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Municipal Water Supply Pumping Station Energy Efficiency Improvement Using Batteries

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Abstract **-** Electrical power distribution networks are inherently susceptible to service interruptions, such as those caused by grid faults. Maintaining the operational continuity of critical infrastructure, particularly isolated water supply pumping stations, requires robust backup power solutions. Uninterruptible Power Supply (UPS) systems commonly utilize Battery Energy Storage Systems (BESS), which, in addition to providing backup power, can facilitate energy arbitrage to reduce electricity costs. This study examines the feasibility of commercially available BESS for ensuring the autonomous operation of a water pumping station equipped with a main electric motor pump drive rated at 330 kW. Using historical municipal water consumption data for the Cres-Lošinj archipelago, obtained from publicly available sources, simulations were conducted to model the operation of pumping stations with and without BESS integration during continuous operation. The resulting data provides a comprehensive analysis of potential energy savings, cost reductions, and estimated return on investment (ROI).

Index Terms - Battery, Water pumping station, Simulation, Energy savings, Return-on-investment

I INTRODUCTION

Maintaining a continuous and reliable supply of potable water is paramount for public health, sanitation, and fire suppression in any municipality [1-3]. Water distribution systems rely on electrically powered pumping stations, which are crucial for ensuring a stable supply. However, electrical grids are vulnerable to disruptions caused by extreme weather events, equipment failures, and cyberattacks, posing a significant threat to these facilities [4-6]. Consequently, ensuring the resilience of water pumping stations against power outages is a critical aspect of urban infrastructure planning and management.

Traditionally, diesel generators have been the predominant backup power solution for water pumping stations [7, 8]. While effective, they present several drawbacks, including high operating and maintenance costs, noise pollution, greenhouse gas emissions, and logistical challenges related to fuel storage and replenishment. Additionally, diesel fuel spills pose an environmental risk [9, 10]. Reliance on fossil fuels for backup power undermines efforts toward sustainable and environmentally friendly urban infrastructure.

In recent years, battery energy storage systems (BESS) have emerged as a promising alternative to conventional backup power solutions [11-14]. BESS offers several advantages over diesel generators, including rapid response times, improved energy efficiency, reduced environmental impact, and the potential for grid ancillary services [15-17]. However, the adoption of BESS in municipal water pumping stations has been relatively slow due to factors such as high initial investment costs, perceived complexity, and concerns about long-term performance and reliability [18, 19].

This study investigates the feasibility and benefits of integrating BESS into municipal water supply pumping stations to enhance energy efficiency and resilience. The study considers factors such as electricity pricing, water demand patterns, and battery performance characteristics. By using historical water consumption data within different simulation scenarios, the aim is to quantify the potential for energy cost savings, return on investment, and improved operational reliability.

The structure of this paper is described in the following way. Section 2 provides a comprehensive overview of the municipal water supply system, detailing its key components and analyzing historical water consumption patterns alongside the corresponding electricity pricing framework utilized in this study. Section 3 introduces the proposed BESS solution, specifically focusing on lithium-iron- phosphate (LiFePO4) technology. This section also elaborates on the parameterization of the BESS based on the manufacturer data and an established battery power versus state-of-charge (SoC) model from [20]. Additionally, a battery aging model is presented, which estimates the equivalent number of charge/discharge cycles to assess the long-term viability of the proposed BESS implementation. Section 4 discusses the control strategies employed for pump system operation, ensuring optimal water distribution efficiency. Section 5 presents simulation results across multiple operational scenarios, ranging from daily functionality assessments to a long-term analysis aimed at identifying electricity pricing conditions and battery system costs under which the ROI remains feasible over the anticipated 16-year lifespan of the BESS. The findings derived from these simulations are critically analyzed and discussed in section 5, while section 6 provides concluding remarks, acknowledges study limitations, and outlines potential avenues for future research.

II MUNICIPAL WATER SUPPLY SYSTEM DESCRIPTION

The water supply system of the islands of Cres and Lošinj is managed by the Water Supply and Drainage Company, Cres Mali Lošinj d.o.o., owned by the cities of Cres and Mali Lošinj.

The system supplies potable water to most of the population, with some settlements and small islands relying on water tankers [21]. The primary freshwater source is the Vrana Lake (Fig. 1), with absolute depth of 74.5 meters, average water level of about 13 meters above sea level, and the deepest part of the lakebed lying about 61.5 meters below sea level.

Figure 1. Photograph of Vrana Lake crypto-depression.

A water pumping station is stationed on the Vrana Lake, which pumps water from the lake and transports it to the Vrana 1 and Vrana 2 water reservoirs (with capacities V_1 = 1000 m^3 and V_2 = 2500 m^3, respectively, and total capacity V_{tot} = 3500 m^3) at the altitude of 220 meters above sea level, with water inlet level being about 10 meters above sea level, as shown by the schematic representation of the water pumping system in Fig. 2. From these two water reservoirs water is brought by gravity to all settlements on the northern and southern branches of the water supply pipelines. The pumping station is equipped with 330 kW variable-speed drives (VSDs) for powering the water pumps, with one of these VSDs assumed to be in use during operation.

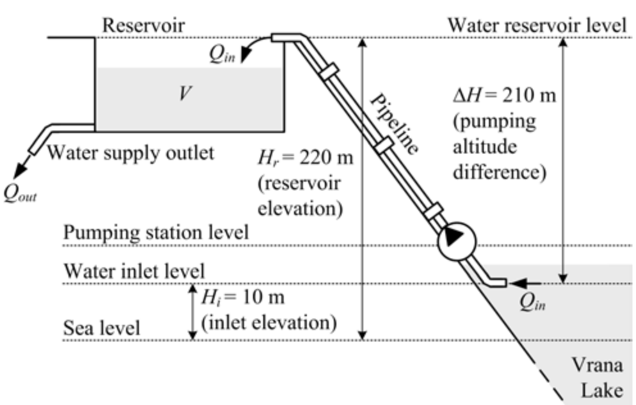

Figure 2. Schematic representation of water pumping system

Based on the schematic representation in Fig. 2, the reservoir filling (water accumulation) process model reads as follows:

$$dV/dt = \dot{V} = Q_{in} - Q_{out}, \tag{1}$$

where V is the reservoir water volume, and Q_{in} and Q_{out} are reservoir input and output water volume flow rates, respectively.

The pumping station input flow Q_{in} vs. pump power P_{pump} static relationship is determined based on the required flow rate for the altitude difference (pumping height) ΔH as follows:

$$Q_{in} = (\rho g \Delta H)^{-1} P_{pump} = K_{pump} P_{pump}, \tag{2}$$

where ρ is the water density (1000 kg/m^3), g = 9.81 m/s^2 is the free-fall acceleration due to gravity, while K_{pump} represents the proportionality factor between the flow rate and pump mechanical power supplied by the pump electrical drive (VSD).

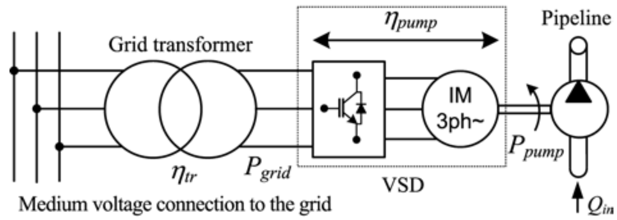

Figure 3. Pump electrical drive schematic representation.

Figure 3 shows the pump station electrical system connection with respect to the medium-voltage (11 kV) main grid and the connection of the pump electrical drive to the low-voltage 0.4 kV side. Based on the electrical system representation in Fig. 3, the relationship between the mechanical power of the pump electrical drive and the electrical power supply to the VSD is defined by the pump VSD efficiency η_{pump} as follows:

$$P_{pump} = \eta_{pump} P_{grid}, \tag{3}$$

which needs to account for the grid transformer efficiency η_{tr} to obtain the total power drawn from the medium-voltage grid P_{mv}:

$$P_{grid} = \eta_{tr} P_{mv}, \tag{4}$$

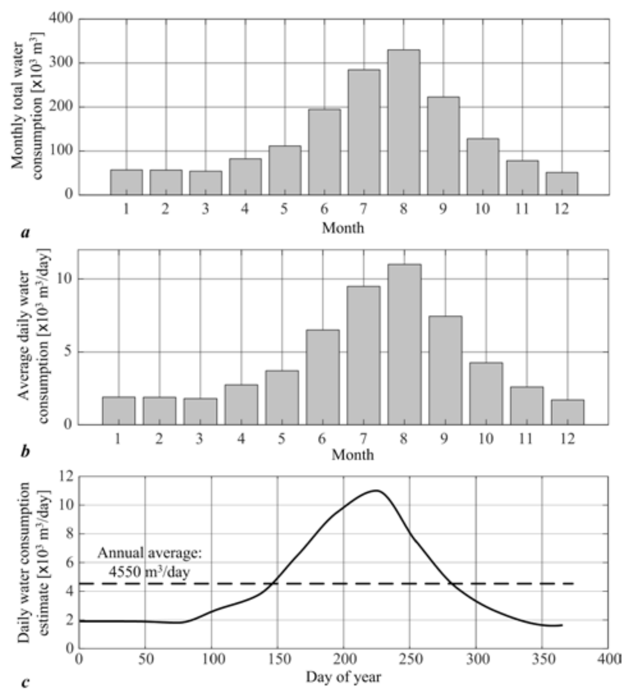

Figure 4. Cres-Lošinj water supply system aggregated monthly water consumption data (a), average daily consumption (b), and estimated daily water consumption throughout the year (c)

The aggregated water consumption data for the Cres-Lošinj water supply system from [22], representing the total water consumed per month for the year 2023, are shown in Fig. 4a. Based on the data in Fig. 3a, average daily water consumption data for each month are estimated as shown in Fig. 4b. Finally, by interpolating the data in Fig. 4b by means of cubic splines, the daily water consumption data for each day of the year is estimated, and the results are shown in Fig. 4c. These estimates are subsequently used for the analysis of the water supply system operation, including seasonal variability of water consumption.

On the other hand, municipal water consumption also exhibits daily fluctuations, initially increasing during the morning, and subsequently decreasing during the late afternoon and in the evening [23]. This daily variability of water consumption (flowrate) can be modeled by a simplified daily water consumption characteristic shown in Fig. 5. The characteristic is determined by only two parameters: average water flow rate Q_0, and the flowrate variation coefficient α_s (Fig. 5).

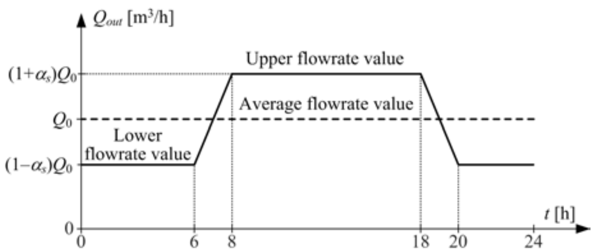

Figure 5. Model of daily water flowrate variations

III Battery Energy Storage System

A commercial 500 kWh BESS turnkey solution (Fig. 6) based on $LiFePO_4$ battery cell technology equipped with integrated grid inverter [24] is considered in this study due to the following inherent advantages:

(i) *Compactness and portability* of a single BESS unit being encased in a standard 20 ft. (6 m) shipping container;

(ii) *Integrated AC grid inverter* facilitating straightforward connection to the local three-phase 230V/400V AC grid;

(iii) *Modularity*, i.e. easy augmentation of the BESS by simply connecting more than one containerized BESS system to the local AC grid;

(iv) *Inherent operational safety* of the $LiFePO_4$ batteries, due to their wide operating temperature margins [25].

Figure 6. Considered $LiFePO_4$ BESS turnkey solution [24]

Since BESS manufacturer's technical data is not provided by the wholesaler (see [24]), the parameters of the BESS need to be determined using the existing experimental data for the standard 3.2V/100Ah $LiFePO_4$ battery cell [26], and upscaling the battery cell model to fit the declared energy storage capacity of the BESS turnkey solution from [24]. For that purpose, the battery cell is modeled by the so-called quasi-static Thevenin model, characterized by its open-circuit voltage and internal resistance:

$$u_{b,c} = U_{oc,c}(\xi_c) - i_{b,c}R_{s,c}(i_{b,c}, \xi_c), \tag{5}$$

where $u_{b,c}$ is the battery cell terminal voltage, $U_{oc,c}$ is the cell open-circuit voltage (OCV), $R_{s,c}$ is the cell series resistance, $i_{b,c}$ is the battery cell current, with minus sign in the above equation denoting positive current direction ($i_{b,c} > 0$) for discharging operation, and vice versa, and ξ_c is the cell state-of-charge (SoC):

$$\xi_c = -\frac{1}{Q_{b,c}}\int i_{b,c}dt, \tag{6}$$

where $Q_{b,c}$ is the battery cell charge capacity.

Figure 7 shows the static characteristics of the $LiFePO_4$ battery cell Thevenin model parameters with respect to cell state-of-charge, which have been previously recorded in [27]. While the Thevenin model parameters remain relatively constant-valued across a wide range of battery cell SoC, notable variations are observed at the extreme ends of the SoC range (i.e. when the cell is either deeply discharged or fully charged). The rather flat OCV vs. SoC characteristic and low internal resistance of the $LiFePO_4$ cell results in relatively small battery terminal voltage variations during its operation, which is beneficial from the standpoint of the integrated inverter voltage control with respect to the grid.

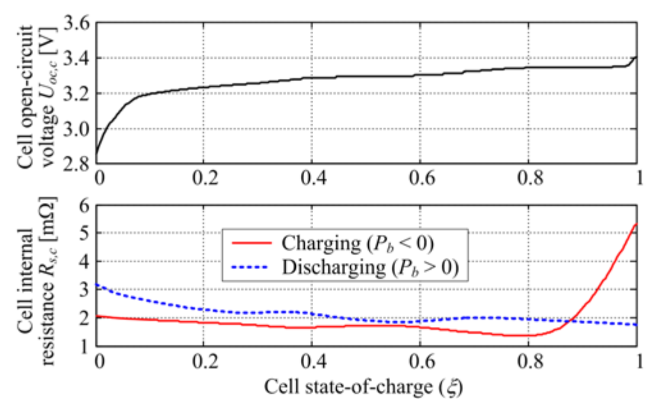

Figure 7. $LiFePO_4$ battery cell Thevenin model parameters [20]

Figure 8. shows the simplified BESS internal arrangement comprising of N_S series connections (stacks) of cells and N_P parallel branches, which is convenient from the standpoint of battery cell model up-scaling to the battery system level. The number of series-connected cells (series) stacks for the nominal cell voltage is given as follows:

$$N_S = \frac{U_{bn}}{U_{cn}}, \tag{7}$$

which yields N_S = 225 for the particular BESS with assumed nominal DC-link voltage U_{bn} = 720 V and the particular $LiFePO_4$ cell whose declared nominal voltage is U_{cn} = 3.2 V [26]

The number of parallel stacks is determined based on the single cell charge capacity, nominal battery voltage and energy storage capacity as follows:

$$N_P = \frac{W_{st}}{U_{bn}Q_{b,c}}, \tag{8}$$

which, after rounding, yields N_P = 7 parallel branches for the BESS with U_{bn} = 720 V, and individual cell charge capacity $Q_{b,c}$ = 100 Ah and overall energy storage capacity W_{st} = 500 kWh.

Using thus-obtained numbers of series stacks N_S and parallel branches N_P, the parameters of the $LiFePO_4$ battery cell Thevenin model are scaled up to the BESS level (Fig. 9) as follows:

$$U_{oc}(\xi) = N_S U_{oc,c}(\xi_c), \tag{9}$$

$$R_s(\xi) = \frac{N_S}{N_P} R_{s,c}(\xi_c), \tag{10}$$

$$Q_b = N_P Q_{b,c}, \tag{11}$$

wherein the BESS state-of-charge ξ is calculated according to the following first-order nonlinear model [20]:

$$\frac{d\xi}{dt} = \frac{\sqrt{U_{oc}^2(\xi) - 4R_s(\xi,P_b)P_b} - U_{oc}(\xi)}{2R_s(\xi,P_b)Q_b}. \tag{12}$$

where $P_b > 0$ represents the discharging power and vice versa.

Figure 9 shows the schematic representation of the pump electrical drive augmented with the BESS. In this configuration, BESS can be charged independently of the pump electrical drive operation, using grid electricity during lower electricity tariff intervals, and subsequently being used to supply the pump drive during lower electricity tariff intervals. Note that the utilization of BESS is also characterized by round-trip losses due to inherent losses within the battery (battery internal resistance losses), and the efficiency of the BESS inverter.

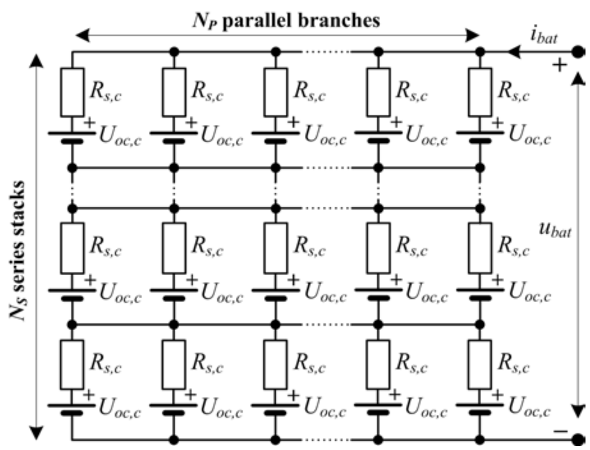

Figure 8. Simplified internal structure of $LiFePO_4$ battery, comprising N_S series stacks and N_P parallel branches

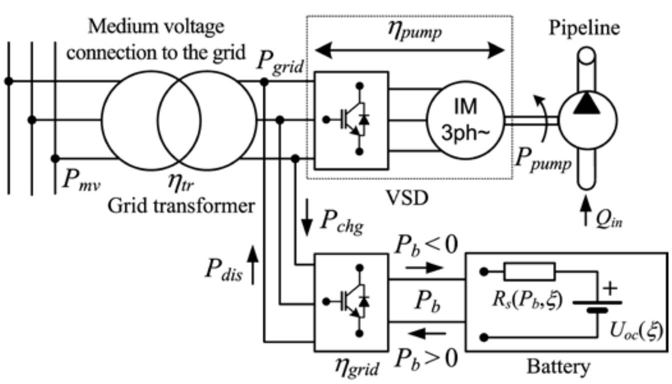

Figure 9. Schematic representation of pump electrical drive augmented with battery energy storage

Battery lifespan is also an important quantity because it determines whether return on investment (ROI) is feasible within the battery system lifetime. Assuming that the battery is fully charged and subsequently discharged to the specified depth-of-discharge (DoD) level (DoD = 80% is assumed herein) once every day, the considered battery, characterized by N_{cyc} = 6000 charge/discharge cycles [24] would be characterized by the lifespan of 16.43 years, which is rounded down to 16 years.

To quantify the BESS deterioration due to repeated charging and discharging cycles, battery state-of-health (SoH) is defined as follows [28]:

$$\text{SoH} = 1 - \frac{\text{DoD}}{2Q_b N_{cyc}} \int |i_b| dt, \tag{13}$$

which can be used to update the parameters of the BESS Thevenin model in the following way, thus signifying BESS series resistance increase and charge capacity decrease during the rather slow battery aging process:

$$R_s(\xi, \text{SoH}) = R_s(\xi)(2 - \text{SoH}), \tag{14}$$

$$Q_b(\text{SOH}) = Q_b(0.8 + 0.2 \cdot \text{SoH}). \tag{15}$$

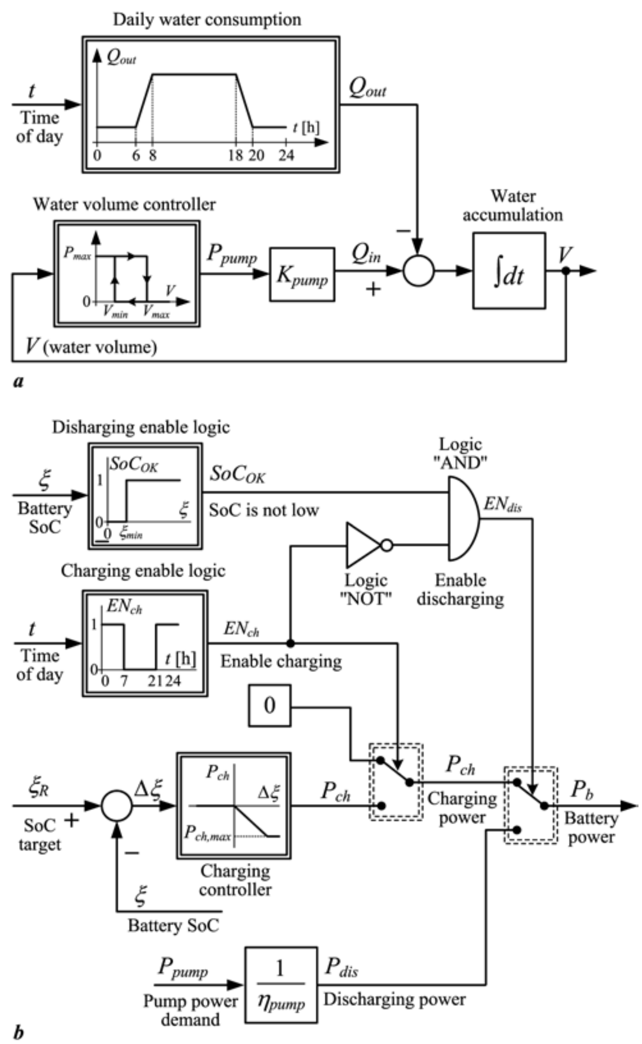

Figure 10. Schematic representations of water accumulation volume control system (a) and BESS charging and discharging control system (b)

IV Pump System Control Strategies

Figure 10 illustrates the control strategies of water accumulation volume control and the battery charging and discharging. The water accumulation volume V is controlled by a simple relay controller (Fig. 10a) which maintains the accumulated water volume between its maximum value (V_{max} = 0.95V_{tot}) and the minimum allowed water volume (V_{min} = 0.25V_{tot}). It turns on the main water pump and operates it at rated power (P_{max}) when the water volume falls below the lower threshold (V_{min}), with pumping being maintained until the water volume reaches the upper threshold (V_{max}). Figure 10b shows the control logic for the charging and discharging of the BESS, wherein battery charging is enabled only during the lower electricity tariff (which is set herein from 21h to 7h, Fig. 10b). Battery charging is based on a simplified proportional-type (P) SoC controller, whose characteristics and design have been adopted from [20]. Battery discharging is enabled when the battery SoC is above the lower SoC threshold ξ_{min} and during the higher electricity tariff (i.e. from 7h to 21h). In this way, load is shifted from the electricity grid to the battery, thus temporarily avoiding consumption of electrical power during higher tariff, at least until the battery SoC falls below the lower threshold ξ_{min}, after which grid electrical power needs to be used instead.

V Simulation Results

All simulations of the water pumping facility have been carried out for five characteristic scenarios that include operation without BESS, and operation with one, two, three and four 500 kWh BESS containers (that is, for 500 kWh, 1000 kWh, 1500 kWh and 2000 kWh storage capacity, respectively). Moreover, two characteristic cases have been considered in this study: (i) a single day of facility operation, and (ii) 16-year operation of the facility without and with BESS for energy price arbitrage, using the water consumption data from Figs. 4 and 5. Fixed efficiencies of the pump electrical drive and the grid inverter η_{pump} = 0.925 and η_{grid} = 0.95 have been used in all scenarios.

Figure 11 shows the simulation results for a single day of operation of the water pumping facility characterized by average water consumption rates (average output flowrates) of Q_0 = {150 m^3/h, 250 m^3/h, 350 m^3/h and 450 m^3/h} and flowrate variation factor α_s = 0.4 (see Fig. 5). All simulations have been run with water accumulation being near-full (i.e. at 95% of the maximum volume V_{max}). The results show that in all cases water accumulation is emptied faster during the daily (higher) tariff, which mandates the engagement of the BESS which provides power to the pumps and ensures pumping continuity until the BESS SoC reaches the lower threshold ξ_{min}. Once the battery is discharged to $\xi = \xi_{min}$, and high-tariff operation is still indicated, the power needs to be supplied from the utility grid. Obviously, higher water consumption rates tend to empty the water accumulation more quickly, and larger-capacity BESS tends to offset the grid power consumption during the high tariff operation for a longer period. However, even the highest-capacity BESS considered herein (2000 kWh) is unable to cover for the whole period of high-tariff operation, especially under increased water consumption conditions during the day hours (i.e. from 6h to 20h, see Fig 4c). Further increase in the BESS capacity (increase of the number of battery containers) could eventually resolve this issue, but it would also result in high initial investments (capital expenses, CapEx) and operational expenses (OpEx) of the BESS, as will be shown later.

Figures 12 and 13 show the results of simulations of the water pumping facility without and with BESS during the anticipated 16-year lifespan of the BESS [24], with the cumulative electricity cost calculated based on the fixed electricity costs during the higher and lower tariffs. According to [29, 30] the current total tariffs (including transmission and distribution costs) are valid for the commercial use in the Republic of Croatia for the case of medium voltage connection to the distribution grid:

- Higher tariff electricity cost C_{HT} = 0.166681 EUR/kWh.
- Lower tariff electricity cost C_{LT} = 0.096390 EUR/kWh.

Based on the results of energy consumption simulation analysis shown in Fig. 12a, the total electrical energy costs during 16-year operation have been estimated using the simple formula:

$$C_{tot} = C_{HT}E_{HT} + C_{LT}E_{LT}, \quad (16)$$

where E_{HT} and E_{LT} are the pumping facility high-tariff and low-tariff electrical energy consumptions, respectively.

Based on thus-obtained total electricity cost, the electricity cost reduction in the case of BESS utilization is obtained by subtracting the total electricity cost in the case of BESS use from the electricity cost when BESS is not utilized:

$$\Delta C_E = C_{tot}(\text{w/o BESS}) - C_{tot}(\text{w/ BESS}). \quad (17)$$

Figure 12 also shows that utilization of a BESS with higher storage capacity results in more substantial electricity cost reductions and vice versa, and the electricity cost reduction is proportional to the installed storage capacity of the BESS.

Figure 13 shows the simulation results of the battery SoH during the anticipated 16-year period of BESS operation. As expected, battery SoH deteriorates due to battery exploitation (according to equation (13)), because the battery is periodically charged and discharged during the facility operation. However, battery SoH at the end of the 16-year exploitation period is moderately lower compared to the initial SoH (by about 35%), which points out to under-utilization of the BESS under the considered scenario. More precisely, in the first 90 days and the last 30 days of a calendar year, the municipal water consumption is quite low (see Fig. 5), so it is expected that the water accumulation can be filled up to the maximum level during the lower tariff operation using electrical power from the grid, and it can supply the water demand without refilling during the day (consumption of about 2000 m^3/day is much less than the total water accumulation volume V_{tot} = 3500 m^3). In that case, BESS would be minimally utilized for water pumping during the daytime under the higher electricity tariffs. Consequently, the BESS would be under-utilized for about 1/3 of the year, which ultimately results in less SoH degradation. This also means that the battery could be used even beyond its estimated end-of-life date. However, such second-life usage of the BESS is beyond the scope of this work.

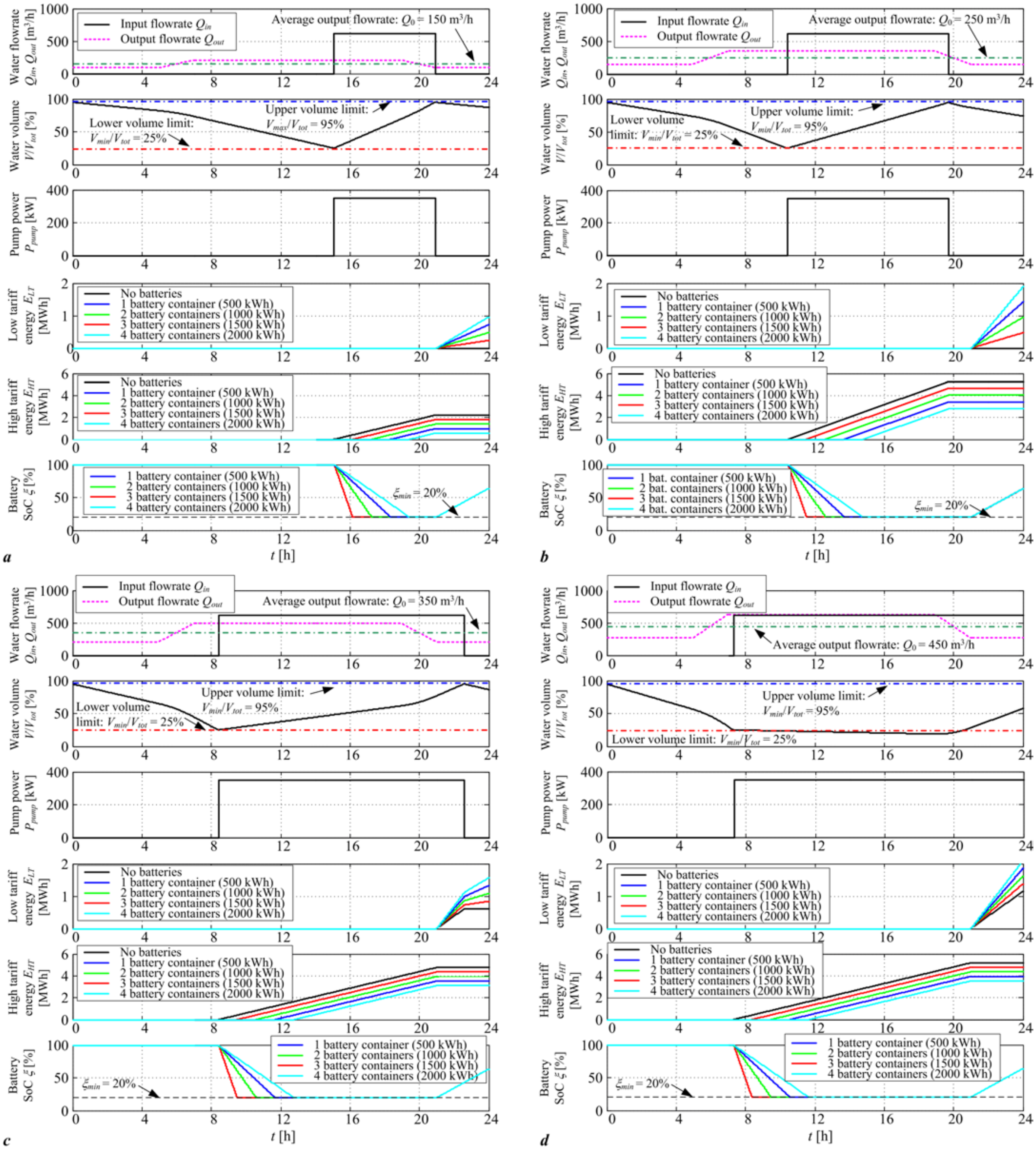

Figure 11. Results of simulations of single day water pumping facility operation without and with BESS for average water

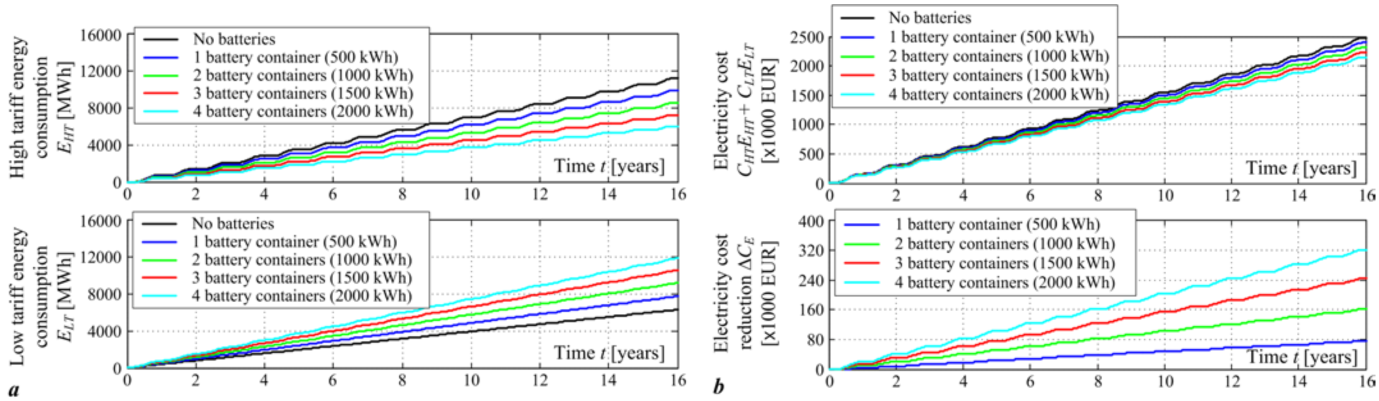

Figure 12. Results of water pumping facility energy consumption without and with BESS (a) and electricity costs and cost reductions for different BESS utilization scenarios (b)

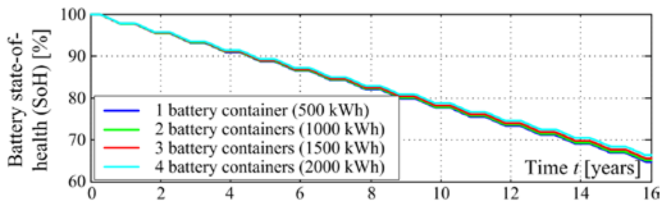

Figure 13. Battery state-of-health degradation for the 16-year BESS utilization scenario

Table 1. CapEx and OpEx for considered BESS configurations.

Number of containers	CapEx	OpEx (16 years)	Total cost of ownership
1	100000 EUR	40000 EUR	140000 EUR
2	200000 EUR	80000 EUR	280000 EUR
3	300000 EUR	120000 EUR	420000 EUR
4	400000 EUR	160000 EUR	560000 EUR

Finally, the estimated electricity reduction costs need to be leveraged against the BESS capital and operational expenses (CapEx and OpEx) using the available battery system cost data. According to [24], the wholesale cost of the grid-ready BESS in question is less than 80000 EUR per a single 500 kWh BESS. After adjusting this cost with respect to value-added tax (VAT) in Croatia (25% VAT rate applies herein), the overall cost of a single 500 kWh BESS container is estimated to 100000 EUR (it may also include shipping costs according to [24]), which represents the CapEx for a single-container 500 kWh BESS. This CapEx amounts to the specific cost of 200 EUR per kWh of energy storage, which agrees with the results presented in [31]. Annual operational costs for a commercial BESS are estimated at 2.5% of CapEx according to [31-33]. This results in the annual OpEx of 2500 EUR/year for a single 500 kWh BESS container, and the cumulative OpEx of 40000 EUR for the anticipated 16-year BESS exploitation period. Table 1 summarizes these results for the cases of one, two, three and four BESS considered herein. By comparing these results with the estimated electricity costs based on the BESS utilization and electricity tariffs (equations (16) and (17)), it is evident that under current tariffs none of the BESS configurations considered herein would break even at the end of the 16-year exploitation period considered herein. Therefore, additional analysis is carried out to find the range of high-tariff and low-tariff electricity costs and battery system costs, which would result in feasible return on investment period (ROI) that is less than the 16-year BESS exploitation period.

Figures 14 and 15 show the results of cost-benefit analysis for a wide range of higher and lower electricity tariff values and for three scenarios related to BESS costs, i.e. the nominal (current) BESS cost based on battery system prices obtained from [24] (Fig. 14), and for BESS costs reduced from nominal costs by 40% (Fig. 15). The latter scenario takes into account the realistic declining trend of battery storage system costs presented in [31-33], wherein 40% lower commercial and utility-scale battery system prices are anticipated in the next five to ten years. The results in Figs. 14 and 15 can be summarized as follows:

- For the nominal case of BESS purchase costs (Fig. 14), characterized by 100000 EUR per 500 kWh BESS container unit, it would only be possible to achieve ROI within very narrow high tariff vs. low tariff electricity cost margins. Namely, ROI periods between 10 and 16 years are theoretically achievable only if high tariffs are kept higher than the current rates (well above 0.16 EUR/kWh) while low electricity tariffs would be consistently below the current rates (i.e. well below 0.09 EUR/kWh). Consequently, the currently valid high-tariff and low-tariff electricity costs cannot yield ROI within the 16-year period for any of the considered BESS utilization scenarios (number of BESS units), as indicated earlier.

- In the case of 40% BESS cost reduction (Fig. 15), proportional reduction of both CapEx and OpEx, and ultimately lower total cost of ownership is achieved. Thus, the margin for achieving ROI within the 16-year BESS calendar life is significantly widened. Moreover, in that case even the current state of electricity tariffs can yield a ROI period of about 12 years. Since the margins for achieving ROI are now significantly widened, ROI periods may be as short as 6 years at the extremes of electrical energy costs (i.e. at 0.21 EUR/kWh for high tariff and 0.06 EUR/kWh for low tariff). However, it would be more realistic to estimate the ROI within the mid-ranges of electricity tariffs, which would yield ROI periods of about 10 years in that case.

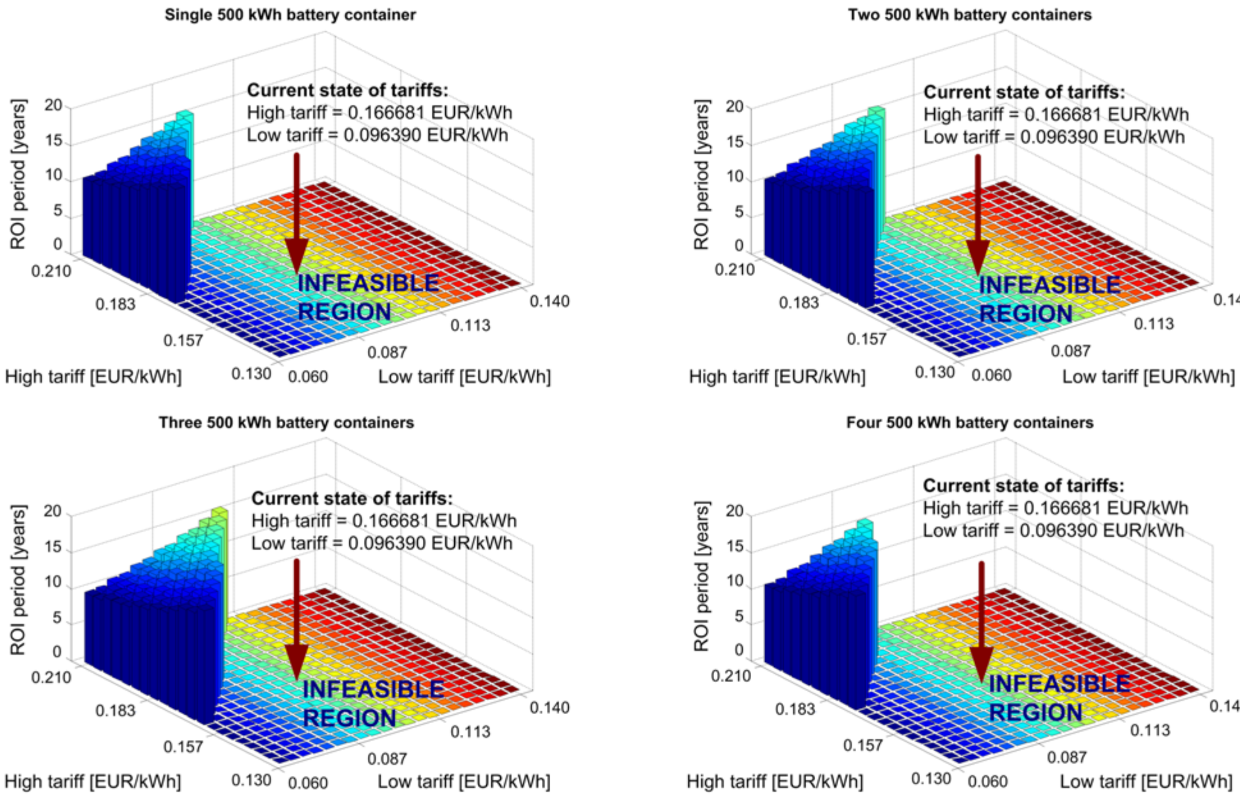

Figure 14. Results of estimation of ROI period for different BESS configurations (1-4 battery system containers) for nominal battery system container purchase cost of 100000 EUR per 500 kWh of battery energy storage (VAT included)

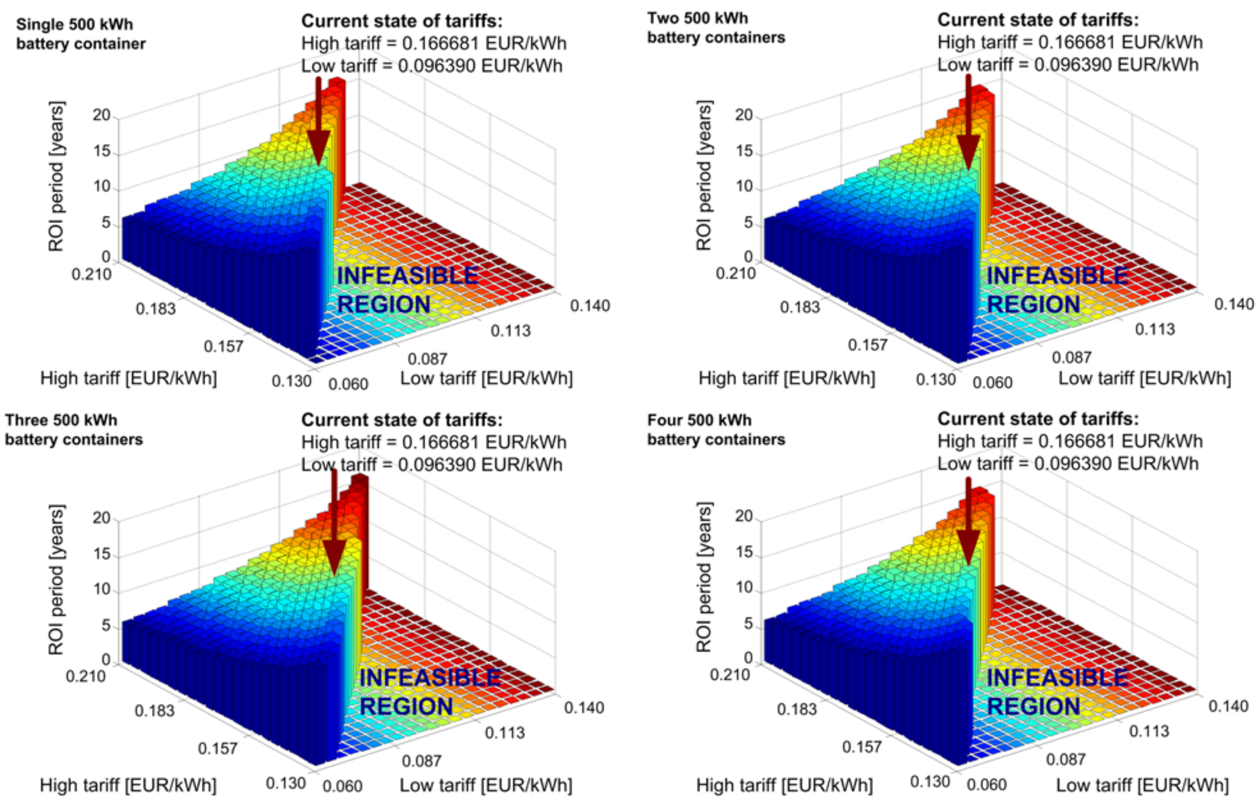

Figure 15. Results of estimation of ROI period for different BESS configurations (1-4 battery system containers) for reduced battery system container purchase cost of 60000 EUR per 500 kWh of battery energy storage (VAT included)

It should be noted herein that the above analysis is based on relatively simple electricity cost reduction vs. investment model, which does not account for electricity tariffs variability, effects of inflation, and various exigent costs such as those related to unscheduled maintenance and other unforeseen events. Even though these issues have not been addressed herein, they can be further researched in future work on this subject.

VI Conclusion

This paper has presented the analysis of a BESS integrated with a municipal water supply pumping station to improve its energy efficiency and reduce its electric energy costs. The analysis focused on utilizing BESS for energy arbitrage and shifting energy consumption from high-tariff to low-tariff periods while ensuring continuous operation of the water pumping station. The study specifically examined the potential benefits of BESS integration for a pumping station serving the Cres-Lošinj archipelago in Croatia.

In order to evaluate the effectiveness of BESS integration, a straightforward simulation model comprising only two state variables (accumulated water volume and battery SoC) has been developed, which also incorporates historical water consumption data for the Cres-Lošinj archipelago, electricity pricing schemes, and a $LiFePO_4$ battery model with realistic aging characteristics. The model simulated the operation of the pumping station under various scenarios, including different BESS capacities and electricity tariff structures. Such an approach allowed for a comprehensive assessment of energy savings, cost reductions, and return on investment (ROI) over the anticipated 16-year lifespan of the BESS.

The simulation results have pointed out that BESS integration can indeed lead to significant reductions in electricity costs by enabling energy arbitrage. However, the economic viability of BESS deployment is highly sensitive to factors such as BESS capital and operational expenses, electricity tariff structures, and battery degradation. Under current market conditions and electricity tariffs, the analysis showed that achieving a reasonable ROI within the BESS lifespan requires about 40% reduction in BESS costs. Alternatively, a significant increase in the difference between high and low electricity tariffs may also produce very favorable results in terms of ROI, but these electricity pricing schemes are unlikely to occur in the current electricity markets.

Future research will focus on expanding the proposed model to include variable electricity tariffs and effects of inflation, as well as the potential of integrating renewable energy sources, such as solar photovoltaic systems. Further research into BESS second-life applications may also be considered in the future work.

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Poboljšanje energetske efikasnosti primenom baterija za komunalnu pumpnu stanicu za vodosnabdevanje

Rezime *- Elektrodistributivne mreže su inherentno podložne prekidima usluga, kao što su kvarovi na mreži. Održavanje kontinuiteta rada kritične infrastrukture, posebno izolovanih pumpnih stanica za vodosnabdevanje, zahteva robusna rešenja za rezervno napajanje. Sistemi za besprekidno napajanje (UPS) obično koriste sisteme za skladištenje energije baterija (BESS), koji pored obezbeđivanja rezervnog napajanja mogu omogućiti arbitražu energije radi smanjenja troškova električne energije. Ova studija istražuje izvodljivost komercijalno dostupnog BESS-a za obezbeđivanje autonomnog rada pumpne stanice za vodu, opremljene glavnim elektromotornim pogonom pumpe snage 330 kW. Koristeći istorijske podatke o komunalnoj potrošnji vode za Cresko-Lošinjski arhipelag, dobijene iz javno dostupnih izvora, sprovedene su simulacije za modeliranje rada pumpnih stanica sa i bez BESS integracije tokom kontinuiranog rada. Dobijeni podaci pružaju sveobuhvatnu analizu potencijalnih ušteda energije, smanjenja troškova i procenjenog povraćaja investicije (ROI).*

Ključne reči *- baterija, pumpna stanica, simulacija, ušteda energije, povrat investicije*