URBAN WATER SUPPLY GENERATED BY PV ENERGY

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Abstract

This work describes the application of a solar photovoltaic (PV) system in the urban water sector, especially related to water pumping. The Sun and gravity are two basic natural and renewable sources of energy. It is pure natural energy that has no harmful effects on the environment, spread everywhere and available for use. Solar photovoltaic systems can be successfully applied in many areas in water sector and especially in water supply. Due to the importance of water supply for urban area sustainability, and due to a significant energy consumer whose price is increasing each day, alternative solutions to power systems are sought in the form of water supply systems, such as a PV generator. It is a complex system, whose functioning is defined by a whole range of factors: climate, soil, hydrological, water consumption in the cities etc. It can be optimized only with the application of a systematic approach and the use of adequate tools. The paper will show that the solar photovoltaic systems are efficient in use in urban water sector.

Keywords – photovoltaic pumping, PV generator, water supply, service reservoir, optimal sizing, energy policy

1. Introduction

Urban Water Systems (UWS) are natural, modified and human-built elements of the urban water cycle that can be found in towns and cities. The systems provide water to support human life, hygiene, health, safety, recreation and amenities.

The natural system includes the local and regional water resources, while a built system includes water intake, water supply pipes, pump stations, service reservoirs, distribution networks, water treatment plants, swage network, channels, drains, wastewater treatment plants, pump stations and outfalls. The built system is a part of the broader urban infrastructure system. Water services are functions provided by the built system of Water Supply (WS), wastewater and storm water infrastructure.

Fig. 1 depicts typical water supply management processes indicating location and transfer elements. The elements of the water supply system are divided in two major types:

- location elements; i.e. physical elements in which water is altered in quantity and quality or consumed (service reservoirs, treatment plants);
- transfer subsystems that connect or feed the location systems (pipes, pump stations, etc.).

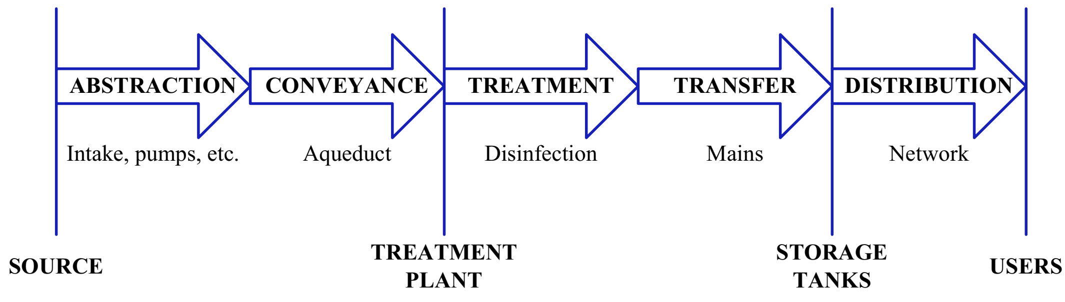

Fig. 1: Typical elements of the water supply management system

The existing situation in many areas in the World requires a shift from the existing linear trends in resources exploitation to sustainable urban water management which will be a part of the ongoing trends towards sustainable cities. Urban water management should contribute to the goal of sustainable urban development, including resources management, like water, energy and other resources.

The main input of the urban water system is water. But the water cycle is not the only input and process of the system. System work also requires materials, energy, labour, capital and other resources. The most significant resource besides water is energy. Urban water supply system is a significant user of energy, since all water has to be brought to a higher elevation in order to produce the required pressures to users. Without energy, the system cannot work and thus provide vital services for the people in the cities. That is why reliable energy sources are a prerequisite for reliable water supply, or sustainable energy source is a prerequisite for sustainable water supply and achievement of strategic goal - sustainable cities. By using green energy, cities minimize energy use from classical sources and reduce the CO_2 output as well as the use of other resources.

Generally, the largest energy user is the Main Pump Station (MPS) of the system, which pumps water into service reservoirs. It is also the most important pump station, since water from the reservoirs flows to the user by gravity. That is why energy supply to this pump station is a priority. However, large water supply systems may have several such pumping stations, as well as reservoirs, while smaller cities and systems in general cases require only one pump station and reservoirs.

Different intermittent renewable energy sources (RES) (wind, solar thermal (ST), (PV) will have different productivity and production of energy (Patel, 1999). Input solar energy in the largest part of the day coincides with the dynamics of living in towns and hence the water needs. This means that energy production and water consumption are easier to adjust by using solar energy (especially PV technology) than other RES. PV generator uses less technological processes and elements in transformation of external energy in the system than ST plant and does not use fossil energy as ST to superheat solar generated steam.

An important factor in the proposed application is the availability of primary energy for operation of the power plant space. Solar energy is generally available in all parts of the Earth where people live, which is not the case with the usable wind energy, because it depends on the location and generally suitable sites are in open areas only. This means that the use of the Sun enables a wider use of PV power plant for water supply.

Another important fact is that, in principle, PV energy can be produced every day in many locations, which is the basic prerequisite for the application of the water supply of a town. Specifically, the daily supply of energy provides daily balancing of water in the city reservoir, which is standard practice in sizing the city reservoirs. A multi-day lack of energy would require the construction of a water reservoir of much larger capacity to ensure the supply in the period when there is no water inflow into the reservoir or use of conventional energy sources.

This issue has already been partially addressed in the literature (Bakelli et al., 2011; Ghoneim, 2006; Hamidat and Benyoucef, 2009). In fact, the use of PV generators for pumping systems has for some time been discussed (Kenna and Gillett, 1985). However, at present there are no significant publications on a more thorough consideration of possible applications of PV generators in solving the energy supply of urban water supply systems. The paper describes the proposed solution for sustainable water supply, its basic features and methodology of sizing and selection of the power of the PV generator P_{el} and volume of service reservoirs V.

2. Concept technological characteristics

The proposed concept of green energy supply to MPS is simple, Fig 2. The concept uses~~,~~ PV power plant that operates together with water supply service reservoirs in order to provide continuous water supply to the consumer. During the day solar energy is primarily used to supply energy to MPS which pumps water into reservoirs. Water from the reservoirs is used according to the consumer needs. The service reservoir should be designed to have sufficient capacity to balance the pumped water and water needs. The PV power plant should have adequate power to supply the pump station with energy throughout the whole planning period. However, PV energy may be parallely used for direct supply to the local grid and other users, when PV generator has sufficient capacity and when the reservoir is full of water. The general objective of the system development is to provide continuous water supply to consumers over a long period (one critical year) with best compromise alternative of the size of the PV power plant and service reservoir.

The reservoir volume is the result of balance estimation between uncontrollable water inflows generated by solar energy and planned water outfall generated by consumer water demand. In that way, the size of reservoirs significantly influences the size/power of the PV plant and vice versa. Larger reservoirs require smaller power plant for the same water needs. This functional interdependence is the basis for system P_{el}-V optimization.

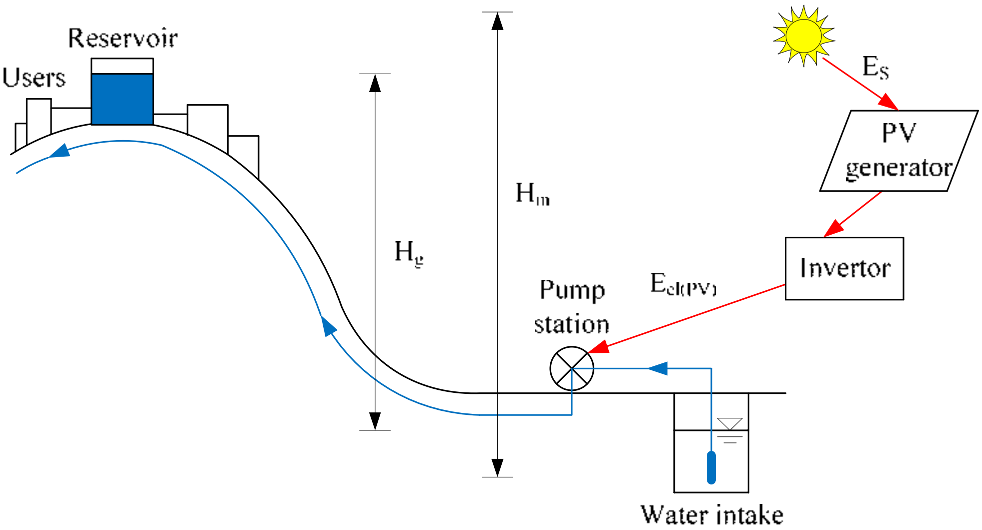

Fig. 2: Concept of sustainable energy supply to the water supply system

The starting equation for nominal electric power of PV generator P_{el} expressed in (W), which established the relation between the output hydraulic energy and radiated solar energy (according to Kenna and Gillett, 1985) is as follows:

$$P_{el} = \frac{1000}{f_m\left[1-\alpha_c\left(T_{cell}-T_0\right)\right]\eta_{MP}} \cdot \frac{E_H}{E_S} \tag{1}$$

where E_H (kWh day^{-1}) is output hydraulic energy from the pumping system, E_S (kWh day^{-1}) is solar energy at the input of the system, i.e. the PV generator, f_m is the load matching factor to characteristics of the PV generator, α_c is cell temperature coefficient (^{0}C^{-1}), T_0 is temperature of the PV generator in Standard Test Condition (25 ^{0}C), η_{MP} is motor–pump unit effectiveness, and T_{cell} is temperature of the PV generator (^{0}C).

Therefore, nominal electric power of PV generator is calculated based on the known average daily demand for hydraulic energy E_H and available average daily solar irradiation E_S in the critical time period and the known efficiency of the motor–pump unit η_{MP}, taking into account the effect of outside temperature on the efficiency of the PV generator. Eq. 1 stands for critical day, i.e. the day in which the ratio between hydraulic and radiated solar energy E_H/E_S is maximum. However, the critical day is not easy to determine, because of the influence of a number of interdependent variables in the system, which should be taken into account (Glasnović and Margeta, 2007). Hydraulic energy E_H, expressed in kWh, can be calculated by the equation:

$$E_H = \frac{2.72 Q_{PS} H_m}{1000} \tag{2}$$

Where Q_{PS} is average daily water volume (m^3 day^{-1}), pumped from the lower location into the service reservoir; H_m is average manometric height (difference between water level in water intake and water level in service reservoir (H_g), increased by hydrodynamical losses in the pumping system) (m).

By inserting eq. (2) into eq. (1) and by combining invertor efficiency η_I with the motor pump unit efficiency η_{MP} into one efficiency η_{MPI} and by inserting it in eq. (3) instead f_m, the final equation for the estimate of electric power of the PV power plant P_{el} is obtained:

$$P_{\mathrm{el}} = \frac{2.72 H_m}{[1-\alpha_{\mathrm{c}}(T_{\mathrm{cell}} - T_0)]\eta_{\mathrm{MPI}}\eta_{\mathrm{S}} E_{\mathrm{S}}} Q_{PS} \tag{3}$$

This equation is the starting element for system sizing.

The PV power plant, of nominal power P_{el}, forms a stationary field of PV collectors, interconnected serially and parallely, in order to obtain the required voltage and current. Inverters are required in order for the PV power plant to provide alternating current (Rashid, 2001).

The limit in the scope of construction of the PV power plant, defined by local conditions generally, the area A_{needed}, required for location of a PV power plant, can be calculated by the Equation (4):

$$A_{needed} = \frac{P_{el}}{1000 \cdot \eta_{oc}} \tag{4}$$

where η_{oc} is PV power plant efficiency.

Water volume, i.e. reservoir, is the key variable in the system. It defines the state of the system and the required water that should be taken from the intake (water resources) into the service reservoir, in order to achieve the required water supply. The reservoir volume is the result of needs for water supply and inflow by work of the pump station, and available energy from PV generator. Consumption of water in the reservoir (due to water needs in town) is compensated by pumping water from water resources, i.e. from the water source into the reservoir.

According to Fontane and Margeta, 1988 and Fig. 1, the equation for system state for the reservoir can be expressed as follows:

$$V_{(i)} = V_{(i-1)} + Q_{PS(i)} - Q_{WS(i)} - Q_{loss(i)} \tag{5}$$

where increment i assumes the values $i = 1$ to N (N is the total number of time stages, e.g. days or hours); $V_{(i-1)}$ and $V_{(i)}$ are reservoir volumes in (i-1) and i period respectively (m^{3}i^{-1}); $Q_{PS(i)}$ is water pumped by the PV power plant in i period (m^3/i) ; $Q_{\mathrm{WS(i)}}$ is water discharged from the upper reservoir into the town and $Q_{loss\mathrm{(i)}}$ is losses from reservoir in i period (m^{3}i^{-1}). The system state equation includes the most important variables of the water balance. The urban water supply service reservoir is closed and waterproof, variable $Q_{loss(i)}$ is 0 for all practical purposes. Water discharge $Q_{WS(i)}$ is the urban water demand during the day and is generally known and prescribed in the process of the system design. That is why these variables in the designing process can be considered as deterministic values. Water pumped by the PV power plant $Q_{PS(i)}$ is the result of available solar energy and therefore is changeable as the solar energy irradiation, or stochastic.

In the systematic approach, for the set output water quantities $Q_{PS(i)}$ (discretizied values of decision variable), the values of nominal electric power are calculated by eq. 6. Namely, $Q_{PS(i)}$ is by water balance (eq. 5) correlated to reservoir characteristics (water volume $V_{(i)}$ and $V_{(i-1)}$) and local climate elements that determine water needs in the reservoir which are to be covered by the PV power plant.

The required volume of the reservoir is determined depending on the availability of inflow (Margeta, 2011):

$$V_{tb} = \max\left[\sum_{t=1}^{j}\left(Q_{PS,t} - Q_{WS,t}\right)\right],\ 1 \le t \le j \le t_b = x{*}T,\ T = 24\ \mathrm{h} \tag{6}$$

where x is number of days, t_b = time step for sizing the reservoir. Urban service reservoirs aren't generally built for balancing periods longer than 5 days, therefore:

$$1 \le x \le 5 \tag{7}$$

The requested result of the optimization process is the best compromise solution between the pairs P_{el} and V that best meets the set objectives.

3. Sizing of the system

The general objective of system design is finding the electric power of the PV power plant that will, in the best manner possible, meet all consumer needs for water with minimal construction and operation cost. However, solar energy is free. Broader objectives of the problem have to be taken into consideration, as well as economical aspects of green energy use instead of classical energy. This means that it is necessary to select a system which will minimize negative economical difference between the green energy system and classical energy system use, since green energy supply is still more expensive than classical energy supply.

Electric energy that can be produced by the PV power plant directly depends on the fluctuating radiated solar energy and on its size (the total area of the PV power plant array A_{needed}), so that for a chosen size of PV power plant, in certain time periods it would pump too much, and in others too little water into the reservoir. That is why the simplest solution is the selection of the PV power plant for the most critical period of pump station work. It is necessary since the water supply system has to meet all needs constantly or at a required level of reliability in the whole planning period.

There are different possible approaches to problem solving according to the objectives of the analysis i.e. solution stages. In the initial analysis of the problem a simplified implicit approach is mainly used, because at the beginning the acceptability of the concept is estimated based on limited information, and only after that its dimensions and operation are accurately determined and economic analysis is conducted. The estimate is mainly carried out in four basic steps:

- the required power of the PV generator P_{el} is determined according to the selected daily balance period.
- for the selected PV generator power P_{el} and the period of its work during the day, the required reservoir volume is determined, according to the foreseen regime of hourly water consumption in a settlement.
- a compromise solution, i.e. PV generator power P_{el} and reservoir volume are selected V_{tb}.
- the dimensions of the main pumping station (MPS) and other elements of the hybrid system solution are determined.

There may be other methodologies according to the characteristics of the problem being solved and the level of problem addressing.

The required power of the PV generator must provide sufficient energy in accordance with daily insolation regime and other climate features, so that in the period when the PV generator is in operation, the required daily quantity of water V_{PS} (m^3) is pumped into the service reservoir throughout the year. This procedure is simple, because the relation between P_{el} and V_{PS} is linear.

Based on the selected/calculated initial value $P_{el}^{(1)}$ and $V_{PS}^{(1)}$, (eq. 3), the minimum required P_{el}^{*} is determined from established differences:

$$\Delta V_t = V_{PS,t} - V_{daily,t}\ ;\ t = 1,\ldots, 365 \tag{8}$$

Where $V_{daily,t}$ is daily water consumption.

The critical day is determined by the minimum daily difference:

$$\min \Delta V_t \Rightarrow t^* \tag{9}$$

The regime of hourly water consumption is assumed based on measurement data or data for the settlement of similar characteristics compared to maximum daily consumption (Fig. 3).

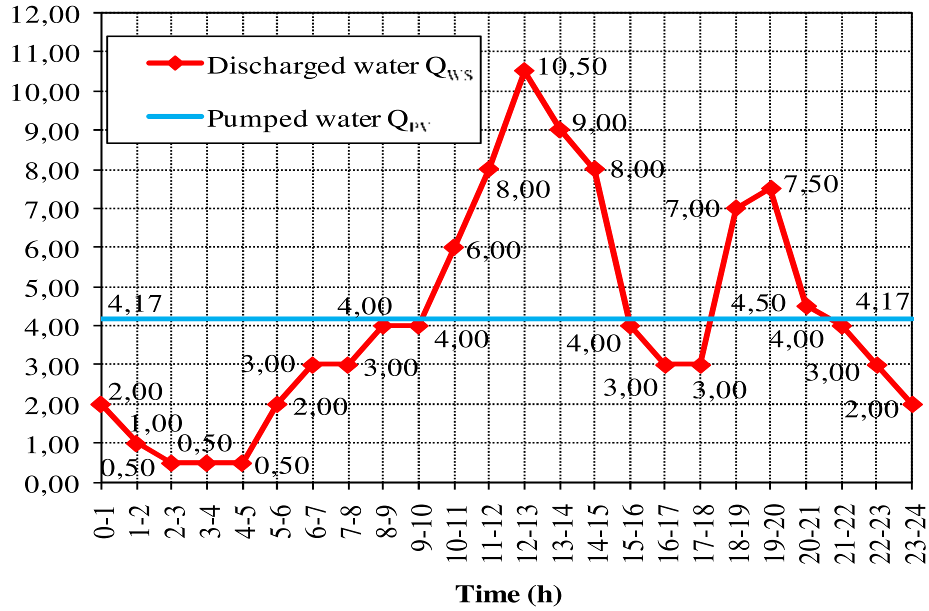

Fig. 3: Hourly consumption of water in settlement (% of daily flow)

This diagram determines the expected regime of water discharge from the reservoir, but there is the question of the pumping station operating regime and water inflow. Available insolation E_S, i.e. electric energy P_{el} determines the period of pumping station operation. In this paper it is assumed that the pumping station will work with the constant necessary capacity Q_{MPS} (m^3 h^{-1}) during the insolation T_S (h):

$$Q_{MPS} = \frac{Q_{\max}^{daily}}{T_S} \tag{10}$$

Therefore, the calculation applies to the average intensity and duration of sunshine in the critical period of the system operation, i.e. in accordance with eq. (1). The optimal combination x of PV generator power (f_1) and operating volume V_{tb} (f_2) is sought for the selected group of pairs - alternatives X.

$$DR[f_1(x), f_2(x)],\ x \in X \tag{11}$$

DR means to apply the appropriate decision rule(s) and find the best-compromise solution x^* from the set of alternatives X. The standard trade-off method could, among other, be used for the selection of a compromise solution (Chankong, and Haimes, 1983). Operating volume V_{tb} (f_2) is a function of number of days x used for balancing the service reservoir. In this case the economic criterion is dominant. However, the problem can be analyzed by extending the criteria of which the reliability of water supply is the most important one.

4. Results and discussions

4.1. Case study

This paper analyses a hypothetical example of a settlement which has a population equivalent of 8970. The settlement is located in a hilly area of the Mediterranean part of Croatia and has one water reservoir located at ground elevation of 140 m above sea. Water flows into the reservoir from the wet basin of the pump station. Water in the wet basin inflows from the spring by gravity. Total head of the pump station is 82.41 m.

The water quality is satisfactory so that it does not need treatment. The positions of the basic facilities of the water supply system are shown in Fig. 4.

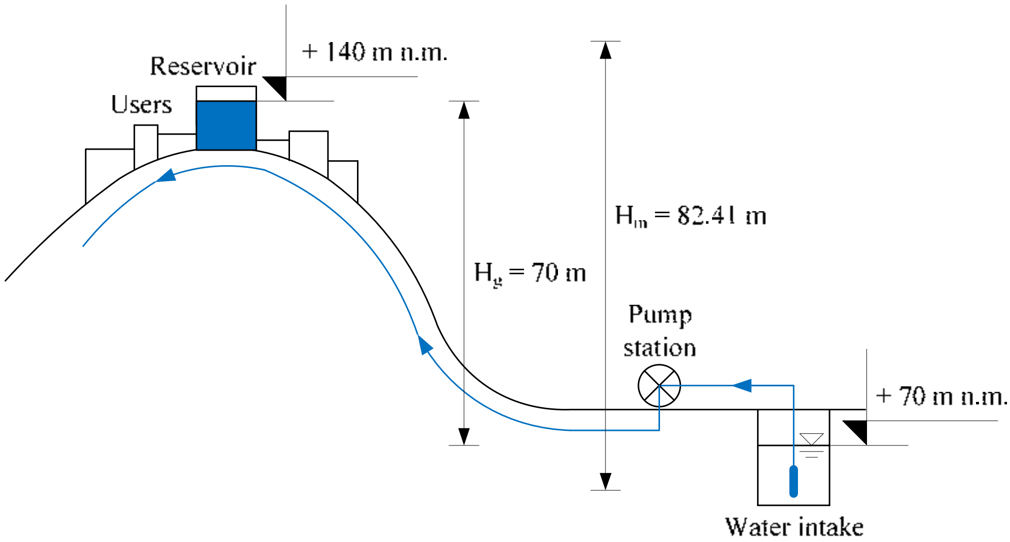

Fig. 4: The position of the basic facilities of the water supply system

The analysis is conducted according to the presented methodology in Section 3. Specific water consumption q_{sp} is 160 litres capita day^{-1}. Annual daily water consumption Q_{daily} is shown in Fig. 5. Maximum daily consumption is 2366 m^3 day^{-1}, minimum Q_{min}^{daily} is 676 m^3 day^{-1}, and average is 1436 m^3 day^{-1}. Hourly consumption of water in the settlement is determined by the daily regime of consumption in accordance with the~~,~~ Fig. 3. Maximum hourly consumption is 248.43 m^{3}h^{-1}, minimum is 11.83 m^{3}h^{-1}, and average is 98.58 m^{3}h^{-1}.

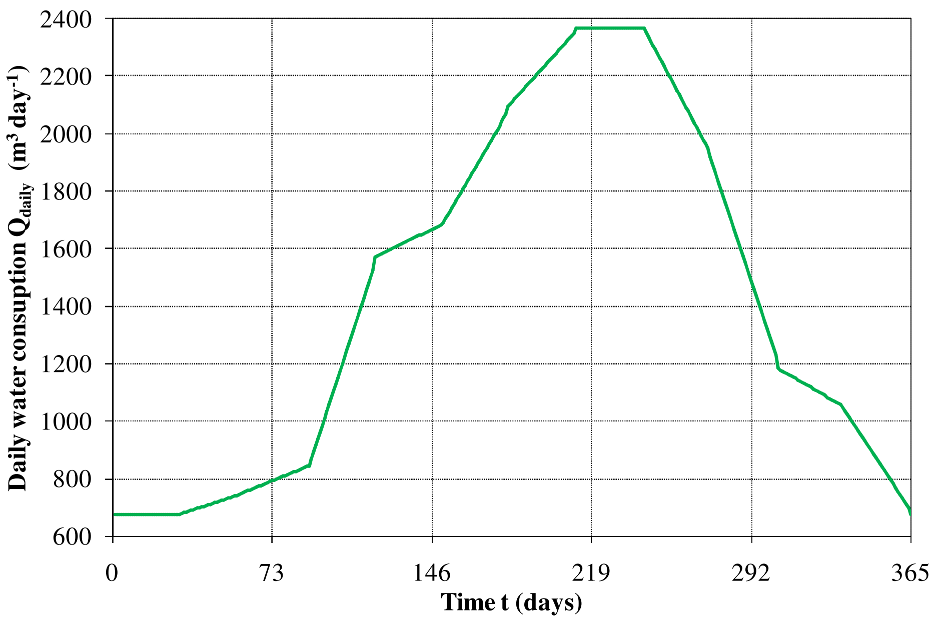

Fig. 5: Daily water consumption in settlement in a typical year

4.2. Determining the PV generator power

Climate features of the area are presented in Tab. 1. Here are presented the average monthly values and the daily values of the average year are used in the calculation.

Tab. 1: Climate characteristics of the area

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
***S* (h)**	3.8	5.8	7.4	6.7	8.9	9.6	12	9.5	9.2	6.3	3.5	3.3
E_S (kWh day^{-1})	1.63	2.20	2.78	4.93	5.98	7.02	7.09	6.26	4.80	3.14	1.86	1.35
T_a (°C)	8.8	9.3	11.1	14.1	18.1	21.8	24.5	24.4	21.5	17.7	13.7	10.4

Starting from the climate characteristics of the location as well as characteristics of the pumping station, and eq. (1-3), a general expression for calculating the PV generator power P_{el} and the quantity of water V_{PS} which it he can pump into the reservoir is obtained:

$$V_{PS} = \frac{1}{2.72H_m}\left[1-\alpha_c(T_{cell}-T_0)\right]\cdot\eta_{MPI}\cdot\eta_S\cdot P_{el}\cdot E_S \tag{12}$$

For the considered location (E_s and T_a), the altitude difference is H_m =82.41 m, the efficiency of the inverter and motor pump unit is η_{MPI} = 0.75. The calculation is made with a 50% probability of exploitation of solar energy η_S = 0.5 (because the calculation used average year, while with the detailed analysis of input data the ratio η_S can be changed according to the set objectives of the analysis), while α_c = 0.005, T_0 = 25 °C. E_S is taken as the average daily value for each typical day in the year.

By analyzing the planning period of water demand and available power of the PV generator, the critical period for sizing of the system is defined, which is the 337th day (V_{PS} = 1012 m^3). The power required for this critical period is calculated for P_{el} = 2.82 MW. Every other day requires less power P_{el} to meet the daily water needs. This means that if several days are balanced t_b with the critical day (t^*) the required power P_{el} will decrease, but the required volume of the service reservoir V_{tb} will grow. In the case of urban service reservoirs computational period is at least 1 day, so that computational steps t_b are always t^* +1.

The next step analyses the impact of the equalization period (critical period) on the PV generator. Consequently, the whole procedure from the previous step was repeated, but with different values of computational step t_b (Fig. 6).

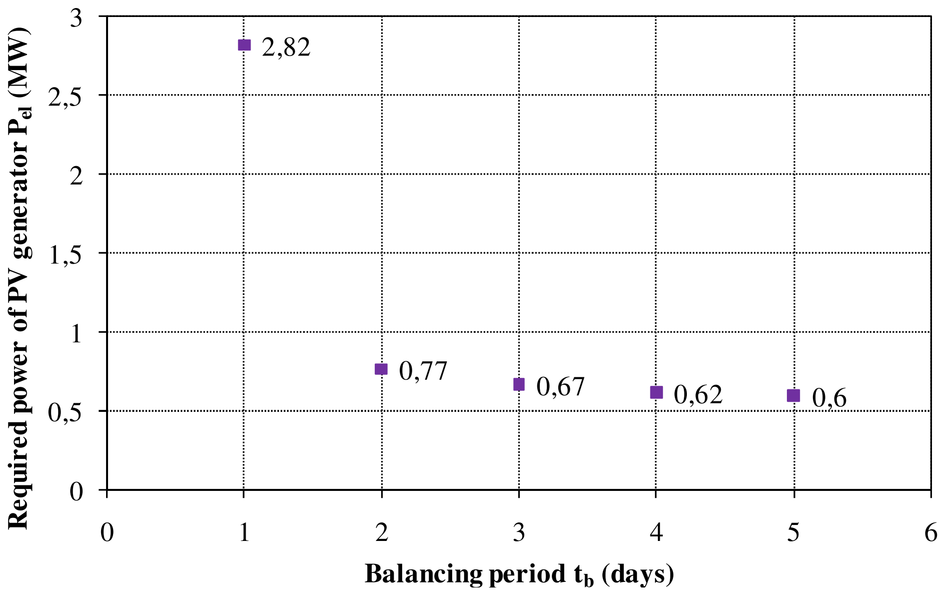

Fig. 6: The required power of PV generator P_{el} as a function of balancing period t_b

If the critical period is extended from one to several days, the required power of PV generator is lower, because it allows long-term balancing of water demand and water inflow, i.e. electric energy of PV generator for pump station operation (Fig. 6). In this case the differences are very significant for t_b = *1* and other alternatives. The differences are smaller with higher t_b, as the result of the relationship which is very big for the critical 337th day. It is obvious that increasing of number of days in the balancing period t_b PV generator power and consequently investment costs can be significantly reduced. However, investment cost of the reservoir should not be disregarded. This approach that will provide for all needs in the critical period results in large surplus of energy in the remaining part of the year (Fig. 7).

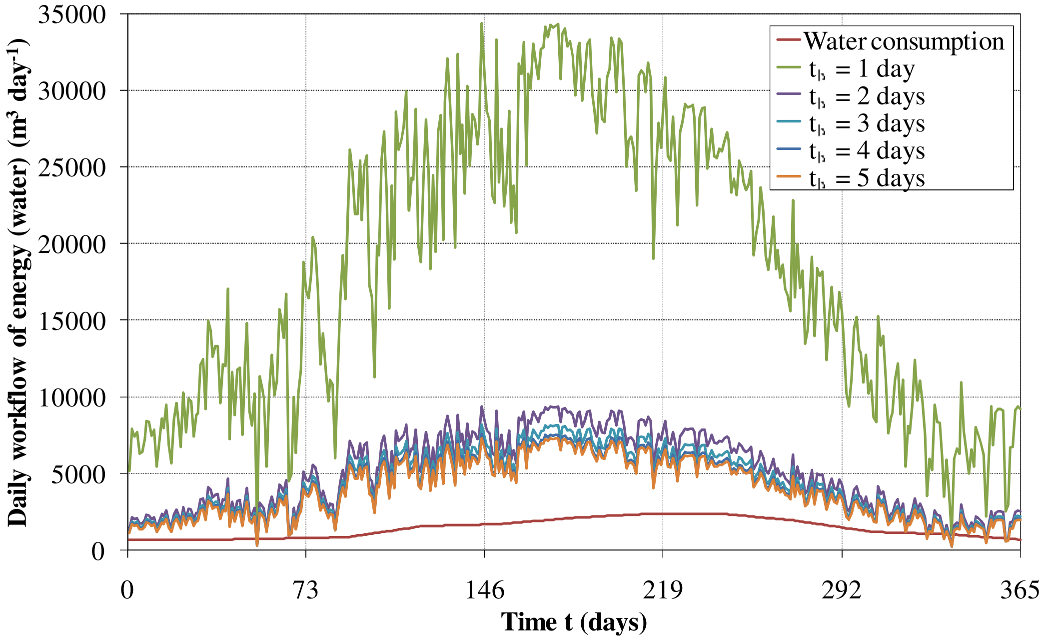

Fig. 7: Daily workflow of energy (water) production for various balancing periods t_b

It can be concluded that it is desirable to build water reservoirs for a two-day balancing period, because the power is reduced by 72 %. For longer periods savings are significantly lower: (2-3) = 13 % (3-4) = 8 %, etc. The available energy surpluses can be used for other purposes or simply placed in the local energy system.

4.3. Determining the reservoir volume

The reservoir volume depends on the regime of pumping and discharge. The regime of hourly water consumption was determined (Fig. 4), but there is the question of the operating regime of the pumping station. In this paper it is assumed that the pumping station will work with the constant necessary capacity Q_{MPS} during the insolation period T_S in one day:

$$Q_{MPS} = \frac{Q_{max}^{daily}}{T_S} \tag{13}$$

This means that the calculation is made for average intensity and duration of sunshine in the critical period of the system operation. In accordance with these assumptions, the calculation for the required reservoir volume $V_{(x,day)}$ for the balancing period t_b = 1, 2, 3, 4 and 5 days is made, taking into account insolation and duration, Fig. 8. The results are as expected and clearly show that with increasing periods of equalization x_t the size of the required volume increases, but that the increment is smaller and smaller. In this example, it is obvious that the balancing period t_b =2 a very acceptable alternative. Considering that water consumption and insolation period do not change significantly over a period of one week, the features of the pumping station and pressure pipe are approximately the same for different equalization periods. This means that the MPS does not have a significant impact on the choice of solutions in function of the equalization period.

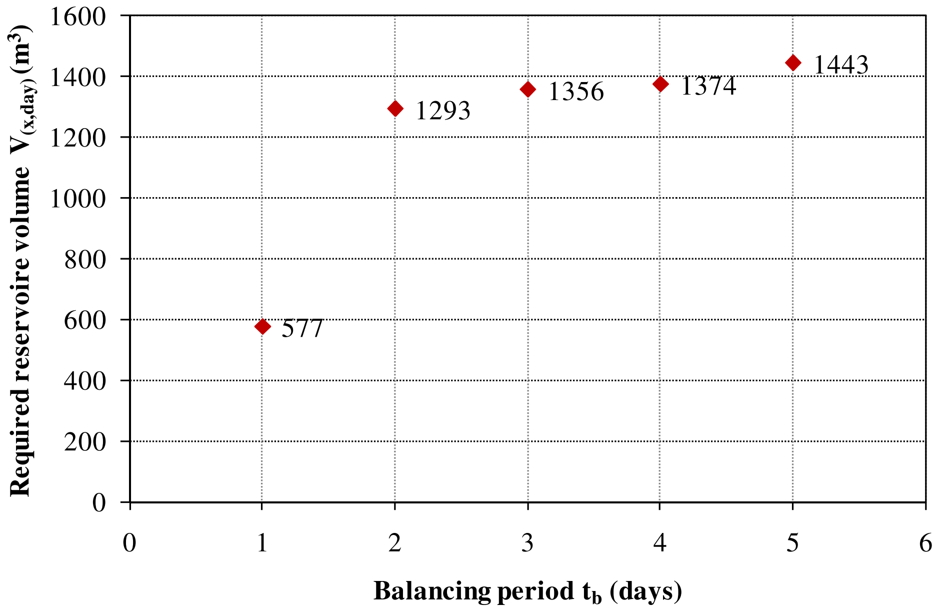

Fig. 8: The required reservoir volume $V_{(x,day)}$ as a function of the balancing period t_b

The resulting set of results provides a good basis for the basic/initial analysis of the possible use of PV generators in the work of water supply system. A simplified economic analysis of alternative solutions was made accordingly.

4.4. Economic analysis

It is pertinent that the basic economic analysis should be made while attempting to optimize the size of the PV generator and service reservoir. The economical approach, according to the concept of life cycle cost (*LCC*) (Euro), is developed to be the best indicator of economical profitability of the system cost analysis (Bakelli et al., 2011). The system consists of three main parts: (1) PV generator and convertor, (2) service reservoir and (3) main pump station and associated rising main. *LCC* takes into account the initial capital cost ($C_{capital}$), the present value of replacement cost ($C_{replacement}$) and the present value of operation and maintenance cost $C_{(O\&M)}$:

$$LCC = C_{capital} + C_{replacement} + C_{(O\&M)} \tag{14}$$

However, the economic analysis of a renewable energy project basically comes to the calculation of cash flow, the Pay-Back-Period (PBP), the Net Present Value (NPV) and the Internal Rate of Return (IRR), where all these factors can be translated into cash flow C_y^*, i.e. reduced to the difference between all profits $P_{x,y}$ and costs $C_{x,y}$ related to generic y^{th} year.

In the case of the water supply system the economic objective is to minimize possible economic losses which occur due to not using conventional energy sources which are still cheaper than green sources. These losses are expected to decrease over the time, because PV generators are becoming cheaper and conventional energy more expensive. Since sustainability projects should be evaluated by three main indicators: (i) economic, (ii) environmental and (iii) social, the single economic approach is obviously not sufficient and that is why a multicriteria approach is necessary for the projects of this type. However, the main goal of this paper is just the presentation of the possible concept of sustainable energy supply to water supply system; we will simplify the economic analysis providing sufficient information for understanding the problem characteristics. Only initial capital cost estimation will be presented.

The results are presented in Tab. 2. Based on these results it is clear that it is cheapest to build a combination with four days of balancing and then 2 days. In fact, alternatives t_b = 2 to 4 days are similar, as expected. It is also evident that for the previous economic analysis it is sufficient to consider two alternatives, with one and two days of equalization, because the change increments for larger equalization steps are relatively small.

Detailed economic analyses can identify more precise data and provide a better insight into the structure of preferences.

Tab. 2: Costs of various alternatives

Balancing period, t_b (days)	**Power P_{el} of PV (MW)**	**Volume V of SR (m^3)**	**$C_{capital}$, PV (Euro)**	**$C_{capital}$, SR (Euro)**	**$C_{capital}$, Total (Euro)**
1	2.82	577	705000	230800	935800
2	0.77	1293	231000	698220	929220
3	0.67	1356	201000	732240	933240
4	0.62	1374	186000	741420	927420
5	0.60	1443	180000	779220	959220

The analysis can be extended according to the presented methodology. The safety of supply and possible increase of the PV generator power or reservoir volume, or both can be analysed. It is evident that with a smaller increase in volume from t_b = 2 to t_b = 4 (ΔV = 81 m^3, or 6 %) and with retention of generator power t_b =2 days, a good compromise between the required power of the PV generator and the equalization period is obtained. We should not forget that the downward trend in prices of PV generator in the last 5 years is very significant (Campoccia et al., 2009; www.pvxchange.com) and will continue to be so. This means that construction costs of the reservoir will have a decisive role. Bigger PV generators provide a significant surplus of energy throughout the year, which allows additional income (Fig. 8).

It is opportune to ask if the construction of a PV generator is profitable. If the problem is viewed from the economic point of view, the answer is no, but if a broader framework is taken into account, the environmental and social answer is not so simple.

The analysis should be adapted to the actual characteristics of the problem. A more detailed, sensitive analysis with respect to input data, the trend of price change of generator and energy from energy system, subsidies for green energy, etc. would give a more complete picture of the problem to be solved. Such analysis goes beyond this work and will be the subject of future research and papers.

5. Conclusions and recommendations

A general concept of the possible use of PV generators in the energy supply of the main pump station of urban water supply system is presented. These results clearly show that the proposed concept can be realized and that it provides a great opportunity of adjusting of the solution (combination of P_{el} and V) to actual needs of the problem to be addressed.

Achieving the sustainability and use of green energy has its price. Although the basic energy resource is free (sun), and so is a significant part of operating costs, the construction costs are significantly higher and predominantly relate to construction costs of the PV generator. However, construction costs of the PV generator are constantly decreasing and their efficiency increases correspondingly (Green et al., 2010). Therefore, by reducing construction costs of the PV generator, the cost effectiveness of application of the planned concept increases.

The sustainability of water supply also has its price, starting from the importance of water supply for every urban settlement. Therefore, it may not be necessary to address all pumping capacities in this way. The gradual introduction of green energy increases the sustainability of water supply systems, reduces the risk and achieves other objectives in the concept of sustainable living, such as reduction of CO_2 emission and environment protection.

Through different periods of use and more favourable conditions for PV generator work, the entire process and solution can be rationalized. For instance, if the PV generator is sized for summer conditions, when insolation is higher, construction costs can be significantly reduced. During the winter period the lack of energy is solved by combining the available solar and conventional energy. This enables significantly lower construction costs, but the realization of the primary goal of "sustainability" is lower. Similarly, the energy from PV generator can be used during the day when energy from the energy system is the most expensive and energy from the energy system/grid during the night when it is the cheapest. There may be various combinations that should always be comprehensively considered.

The climate has a dominant impact on the solution; therefore it is clear that the locations with longer and constant insolation throughout the year are more favourable for the application of the proposed solution. The increase of the PV generator efficiency can be better achieved by harvesting of solar energy and thus allow a favourable application of the proposed solution in areas with less and variable insolation. It is clear that the proposed solution always provides sustainable supply of energy to the water supply system with varying efficiency, because the solar energy is always available at places where people live.

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