THE CONCEPT OF SUSTAINABLE IRRIGATION ON THE EXAMPLE OF FOOTBALL FIELD OF F.C. "OBREŠ", SVETI ILIJA, CROATIA

KONCEPT ODRŽIVOG NAVODNJAVANJA NA PRIMJERU NOGOMETNOG TERENA N.K. ''OBREŠ'', SVETI ILIJA, HRVATSKA

Boyan Borisov[1], **Bojan Đurin**[2*], **Josip Matin**[2]
[1] *University of Civil Engineering, Architecture and Geodesy, Faculty of Hydrotechnics, Sofia, Bulgaria*
[2] *University of Zagreb, Faculty of Geotechnical Engineering, Varaždin, Croatia,*
*E-mail of corresponding author: bojan.djurin@gfv.hr

Abstract: *Rational and efficient use of water and energy in all kinds of human activities includes a system approach to the stated issues. Accordingly, new methodologies and processes for realization of the previously mentioned are understood as an imperative. This paper deals with the application of Solar Photovoltaic (PV) energy for driving the pumps for irrigation water pumping. This concept will apply an innovative and originally designed dimensioning method, called Critical Period Method. Irrigation system includes a Solar Photovoltaic (PV) generator and inverter, a pump station and water reservoir, pipelines and an irrigation device. This methodology or concept of irrigation will be applied in the case of the local football club "Obreš" in the municipality of Sveti Ilija near Varaždin in Croatia. The presented solution is in conformity to the world and European legislation, directives and strategies related to the negative impacts of climate changes and greenhouse gas emissions.*

Keywords: *Solar photovoltaic energy, irrigation, Critical Period Method*

Sažetak: *Racionalno i učinkovito korištenje vode i energije u svim područjima ljudske aktivnosti podrazumijeva sustavni pristup u navedenoj problematici. U skladu sa time, kao imperativ podrazumijevaju se nove metodologije i postupci za ostvarenje prethodno navedenogaU ovom radu opisuje se primjena solarne fotonaponske (FN) energije za rad crpki za vodu za potrebe navodnjavanja. U ovom konceptu primijeniti će se inovativna i originalno osmišljena metoda dimenzioniranja, nazvana Metodom Kritičnog Perioda. Sustav za navodnjavanje uključuje solarni fotonaponski (FN) generator i pretvarač, crpnu stanicu, vodospremu, cjevovode i uređaj za navodnjavanje. Navedena metodologija, odnosno koncept navodnjavanja primijeniti će se na primjeru lokalnog nogometnog kluba F.C. ''Obreš'', na području općine Sveti Ilija u blizini Varaždina u Hrvatskoj. Prikazano rješenje je u skladu sa svjetskim i europskim zakonima, smjernicama i strategijama vezanim uz negativni utjecaj klimatskih promjena i emisija stakleničkih plinova.*

Ključne riječi: *Solarna fotonaponska energija, navodnjavanje, Metoda kritičnog perioda*

Received: 02.03.2016 / Accepted: 02.06.2016

Pregledni rad / Review paper

1. BACKGROUND AND INTRODUCTION

Sustainable water supply is of great importance for the quality of living of both urban and rural areas throughout the world. Given the negative climate changes and reducing volumes of available sources of fossil fuels, which today is used extensively as a source of energy, sustainable use of water and energy by itself becomes imperative. Political and legal provisions contained in a big number of laws, guidelines and accompanying regulations also contribute to such reasoning. An important segment of sustainable urban and rural areas is the efficient use of water and energy for irrigation.

In comparison to all other renewable energy sources (RES), solar photovoltaic (PV) energy is the most suitable form for various uses in water supply (Boizidi, 2013; Đurin & Margeta, 2014; Chandel et al. 2015; Bakelli et al. 2011; Ebaid et al. 2013; Ghoneim 2006; Hamidat & Benyoucef 2009), as well as for the irrigation (Margeta & Glasnović 2007; Hamidat et al. 2002; Cuadros et al. 2004) and many others. The analyzed irrigation system includes a PV generator and inverter, a pump station, a water reservoir and pipelines. PV energy is used as energy source for the pump station to supply the water reservoir with water. The water from the reservoir is dispatched to a grass lawn via the pipelines or irrigation device.

Irrigation systems don't typically have security requirements in view of quality or quantity of energy and water inflow and outflow, as opposed to water which is intended for water supply, since the water used for such purposes is not a food product for humans and animals. This is especially pronounced in the case of water used for irrigation of sports fields. However, in accordance with current trends to reduce energy and water consumption, these systems also require attention in the dimensioning process. Therefore, for this purpose it is necessary to apply the existing knowledge and treat the irrigation system as if it were a water supply system for the peoples' needs. The following will give an overview of the usual dimensioning methods of water supply systems, which are linked to the aforementioned Critical Period Method which improves the common dimensioning methods (Đurin & Margeta 2014).

The elaborated sizing procedure of such type of the water supply systems, using the Method of Worst Month, (Ebaid et al. 2013), has been improved in (Đurin

& Margeta 2014) and especially in Đurin (2014), using the original and innovative designed Critical Period Method. In doing so, each part of the water supply system is separately sized with respect to its corresponding critical day/period of the year. The Critical Period Method will be modified for application in irrigation, because for this purpose it includes certain specific characteristics which affect the relationships of all parts of the system. This will be described in the case of irrigation of a pitch of the local football club, named F.C. ''Obreš'' on location Sveti Ilija, near Varaždin in Croatia. For irrigation water demands, groundwater is used in combination with rainwater.

2. DESCRIPTION OF THE OBSERVED IRRIGATION SYSTEM

This paper analyses an autonomous water supply system, which uses PV energy to drive the pump stations, which pumps the water into the water reservoirs, **Figure 1.**

PV cells forms the PV generator. PV generator is used for the conversion of solar radiation into direct current power, which is converted by inverters into alternating current necessary for pump drive. Available insolation E_s, i.e., electric energy $P_{el,PV}$ determines the appropriate period of the pump station operation T_s with uniform rate during daily work period.

It is necessary to set up two pumps; first pump (pump 1 in a well) is used to pump water from a well and deliver it to the water reservoir 1. Rainwater is collected in this water reservoir. Rainwater is collected from the existing roofs and PV cells via grooves for water storage into the water reservoir 1. If the roof or the solar cells are at a sufficient slope, the rainwater is drained by gravity (free fall). In case if such gravitational flow is not possible, it is necessary to install a "booster" pump for pumping over. It should be noted that in considered case water reservoir 1 does not have usual function as a conventional water reservoirs for flow and consumption equalization, since both pumps operate when the intensity of solar radiation is at its optimal operating level. This implies that the hourly, as well as daily water input is the same as hourly/daily water output from this water reservoir, so there is no need to provide volume for the equalization. Water is drawn by surface pump 2 from the water reservoir 1 into the water reservoir 2 by gravity or by booster pump. From water reservoir 2, water is collected and distributed to the areas being irrigated. However, if the irrigation system with water reservoir on tower is applied in urban area, there would be no need for tower construction, since some other existing elevated structure could be used for this purpose, skyscraper for example, or the existing spotlight pillars on football stadiums etc. These types of irrigation can be also used for enclosed areas (greenhouses).

Typically, water is pumped over into water reservoirs during the day, while the irrigation takes place at night, which is more suitable for the vegetation, with the reduced evapotranspiration as well. The distribution of water from water reservoir to the crops is gravitational, since the water reservoir is situated at a certain height above the ground surface thus achieving the required water pressure.

In any case, it is necessary to provide the required volume of the water reservoir 2, namely the water required to meet the irrigation needs. Primarily this need will be provided by groundwater, with a certain amount obtained from rainwater. However, an additional volume of rainwater will not be foreseen for the water reservoir 2, since it is assumed that this quantity of water will be considerably lower than the planned amount of water quantity from the well. Rainwater has an additional purpose of mixing with underground water, which makes it more suitable for the irrigated vegetation. In addition, this amount of water to some extent also relieves the underground aquifer layer.

The last part of the observed system includes the output pipelines from the water reservoir 2. In this case one can predict the irrigation of an area based on the installed connected pipelines or irrigation devices.

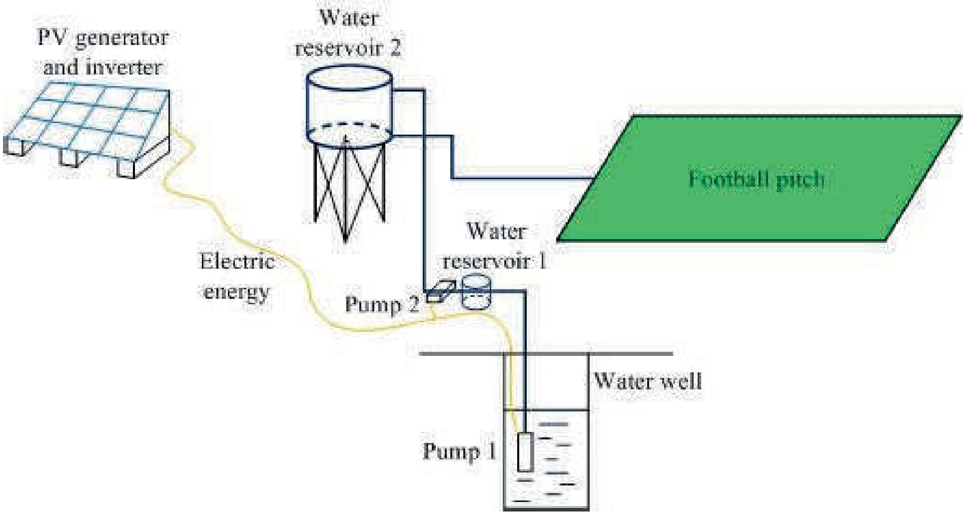

Figure 1. General (schematic) view of the observed irrigation system (modified from Agriwaterpedia 2015)

3. METHODOLOGY

3.1. Sizing procedure

Power of a subsystem PV, $P_{el,PV}$ (W) which generates electrical energy for pumping the water to water reservoir at a certain period of time i, representing days of the year, i = 1, 2,… 365 days, is equal to (Đurin & Margeta 2014):

$$P_{\mathrm{el},PV(i)} = \frac{2.72 H_{PS(i)}}{\left[1-\alpha_c\left(T_{cell(i)}-T_0\right)\right]\eta_{PSI} E_{s(i)}} V_{PS(i)} \tag{1}$$

where $H_{PS(i)}$ (m) is manometer height, $V_{PS(i)}$ (m^3/day) is daily amount of water pumped into the water reservoir at a certain time period (day) i, α_c is solar cell temperature coefficient (°C^{-1}), T_{cell} is solar cell mean daily temperature (°C), T_0 is solar cell mean daily temperature in standard test conditions, which is 25°C, η_{PSI} is pump station and inverter mean efficiency (%), $E_{s(i)}$ (kWh/m^2) is available mean daily average intensity of solar radiation for the time interval i.

Electricity produced, $E_{el,PV(i)}$ (Wh), in period T_i is expressed by:

$$E_{el,PV(i)} = P_{el,PV(i)} \times T_i \tag{2}$$

Mean daily temperature of a solar cell, $T_{cell(i)}$, is obtained using (Đurin & Margeta 2014):

$$T_{cell(i)} = 2.7 \times E_{s(i)} + T_{a(i)} \tag{3}$$

where $T_{a(i)}$ is a mean daily air temperature (°C).

Mean efficiency of the pump station and inverter η_{PSI} is obtained as (Đurin & Margeta 2014):

$$H_{PSI} = \eta_{PS} \times \eta_I \tag{4}$$

where η_{PS} is pump station efficiency, while η_I is inverter efficiency.

For a given power of a subsystem PV, $P_{el,PV(i)}$, the possible amount of water $V_{PS(i)}$ (m^3), pumped into the water reservoir during the time interval i is equal to:

$$V_{PS(i)} = \frac{\left[1-\alpha_c\left(T_{cell(i)}-T_0\right)\right]\eta_{PSI} E_{s(i)}}{2.72 H_{PS(i)}} P_{\mathrm{el},PV(i)} \tag{5}$$

The required area of a PV generator A_{PV} (m^2) is obtained from (Đurin & Margeta 2014):

$$A_{PV} = \frac{P_{el,PV}}{1000\eta_{PV}} \tag{6}$$

where η_{PV} is a mean efficiency of a subsystem PV.

If all the available daily solar energy E_s, or electricity produced, will be used for pumping $V_{PS(i)}$ into the water reservoir, the average necessary capacity of the pump station $Q_{PS,available(i)}$ will then be equal to:

$$Q_{PS,available(i)} = \frac{V_{PS(i)}}{T_{s(i)}} = \frac{P_{el,PV(i)}}{T_{s(i)}} \frac{\left[1-\alpha_c\left(T_{cell}-T_0\right)\right]\eta_{PSI} E_{s(i)}}{2.72 H_{PS(i)}} \tag{7}$$

namely:

$$Q_{PS} \geq \max Q_{PS,available(i)} \tag{8}$$

$T_{s(i)}$ is the daily number of peak sun hours or usable duration of insolation, which is obtained by the (Ebaid et al. 2013):

$$T_{s(i)} = \frac{E_{s(i)}}{1000} \tag{9}$$

The number of peak sun hours is merely an estimation of the amount of time per day that the irradiance is equal to a peak Sun, and because PV models are rated for their output under peak sun conditions, the number of daily peak Sun hours indicates how many hours of each day the PV array will operate at its full power output.

However, if all water quantity $V_{PS(i)}$ does not necessarily need to be pumped over, namely if the water quantity $V_{PS(i)}$ is greater than the required amount of water for the irrigation needs $V_{daily(i)}$, then minimal average required pump capacity $Q_{PS,needed(i)}$ is equal to:

$$Q_{PS,needed(i)} = \frac{V_{daily(i)}}{T_{s(i)}} \tag{10}$$

Since the purpose of the pump is pumping (lifting) water into the water reservoir, the required capacity Q_{PS}^* is:

$$Q_{PS}^* = \max\left(Q_{PS,needed(i)}\right) \tag{11}$$

Average power of the pump station P_{PS}^* is then:

$$P_{PS}^* = \frac{\rho g Q_{PS}^* H_{PS}}{\eta_{PS}} \tag{12}$$

where η_{PS} is average efficiency of the pump station.

Water reservoirs are typically sized for one-day water equalization of supply and consumption for a day with maximum consumption, but equalization can also be done for more days, up to seven. Volume of the water reservoir V is defined for each day in a year by method of integral curve, i.e. Ripley method (Đurin et al. 2015):

$$V = \max\left\lfloor \sum_{t=1}^{24}\left(Q_{PS(i)} - Q_{hour(t)}\right)\right\rfloor \tag{13}$$

where t = 1, 2,…, 24 h.

Equation (13) applies if within a period of t = 1 hour up to 24 hours (one day) the water inflow of the water reservoir is the same as water outfall from the water reservoir. It is a simple methodology based on the fact that within the period of exchange, which can be the period of one up to seven days, all the water inflow is the same as the outfall from the reservoir.

3.2. Definition of the Critical Period Method

In this paper we used the approach based on critical design period, whereby the Critical Period Method was devised (Đurin & Margeta 2014). This approach includes design elements of the solution: PV generator, pump station and water reservoir based on the critical period of operation of each one. It is also a conservative approach, meaning that the elements of the solution are potentially overdesigned. However, such an approach provides a reliable solution and a required level of reliability, necessary for the functioning of water supply systems. The reliability of the bulk water supply system can be defined in terms of reliability of its storage reservoir/tank, as consumers will only notice a service interruption if the storage tank has failed (i.e., run dry).

The balancing period of water pumping and water reservoir water balance is usually at least one day and may be several days, usually no more than five, (t_b = 1 till 5 days). A longer balance period reduces the uncertainty of solar irradiation and increases the reliability of the solution. With a longer balancing period, the system is more cost-effective from the perspective of solar energy harvesting, because the sum of overall available solar radiation is greater when the balancing period is longer. This means that the required water volume can be pumped with lower installed PV system power $P_{el,PV}$. Normally, with a longer balancing period, the storage capacity of the reservoir V_{op} will be higher.

At the beginning of the analysis it is necessary to define the daily quantity of water for irrigation purpose $V_{daily,i}$ (m^3/day), according to the vegetation characteristics and water consumption regime throughout the analyzed months of the planning period. After this, the daily water usage pattern $V_{hourly,t}$ (m^3/h) in the period of t = 1, 2,…, 24 hours is determined (diurnal pattern). To simplify further calculations, it is assumed that the same pattern is used for each day and throughout the analyzed months. In such analyzes, a hydrological analysis, taking into account evapotranspiration and soil moisture of the football field, as well as agronomic and pedological analysis should be made. However, since it is a conceptual level of the observed problem, that analysis is not taken into account.

Based on the obtained values, the minimum required size of the PV system is determined, which provides the necessary inflow of water in the critical period. Based on the selected/calculated initial values, $P_{el,PV}$ and V_{PS}, which satisfy water demand V_{daily} in the planning period, the minimum required $P_{el,PV}$ is determined from established differences $\Delta V_{tb,i}$:

$$\Delta V_{tb,i} = V_{PS,tb,i} - V_{daily,tb,i} \tag{14}$$

The critical day/period $t^*_{Pel,PV,tb,i}$ for PV generator design is determined by the minimum daily difference using statistical minimization:

$$\min \Delta V_{tb,i} \Rightarrow t^*_{Pel,PV,tb,i} \tag{15}$$

where $\Delta V_{tb,i}$ is an acceptable difference in practice application which is typically equal to 0.

The required operation volume of water reservoir 2, V, is obtained using the (13). Time step for calculation is one hour, t = 1, 2…, 24 hours. In general, the critical day/period for the design of volume reservoir $t^*_{V,tb,i}$ is the day with maximum water demand and the shortest duration of solar radiation suitable for pump station operation, providing that on the available day insolation $E_{s(i)}$ is sufficiently high. A critical day/period for the pump station $t^*_{PS,tb,i}$ also coincides with this critical day. It should be noted that the fire volume is not taken into account for this case, because in this case there are water needs only for irrigation. Also, it is not foreseen to provide additional volume of water reservoirs for emergency situations since it is meant irrigation. Based on the above mentioned, the required volume V^* for each variant t_b is obtained using statistical maximization, with the associated critical day:

$$V^* \geq \max V => t^*_{V,tb,i} \tag{16}$$

The same situation applies to the capacity of pump stations:

$$Q^*_{PS} \geq \max Q_{PS} => t^*_{PS,tb,i} \tag{17}$$

Daily quantity of water for irrigation purpose V_{daily} (m^3/day) is obtained to the most part by pumping groundwater and to a lesser extent from rainwater. Due to stochastic nature of the rain, the safest option is providing backup volume of water reservoir 1 of a same volume as the quantity of collected rainwater. At the same time this size represents the additional quantity of water for emergency situations.

The same procedure is used for balancing periods t_b bigger than one day, where is used scheme as is shown on **Figure 2**, on example for t_b = 2 days.

4. CASE STUDY AND RESULTS

4.1. Location

Described methodology of sizing the irrigation system, i.e. Critical Period method, will be illustrated on the example of pitch irrigation for the local football club Obreš, located near Varaždin on the territory of Sveti Ilija municipality (**Figure 3**). The football pitch covers the area of 105 x 70 m. The altitude of the location is 173 m asl. **Figure 4** shows the position of all elements of the analyzed system. According to the recommendations from bibliography (Ghoneim 2006) and the position of the available area, the azimuth (angle spread) of the PV generator is in the south direction, while the angle of inclination is equal to 15°.

Groundwater, which is situated in shallow layers already at a depth of 5 m, is used for irrigation, and the usage of the existing well showed that its capacity is sufficient. Another favorable fact is that the level of underground water on case study location is situated in the shallow area of rich Varaždin aquifer (Hlevnjak et al. 2015). Since the biggest problems include the impracticality of the existing irrigation system with rubber hoses, unsustainable water and energy consumption, as well as insufficient capacity of the existing lifting pump in the well, there is a plan to build a new, more modern and sustainable irrigation system.

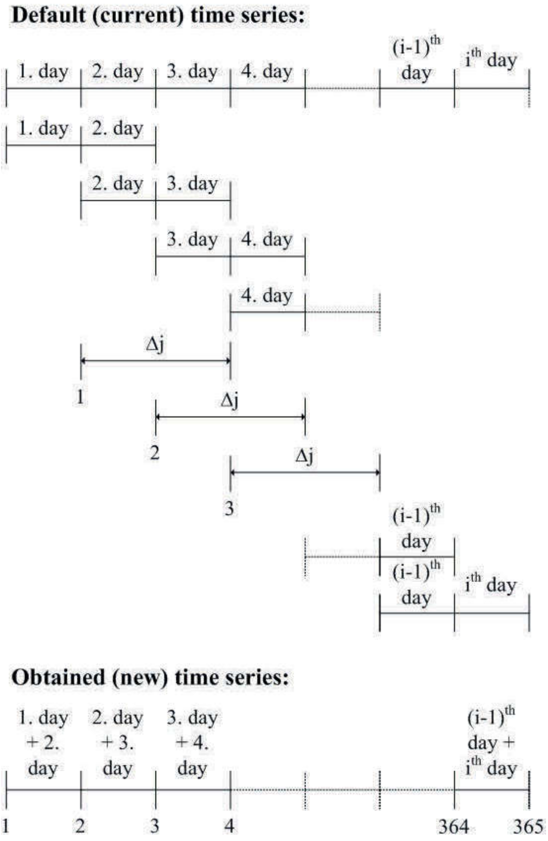

Figure 2. Schematic view of the forming of the time series membership for the balancing period t_b = 2 days

Figure 3. Position of the municipality Sveti Ilija, Croatia (modified from Adria24 2015 and Google maps 2016)

Figure 4. Irrigation system layout scheme (modified from Google maps 2016)

4.2. Input values

According to the recommendations from the bibliography (Buy Irrigation 2015) and the actual needs, the adopted daily constant water need (consumption) V_{daily} from May to August, and within these 4 months amounts to 30 m^3 (**Figure 5**). During the system operation over (out of) a period of 4 to 8 months, there will be an electric power surplus (or water surplus), which can be sold within the power (water) distribution system, or used for other purposes.

The football pitch is not irrigated during other periods of the year. There are two daily regimes of water consumption, i.e. water inflow and outfall (input/output) of water reservoir (**Figure 6**). In every hour, regarding of the daily irrigation regimes, football pitch is irrigated with 3 m^3/h.

Regime 1 (from 22 to 6 hours and from 14 to 16 hours) is more favorable if the pitch is busy during the day, and also it is more suitable for the grass if irrigation takes place during the night. Regime 2 (from 9 to 18 hours) is more practical considering the possibility of theft of the irrigation equipment, as well as the need to impose security measures for its prevention (alarms, physical protection). This irrigation regime is especially suitable if lighting of the field, respectively training and playing, is provided on night conditions.

Figure 7 shows average daily insolation intensity, where the angle of inclination of PV generator surface is equal to 15° and azimuth (angle spread) is in the south direction (SODA 2016) and peak hours period, **Equation (9)**. **Figure 8** shows average daily air (MHSC 2015) and solar cell temperature, **Equation (3)**, for the observed area. The data from MHSC (2015) are expressed as mean values for the duration of 10 years, i.e. for the period from 2004. to 2013. Also, the data from SODA (2016) was available and expressed as a mean values only for the duration of two years, 2004. and 2005.

Based on common values from references, (Đurin & Margeta 2014) the following values of input data are adopted. Average inverter efficiency is $\eta_I = 90$ %, while the average pump station efficiency is $\eta_{PS} = 60$ %. Average inverter and pump efficiency, with respect to **Equation (4)**, is $\eta_{PSI} = 54$ %, solar cell temperature coefficient is $\alpha_C = 0.005$ °C^{-1}, and solar cell temperature in Standard Test Conditions is $T_0 = 25$ °C. Adopted PV system efficiency is $\eta_{PV} = 15$ %. **Figure 9** shows mean of the monthly cumulative precipitation heights from May till August from 2004. to 2013.

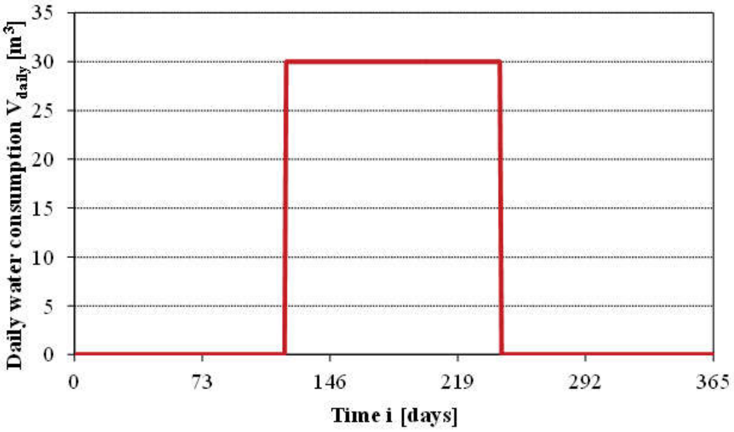

Figure 5. Yearly regimes of football pitch irrigation

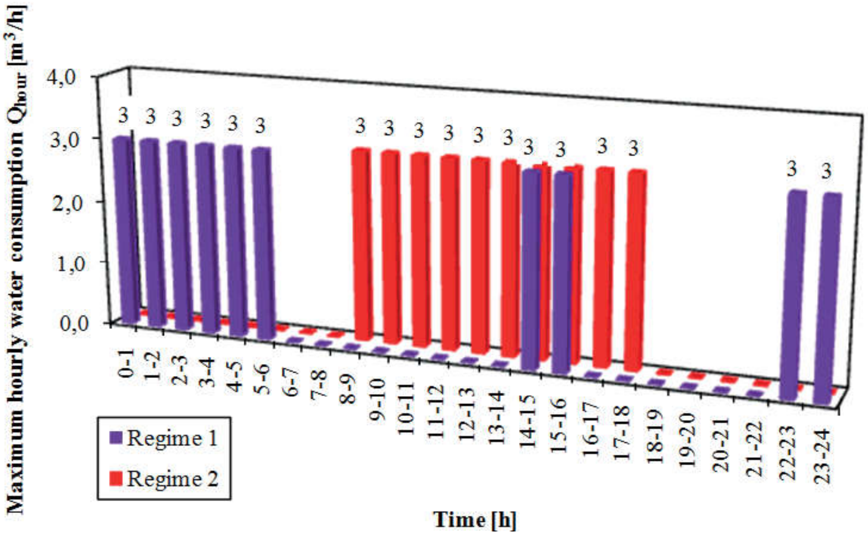

Figure 6. Daily regimes of football pitch irrigation

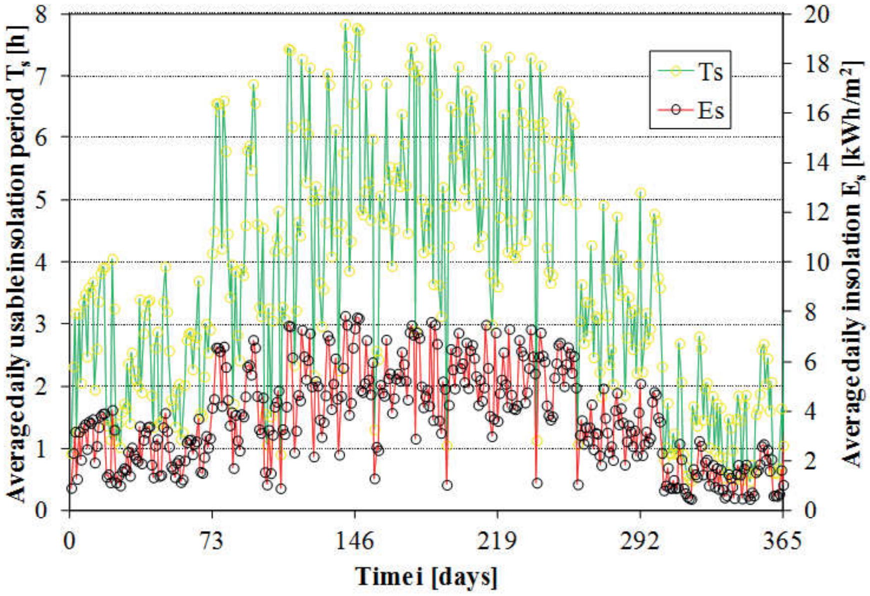

Figure 7. Average daily usable insolation period and insolation intensity

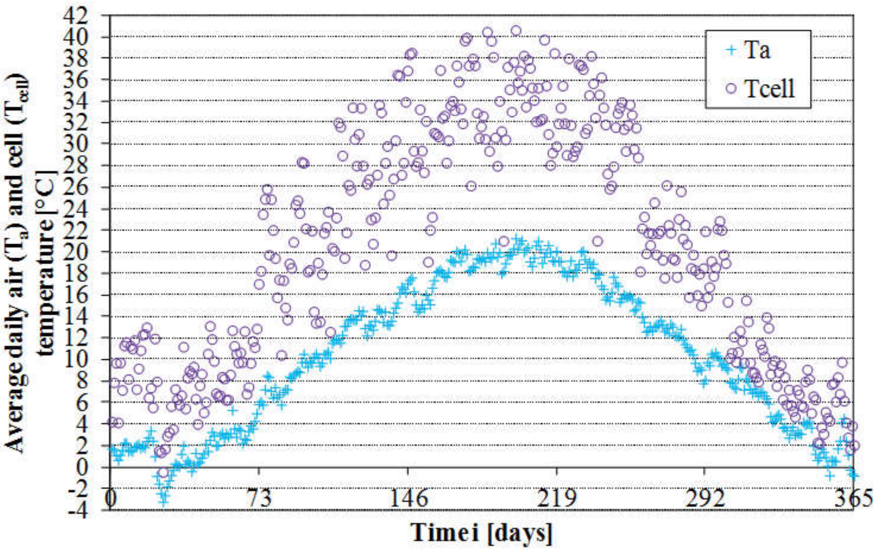

Figure 8. Average daily air and solar cell temperature

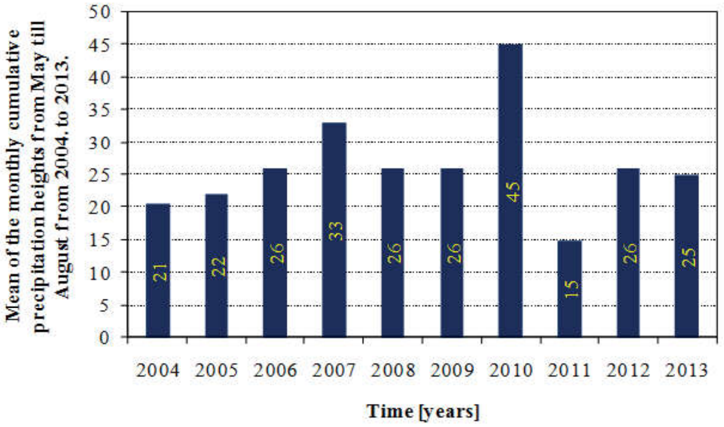

Figure 9. Mean of the monthly cumulative precipitation heights from May till August from 2004. to 2013.

Table 1. Critical days for sizing of all parts of the irrigation system

Balancing periods t_b (days)	1	2	3	4	5
Critical period (days in year) for the subsystem PV, t^*_{PV}	239	156-157	156-158	156-159	156-160
Critical period (days in year) for the subsystem V, t^*_V	239	238-239	155-157	154-157	156-160
Critical period (days in year) for the subsystem PS, t^*_{PS}	239	238-239	155-157	154-157	156-160

5. OBTAINED RESULTS AND DISCUSSION

The sizing procedure will be carried out for the period of balancing from one day (t_b = 1 day) to five days (t_b = 5 days). Critical days for sizing of all parts of the subsystem are shown in **Table 1**, according to the **Equations (15-17)**.

Table 1 shows that critical day for dimensioning of PV subsystems are in the same period of the year. Since the PV subsystem power and the amount of pumped water are functionally linked, **Equations (1)** and **(5)**, and the water consumption regime is constant, the observed overlapping is explained by the above mentioned. As for the critical period for sizing the subsystem V, $t^*_{V,tb,i}$ and PS, $t^*_{PS,tb,i}$, overlapping is also observed. According to **Equations (17) and (18)**, these critical periods depend on water consumption regime and the duration of pumping water into the water tank, or on the duration of pump operation. In other words, they depend on the duration of solar radiation suitable for pumping water, T_s. Since the water consumption regime is constant and critical periods depend on the duration of the pump operation, these critical periods will be at the time of the year when the duration of solar radiation suitable for pumping is minimum.

Taking into account the estimated total pressure losses in all the pipelines, secured height to prevent cavitation, as well as the required pressure of 3.5 bar for operation of the irrigation device (Buy Irrigation 2015), the adopted height of the water reservoir is 50 m, with the adopted pipeline diameter of 5 cm (as well as all pipelines) to the water reservoir. Pipe material is cast iron with bitumen, roughness coefficient is 0.1 mm, while the operating roughness coefficient is 0.11 mm (with the increase of 10 % to compensate local losses). The total calculated manometer height of a submersible well pump (with total pressure losses included, as well as secured height to prevent cavitation) is 10 m. Water is delivered from water reservoir 1 to water reservoir 2 by surface pump 2. The minimum or maximum speed range for water flow in inlet pipelines in both water reservoirs ranges from 0.5 m/s up to 2 m/s with respect to minimum (3.75 m^3/h) and maximum (15 m^3/h) hourly input water flow values to reservoirs 1 and 2. This means that the adopted capacity for both pumps is 15 m^3/h.

The necessary power of PV generator and invertor $P_{el,PV}$ i.e. required power for pump operation for every balancing period t_b is obtained using **Equations (1, 3, 4, 14 and 15)** and adopted required input values. These obtained values of the PV system power $P_{el,PV}$ are shown on **Figure 10**.

Figure 10 shows a trend of decline in the PV subsystem power $P_{el,PV}$ with increased balancing period t_b, which is in line with the input assumptions. The largest decrease was observed between t_b = 1 day and t_b = 2 days, 2714 W, i.e. a decrease of 58 %. Between t_b = 2 days and t_b = 5 days the decrease is 62 %. This also confirms the analogous conclusions obtained in earlier papers (Đurin & Margeta 2014; Margeta et al. 2011).

Figure 11 shows the required area of PV generator A_{PV}, obtained by using of the **Equation (6)**. Analogously of the decreasing of the required area of PV generator A_{PV} with increasing of the balancing periods t_b, there are identical conclusions which were adopted for the power of PV generator $P_{el,PV}$, **Figure 10**.

The required volume of the water reservoir 2 is V = 24 m^3 for all balancing periods, based on **Equations (9, 11, 13, 16)** and with regard to water needs, as well as both water consumption regimes (Regime 1 and 2), **Figure 12**.

It should be noted that water reservoir 1 volume is adopted based on the mean daily value of measured precipitation height within the observed period of 10 years (from 2004. to 2013.), which is 27.9 mm (MHSC 2015), with assumptions that losses of the storm water and also an evaporation is equal to 0. As a rule, the amount of storm water is calculated using statistical methods, taking into account certain probabilities of occurrence and return periods. This was not done due to the limited scope of this work as well as relatively small areas for rainwater collection. Because of this, it is necessary to ensure a certain capacity of the reservoir 1 which is equal to this extreme amount of water, rather than equalization of water inflow from the well and flow that goes from reservoir 1 to reservoir 2. It can be seen that required water reservoir volumes are decreasing with increasing of the balancing period, which is explained by decreasing of the PV generator area, A_{PV}.

Required power of the pumps P_{PS} are obtained by using of the **Equations (10-12, 17)** and shown on **Figure 13**.

Analogously to the case of reservoir volume, it is evident that the power of the pumping station is constant for each balancing period t_b. This is explained by the necessity to provide the capacity, i.e. pumping station power so that it can pump the required quantity of water. Since the amount of water is constant throughout the year, or days (**Figures 5 and 6**), this means that the capacity or pumping station power must be the same.

6. CONCLUSIONS

The aim of this study was to show the concept of systematic and sustainable use of water and energy in the case of football field of the local club. This solution can also be applied for urban areas, on local as well as regional scale for different purposes. Also, this solution can be used in combination with conventional sources of energy from the electricity grid. The resulting solution is conservatively selected/sized, enabling high reliability of irrigation system, which is particularly affected by the increase in the balancing period t_b. It also allows the use of surplus electricity generated for other purposes (lighting, operation of various electrical devices, etc.) or for distribution or sale within the electricity network. It is necessary to take into account the long-standing trend of decreasing prices of PV cells, where the current average price is 0.4 US $ per 1 peak Watt of power (Energy Trend 2016; PVinsights, 2016; SolarServer 2016). An additional fact in favor of this is the current trend of increasing the efficiency of PV cells, where currently the largest practical efficiency of the cells is 38.8% (Green et al. 2015), while laboratory efficiency is 46.0 % (National Energy Renewable Laboratory 2016). Due to small quantities of collected rainwater, in this analysis it does not replace the affected groundwater, but still ensures a certain backup volume of water. Storm water also improves the quality of water used for irrigation. It is important to note that purified wastewater can also be used for irrigation of grass areas, especially in rural areas without significant influence of industry. It is also shown that water reservoirs, apart from irrigation purposes and hydraulic function of water storage, function as energy storage as well. Shown solution fits into global and European strategies and guidelines related to the reduction of greenhouse gasses, increasing the use of renewable energy sources and energy efficiency increase.

Further research would consist of using of the multicriterial methods, taking into the account economic, environmental and social criterions.

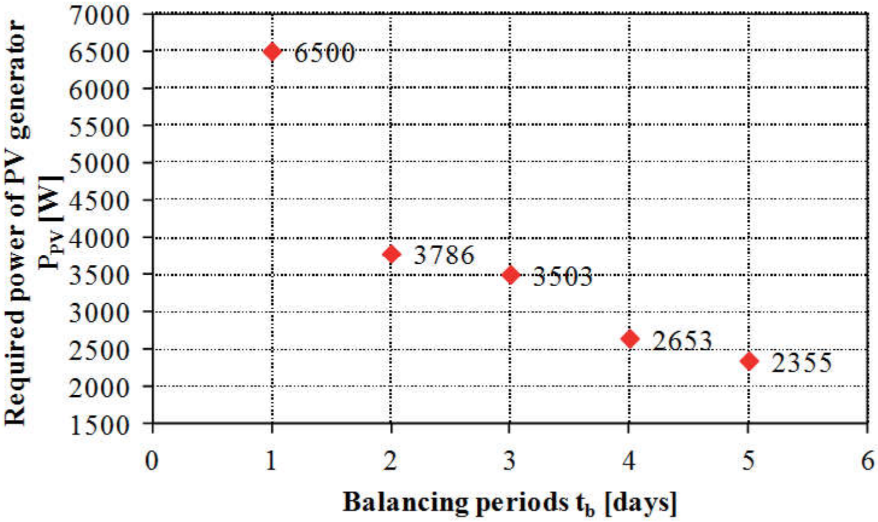

Figure 10. Required power of a PV generator in accordance with the length of the balancing period

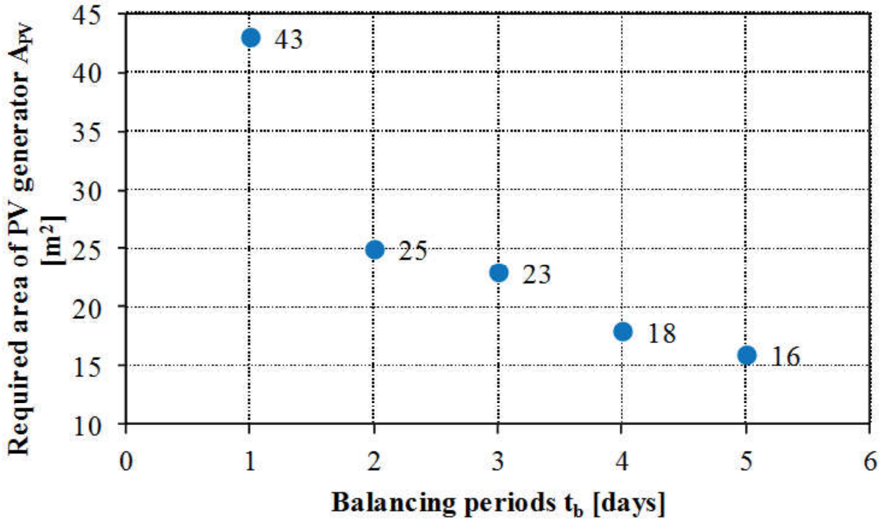

Figure 11. Required area of a PV generator in accordance with the length of the balancing period

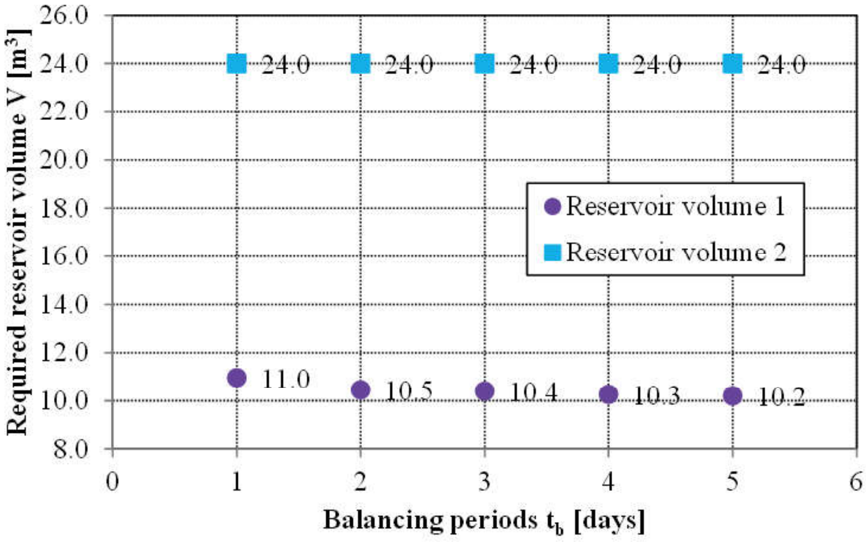

Figure 12. Required volume of a water reservoirs in accordance with the length of the balancing period

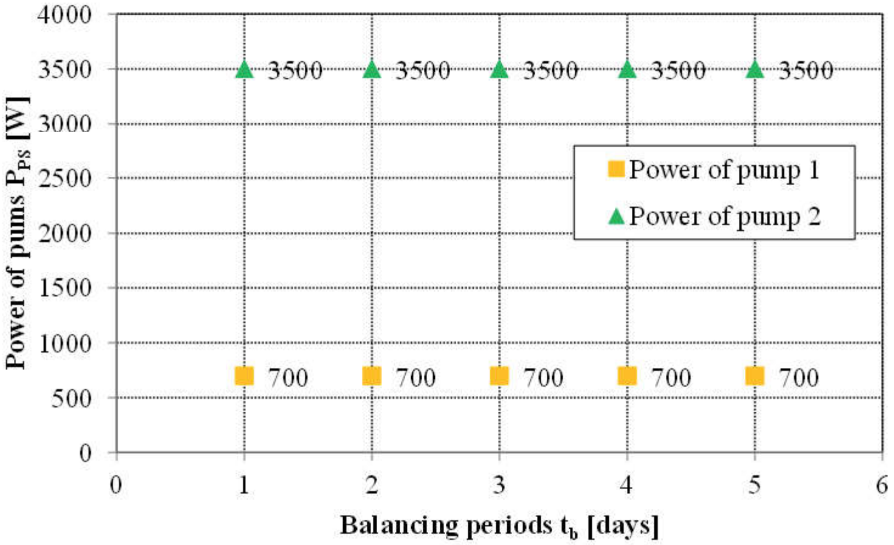

Figure 13. Required power of the pumps in accordance with the length of the balancing period

7. REFERENCES

Adria24, http://www.adria24.hr/destinacije/, (Access Date: 27 December, 2015)

Agriwaterpedia, http://agriwaterpedia.info/wiki/Solar_Powered_Water_Pumps (Access Date: 20 December 2015)

Boizidi B. (2013) New sizing method of PV water pumping systems, Sustainable Energy Technologies and Assessments, vol. 4, pp. 1-10

Bakelli Y., Hadj A. A., & Azoui B. (2011) Optimal sizing of photovoltaic pumping system with water tank storage using LPSP concept, Solar Energy, vol. 85, pp. 288-294

Buy Irrigation, https://buyirrigation.wordpress.com/tag/football-pitch-irrigation/, (Access Date: 28 July, 2015)

Chandel S. S., Nagaraju M., Naik, & Chande R. (2015) Review of solar photovoltaic water pumping system technology for irrigation and community drinking water supplies, Renewable and Sustainable Energy Reviews, vol. 49, pp. 1084-1099

Cuadros F., Lopez-Rodriguez F., Marcos A. & Coello J. (2004) A procedure to size solar-powered irrigation (photoirrigation) schemes, Solar Energy, vol. 76, pp. 465–473

Đurin B. & Margeta J. (2014) Analysis of the possible use of solar photovoltaic energy in urban water supply systems, Water, vol. 6, pp. 1546-1561

Đurin B. (2014) Sustainability of the urban water supply system operating, PhD thesis (on Croatian), Faculty of Civil Engineering, Architecture and Geodesy, University of Split, Split, Croatia

Đurin B., Margeta J. & Bojanić D. (2015) The Impact of the Water Consumption Regime on the Work of Reservoirs, E-Water, 2015, vol 1, pp. 1-21

Ebaid M. S. Y., Qandil H. & Hammad M. (2013) A unified approach for designing a photovoltaic solar system for the underground water pumping well-34 at Disi aquifer, Energy Conversion and Management, vol. 75, pp. 780-795

Energy Trend, http://pv.energytrend.com/pricequotes.html (Access Date: 18 february 2016)

Ghoneim A. A. (2006) Design optimization of photovoltaic powered water pumping system, Energy Conversion and Management, vol. 47, pp. 1449-1463

Green M. A., Emery K., Hishikawa Y., Warta W. & Dunlop E. D. (2015) Solar cell efficiency tables (version 46), Progress In Photovoltaics: Research And Applications, vol. 23, pp. 805–812

Google maps, location of municipality Sveti Ilija and football pitch F.C. Obreš, https://www.google.hr/maps/, (Access Date: 20 January, 2016)

Hamidat A. & Benyoucef B. (2009) Systematic procedures for sizing photovoltaic pumping system, using water tank storage, Energy Policy, vol. 37, pp. 1489-1501

Hamidat A., Benyoucef B. & Hartani T. (2002) Small-scale irrigation with photovoltaic water pumping system in Sahara regions, Renewable Energy, 2002., vol. 28, pp. 1081-1096.

Hlevnjak B., Strelec S. & Jasmin J. (2015) Hydrogeological Conditions of Occurrence of Clay Interbed within Varaždin Aquifer, (on Croatian), Inženjerstvo okoliša, vol. 2, pp. 73-81

Meteorological and Hydrological Service (MHSC) (2015) Meteorological and hydrological data for Varaždin from 2004. till 2014., (In Croatian), MHSC: Zagreb, Croatia

Margeta J. & Glasnović Z. (2007) Optimization of Irrigation with Photovoltaic Pumping System for Irrigation, Water Resources Management, vol. 21, pp. 1277–1297

Margeta J., Đurin B. & Glasnović Z. (2011) Urban water supply generated by PV energy, ISES Solar World Congress, Kassel, Germany, pp. 1-11

National Renewable Energy Laboratory, http://www.nrel.gov/ncpv/images/efficiency_chart.jpg (Access Date: 21 February 2016)

PVinsights, http://pvinsights.com/ (Access Date: 22 February, 2016).

SODA-Solar Radiation Data-Solar Energy Services for Professionals, http://www.soda-is.com/eng/services/services_radiation_free_eng.php, (Access Date: 2 August, 2015).

Solar Server, http://www.solarserver.com/service/pvx-spot-market-price-index-solar-pv-modules.html (Access Date: 15 January 2016).