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Energy Management System for Water Distribution Systems: Application to Crete

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Abstract

Water distribution systems represent one of the largest infrastructure components of an industrial country. In such systems, significant part of their operational cost is related to energy costs for pumping. As a result, significant cost and energy savings can be achieved with the optimization of pump operation, as well as with the exploitation of renewable energy technologies in order to reduce electricity consumption from the grid. This paper presents measures in both ways that are applied to the water distribution system of Western Crete. The results show that there exists a large potential for cost savings that is combined with a more environmental friendly operation of the whole system.

Keywords

Water distribution system; irrigation systems; pumps; optimization; renewable energy sources; photovoltaics; pumps-as-turbines

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I. Introduction

Water distribution systems are significant consumers of electric energy. Each stage of water production and supply chain requires the consumption of significant amounts of electric energy [1]. More specifically, energy is consumed during water pumping, water treatment and finally water distribution. Several measures and optimization techniques are nowadays available for the improvement of the overall energy efficiency of such systems.

Optimal design of the pump stations and the distribution system together with leakage detection techniques can greatly improve their efficiency [2]. To this end, suitable detailed models can be developed in order to accurately simulate the system and also design optimally parts of the system [3] [4]. These models can be also used for leakage detection and pressure management purposes; thus enabling the reduction of energy losses and the improvement of the reliability of the system.

The use of modern variable speed pumps, where it is necessary, can also lead to energy efficiency improvement and enable for more flexible pump station operation. In addition to the use of variable speed pumps, techniques to shift the pumping load from high to low-tariff periods can greatly contribute to the decrease of the cost of electricity. Moreover, the exploitation of renewable energy sources for the production of electricity that will partly satisfy the demand for electric power will drastically reduce the electricity bills. Photovoltaics (PVs) and small hydro can exploit the available energy resources in the territory owned by the water distribution organization.

In this paper, the above optimization techniques and measures will be presented and their application to the water distribution and irrigation system of Western Crete will be explored. The paper is organized as follows: Section II gives details for the modelling of water distribution system in Western Crete. Section III describes the developed software for optimal pumping system operation in real-time. Section IV provides information about the installation of renewable energy technologies (including PVs and small hydro) that can help to reduce significantly electricity consumption from the grid for pump operation. Section V concludes the paper.

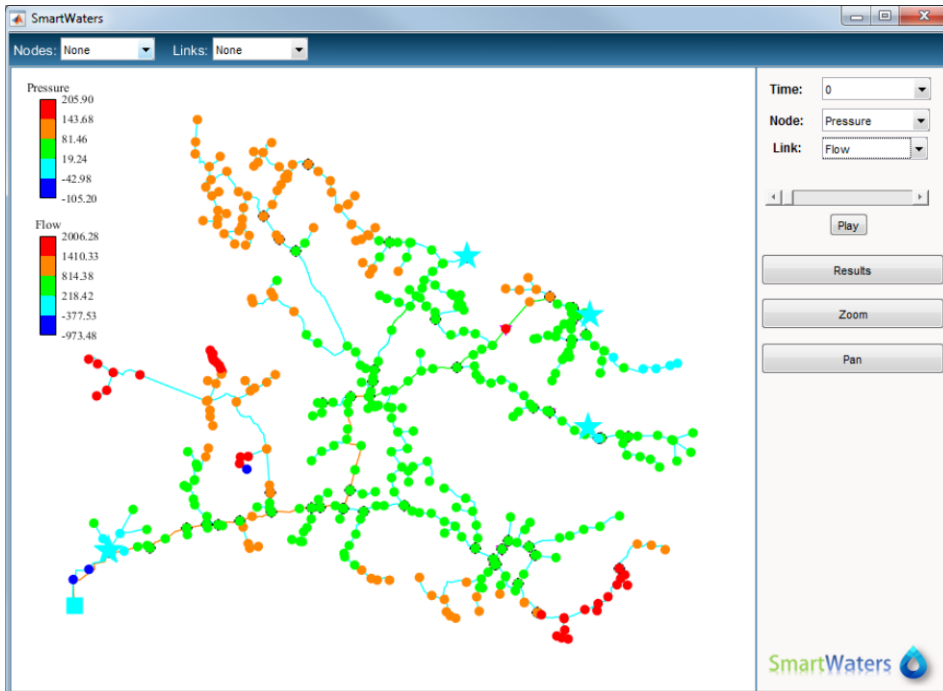


Fig. 1. Screenshot of SmartWater's software that shows simulation results.

II. Modeling of water distribution system

In order to simulate the hydraulic and energy demands of the water distribution system, SmartWaters software was developed that is based on EPANET [5], which is a widespread software for modeling and simulation of flow in closed conduits. EPANET provides simulation capabilities permanent and non-permanent flows in fluid distribution networks under pressure, of any size and topology. EPANET can calculate flows and pressures in nodes and conduits of the network; pressures, consumptions and heights in tanks; and velocities on pumps and valves. Moreover, apart from the hydraulic analysis, EPANET can resolve a network regarding its quality characteristics, water aging and concentration of chemicals. Implementation of a simulation in EPANET requires:

- Introduction of network topology and its characteristics through an input file
- The hydraulic solution performs simulation of network hydraulic operation and the results at each simulation step are kept in an external

file. The hydraulic solution is performed either at one step or for an extended period

- For the simulation of water quality, data from this external file are used, for the calculation of substances transfer and chemical reactions that take place in each step of the hydraulic simulation

The developed SmartWaters software is developed in MATLAB and it is combined with EPANET by using the libraries EPANET Programmer's Toolkit and EPANET Toolkit MATLAB. In this way the computational libraries of EPANET are running independently from the environment of the software, allowing cooperation with other algorithms (control, optimization, etc). Fig. 1 shows a screenshot of SmartWater's software that shows pressure and flow simulation results for a specific scenario for the water distribution network of Western Crete.

III. Software for optimal pumping system operation in real-time

An additional software was implemented in MATLAB, which is related with the optimal pumping system operation in order to minimize the operating costs in real-time while meeting the operational constraints and quality requirements of the system. This software uses information from SmartWater software that was described in Section II. The main inputs are the 24-hour program of optimum pump commitment, and measurements or estimates (in real-time) of critical system's parameters such as water demand, water flow and pressure, active and reactive power consumption. The software counterbalances in real-time any existing errors in demand forecast and it responds optimally to system disturbances that cannot be predicted. An additional factor that this software can have a huge positive impact is the optimal management of the pressures in the network in order to operate properly. This can be achieved by the simulation of a large number of system's operating conditions, which can export operating rules using as criterion the minimization of operating cost with respect to the desired operating conditions. Fig. 2 shows the diagram of the combined operation of optimal pump commitment and their optimal operation in real-time.

The expected future use of variable speed pumps in specific locations of water distribution system gives an additional degree of freedom to this optimal management system, because it provides to the pumps the option to vary their speeds in order to maximize the efficiency and minimize the operating costs. Moreover, in the future this system could use a capacitor system to optimally compensate the reactive power consumed by electric motors of the pumps. In

this way, electric losses will be minimized, and additional charges from grid consumed electricity due to low power factor ($\cos\phi$) will be eliminated.

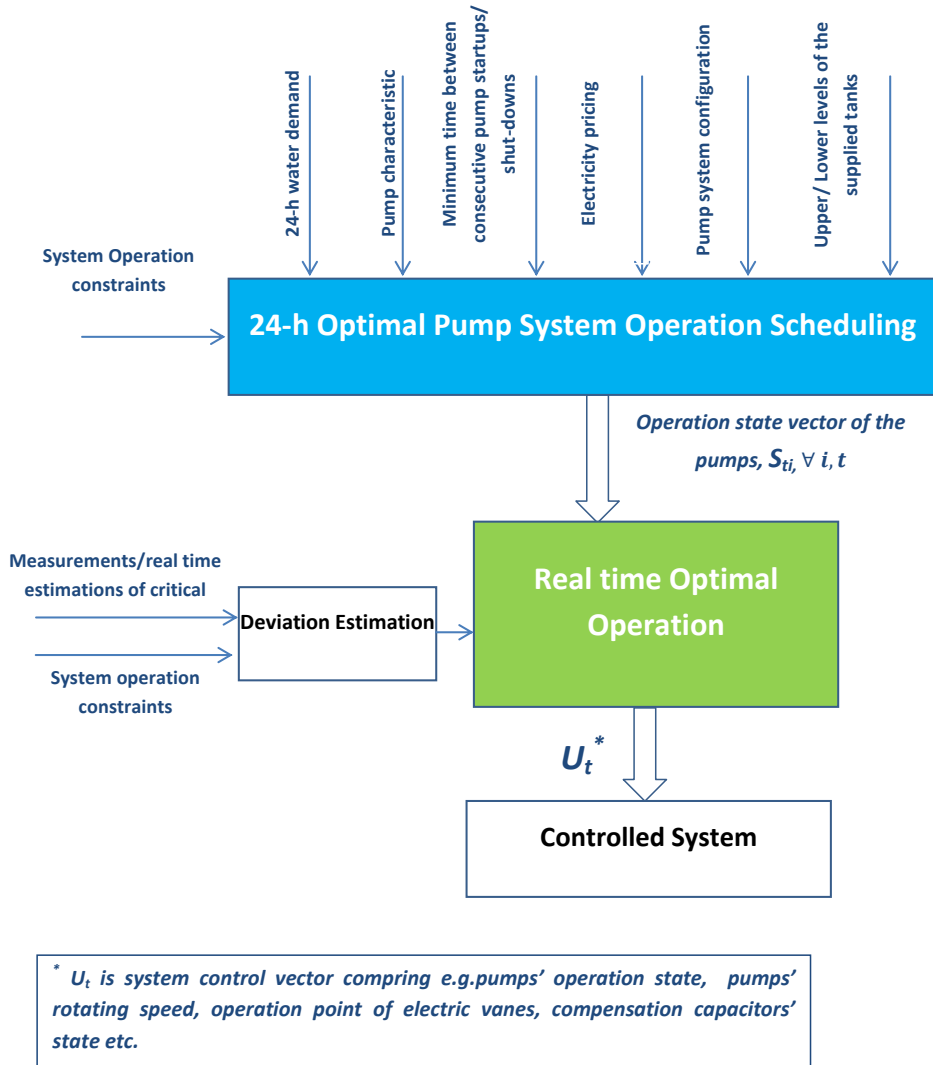


Fig. 2. Diagram of optimal management of pumping/irrigation hydro system

IV. Utilization of renewable energy technologies

Regarding the utilization of renewable energy sources, the examined technologies were small wind turbines, PVs and small hydro. Wind turbines were not proven to be viable because the wind potential is not significant in all

available locations that surround the studied water distribution system. However, PVs and small hydro seem to be an interesting alternative for reducing electricity consumption from the grid. The technology that was proven to be more cost effective for small hydro was pump as turbines (PATs). Fig. 3 shows the proposed locations for the installation of PV park and PAT system, which is identical (Miloniana pumping station).

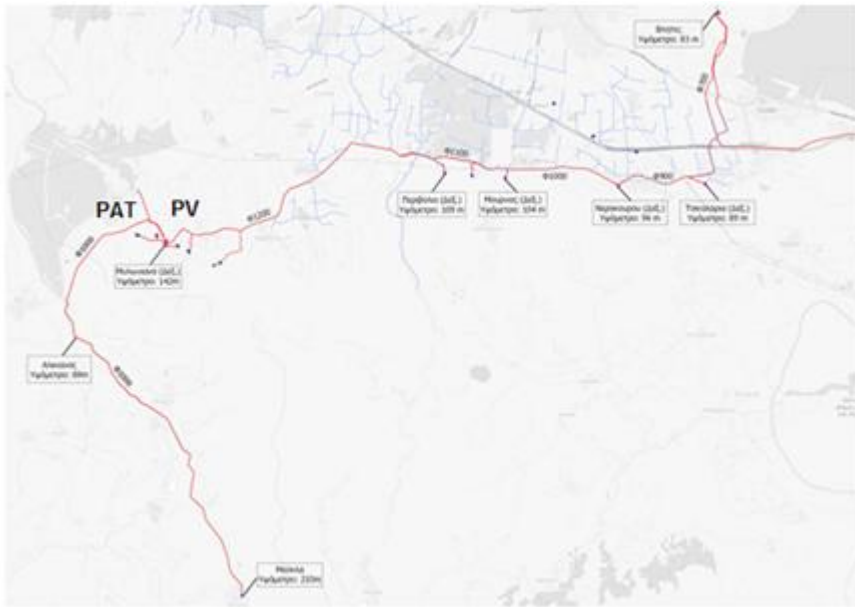


Fig. 3. Proposed location for PV park and PAT system installation.

A. Photovoltaics

Under the Greek legislative framework, there are two main options for PV park installation: a) to sell electricity at a specific price (feed-in-tariff) which is related to Greek system marginal price, and b) to use the net-metering scheme that aims for self-consumption (energy compensation for net-metering owners is taking place on an annual basis). The second alternative is much more attractive, because for the last year in Crete Island the mean feed-in-tariff was 0.057€/kWh, whereas for the Miloniana pumping station the electricity cost (which is equal to the saved cost by the PV produced electricity in net-metering) was 0.141€/kWh. For Crete Island, the upper limit for net-metering installations was set at 50 kW_p. In order to estimate the annual electricity production of a 50 kW_p PV park, PVsyst software⁶ was used, considering polycrystalline silicon PV panels. The case study considerations include PV installation cost of 1200€/kW_p, PV lifetime

of 25 years, interest rate of 6%, 70% bank loan (30% equity) of initial investment with rate 7% for 10 years, 2000€/year operational and maintenance costs. Table 1 presents the evaluation of this investment according to the following investment criteria: net present value (NPV), internal rate of return (IRR) and benefit to cost (B/C) ratio. The results of Table 1 prove the economic viability of this project.

Table 1. Financial evaluation of a 50kW_p PV park (net metering)

Case study	NPV	IRR	B/C ratio
50kW _p PV park, net metering, Miloniana pumping station	70,249€	27.1%	4.90

B. Pump as Turbine

The concept of running pumps as turbines is well-known in the water supply industry. It has been considered as an efficient method of generating power, especially in projects up to 100kW [7]. Most commonly, an asynchronous generator is driven by the pump (a standard induction motor driven in reverse) converting the mechanical energy to electricity [6]. Hydraulically, the pump in turbine mode can handle a higher volume of water than when in conventional pumping mode. There is a higher flow inside the pump and this means that the amount of energy that comes out is higher. An added bonus is that when it is in reverse operation and running as a turbine the pump runs more efficiently than in conventional mode. The operating range for ring section and volute casing pumps is illustrated in Fig. 4.

The capability to operate multiple PATs modules is highly relevant for locations where the water supply can fluctuate. Unlike conventional turbines, PATs do not have adjustable guide vanes for adapting to fluctuations in the water supply and this is perceived as a drawback to their use [8]. By employing a number of differently sized units to distribute the total volume of water available, this difficulty can be overcome [9].

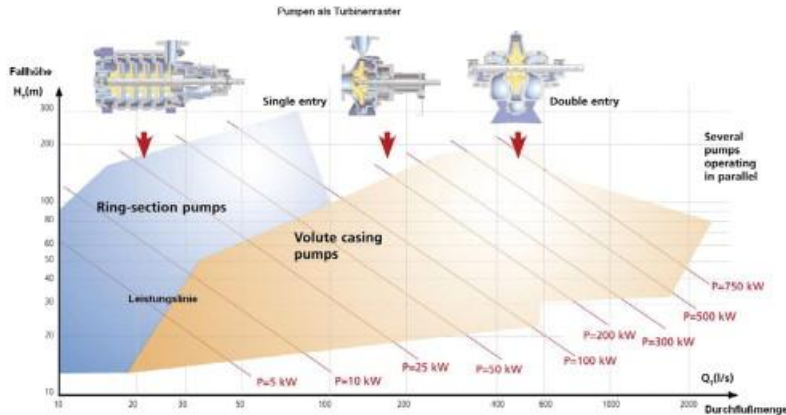


Fig. 4. Application range for ring section and volute casing PATs.

The case study considerations include PAT installation cost of 800€/kW, installed power 150kW, lifetime of 20 years, interest rate of 6%, 70% bank loan (30% equity) of initial investment with rate 7% for 10 years, 5000€/year operational and maintenance costs. Table 2 presents the evaluation of this investment according to NPV, IRR and benefit to cost B/C ratio. The results of Table 1 prove the economic viability of this project.

Table 1. Financial evaluation of a PAT system installation

Case study	NPV	IRR	B/C ratio
PAT system, net metering, Miloniana pumping station	144,601€	33.5%	5.02

V. Conclusions

This paper showed the application of various energy management and efficiency improvement techniques in order to improve the energy management of water distribution system of Western Crete. The examined water distribution system is an ideal case for the application of all the above measures. The results show that significant reduction of electricity cost can be achieved in all cases.

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