithm.

Genetic algorithms are proposed to optimize pumping operations and are proving effective in increasing efficiency and reducing operating costs. Research has shown the successful use of genetic algorithms such as the non-dominated sorting genetic algorithm II (NSGA-II) for optimizing different types of pump control, which has led to cost reductions [3,4]. These technologies are not yet used in the Czech environment, and this

study investigates their applicability in the national environment. Similarly, the aim of this study is to focus on smaller systems and show that even for these systems, the use of new technologies can lead to significant operational savings.

A flow chart of the water distribution network management process is shown in Figure 1. The main decision-making element is the genetic algorithm. This must be supplemented by the inputs of the water consumption expected on the following day (generated by the neural network), the electricity price according to the electricity market operator and, of course, the boundary conditions of the water distribution network (reservoir volumes, pump capacities and power inputs).

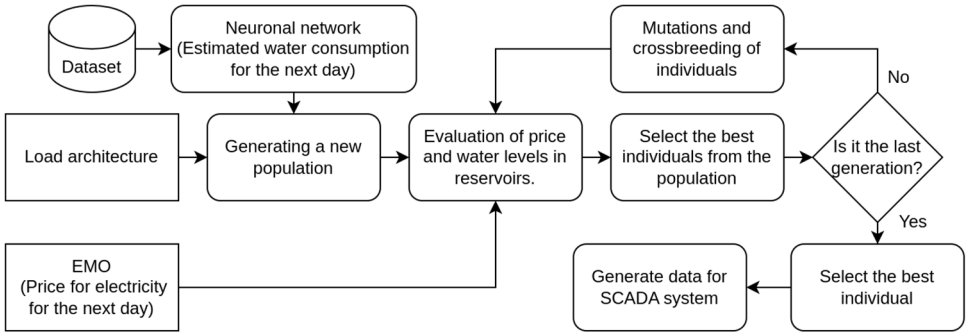

Figure 1. A flow chart of the management process.

The creation of a PV plant is possible by supplementing the input dataset with the outputs of a predictive power generation model for a given location.

The output of the genetic algorithm is a set of instructions for the SCADA system. The aim is to minimize the intervention of protection systems and operators. The goal is to minimize operator intervention so that the operator can devote all their attention to monitoring system faults, such as burst water pipes, equipment faults, etc.

3. Deployment Process

A time step of 1 hour was chosen for the genetic algorithm described in this paper. Optimization was performed for the following day (that is, 24 time steps). The known value of the next day is the selling price of electricity. Another known input is the boundary conditions of the water distribution network. The unknown input to the genetic algorithm is the water consumption in each hour of the following day. For the purpose of this study, an LSTM-type neural network was used. Its description is beyond the scope of this paper.

Historical data from the year 2023 were used for the simulation and comparison with reality. Historical data were obtained from the SCADA system of the respective water distribution networks and from the website of the electricity market operator. Inconsistent data (e.g., different time steps being used for flow volume measurement) were adjusted to create a unified time step. The neural network and genetic algorithm were then run in "real time".

4. Case Studies

4.1. First Site—Small System

The first selected water distribution network supplies a smaller populated area in the Olomouc region of the Czech Republic with approximately 600 inhabitants. Their water supply is largely provided by domestic wells—a common situation in villages where the water supply system was completed only a few years ago. The water supply network includes one pumping station with two pumps (one main, one backup) and one ground water tank with a total capacity of 200 m^3. The source of water is the regional water supply. The majority of the population is supplied by gravity from the reservoir, except for a few buildings near the tank.

4.2. Second Site—Medium-Sized System

The second selected water supply network supplies several neighboring localities in the Czech Republic with approximately 9600 inhabitants. Their water supply is primarily provided by the water distribution network. The water supply network includes one water treatment plant, one pumping station with two pumps (one main, one backup) and three ground water tanks with a total capacity of 900 m^3. Two boreholes are the sources of raw water for the water treatment plant. The water treatment plant reduces carbon dioxide, iron and manganese concentrations. The majority of the population is supplied by gravity from the reservoir, except for one smaller locality (about 200 inhabitants) supplied by an automatic pressure station. The total daily water demand of all customers is around 950 m^3.

5. Evaluation

The achievable electricity cost saving for the first site was approximately 54% for 2023 when using spot prices compared to an existing long-term contract.

An example of the output of the comparison of electricity prices for the full year 2023 is shown in Figure 2—in this case, it is the sum line of the price of electricity consumed for pumping and treating water for containment in water tank 1.

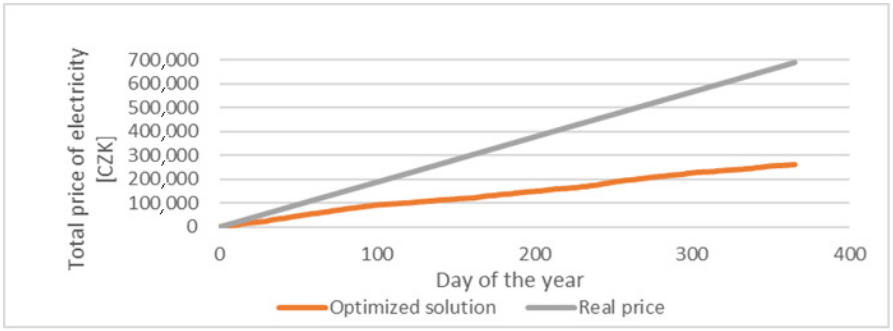

Figure 2. Cumulative cost of electricity consumed in 2023—water tank 1.

The potential cost saving of operating the system at the second site in 2023 was approximately 42%. This point is illustrated in Figure 3, which shows the cumulative daily electricity costs of the entire water distribution network. The cost takes into account electricity trading fees and so-called system deviation responsibilities.

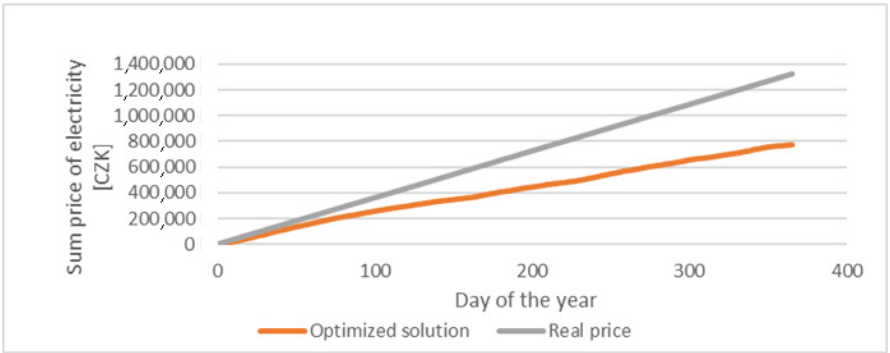

Figure 3. Cumulative cost of electricity consumed in 2023—whole second site.

6. Conclusions

The process of using neural networks and genetic algorithms, in conjunction with the use of short-term electricity markets, appears to be a promising source of savings in operating costs according to the case studies above. Cost savings of around 40–50% are promising.

Further work is needed to refine the algorithm to find the optimal solution. However, even in this state, deployment, in practice, is possible. There is, however, a risk of rapid price deterioration in the short-term market, against which the customer is otherwise protected by a long-term contract with their electricity supplier.

As part of the data preparation process, it was found that there were occasional failures in the measurement of the flow at the outlet of the tanks and the pumping stations. However, for the deployment of the tools described above, flow measurement is essential, and measurement failures would, therefore, need to be addressed promptly. With poor quality data input, the neural network and genetic algorithm cannot produce quality results usable for operational management.

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References

1. Sperlich, A.; Pfeiffer, D.; Burgschweiger, J.; Campbell, E.; Beck, M.; Gnirss, R.; Ernst, M. Energy Efficient Operation of Variable Speed Submersible Pumps: Simulation of a Ground Water Well Field. *Water* **2018**, *10*, 1255. [CrossRef]
2. Do, P.; Chow, C.W.K.; Rameezdeen, R.; Gorjian, N. Understanding the Impact of Spot Market Electricity Price on Wastewater Asset Management Strategy. *Water Conserv. Sci. Eng.* **2022**, *7*, 101–117. [CrossRef]
3. Marchi, A.; Simpson, A.R.; Lambert, M.F. Optimization of Pump Operation Using Rule-Based Controls in EPANET2: New ETTAR Toolkit and Correction of Energy Computation. *J. Water Resour. Plan. Manag.* **2016**, *142*, 7. [CrossRef]
4. Studziński, J.; Ziółkowski, A. Control of Pumps of Water Supply Network under Hydraulic and Energy Optimisation Using Artificial Intelligence. *Entropy* **2020**, *22*, 1014. [CrossRef]

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