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PV water pumping for irrigation equipped with a novel control system for water savings

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Abstract

Typically, PV water pumping (PVWP) systems for irrigation are normally designed based on the worst conditions, such as high water demand and low solar irradiation. Therefore, the installed PVWP systems become oversized in most of time. Since the conventional control systems don't optimize the water supply, the water losses are increased. To remedy the problems related to the operation of the oversized systems, a novel control system is proposed. The control unit interacts between water demand and water supply in order to pump only the amount required by crops. Moreover, the novel control system substitutes the conventional protection approach with a method based on the ground water resources availability and response. The novel control system represents an innovative solution for water savings in PV watering applications.

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Keywords: PV, water pumping, water resources availability and response, energy analysis, control system.

1. Introduction

Photovoltaic water pumping (PVWP) systems represent a feasible and renewable solution to support and promote the sustainable management of the water resources and the development of the agricultural sector [1-4]. In order to guarantee the match between the water demand and the water supply, the PVWP system is commonly designed for the month that has the highest ratio of water demand to available solar irradiation [5]. As a result, the installed system becomes oversized for most of the irrigation season due to the variability of water demand and solar irradiation. Moreover, the conventional PVWP control system is unable to adjust the pumped water according to the water demand. Typically, only a control sensor is installed in order to protect the pump in case of drying up of the well. Due to the oversizing of the system, the pumped water may be too much, and therefore, much water is lost. Another potential consequence is over-exploiting the water resource may damage the ecology system. To overcome these problems, a novel control system is proposed. It can consider the groundwater resources, the pumped water and the water demand simultaneously. The proposed control system guarantees a sustainable management of the water resources by matching the water demand and water supply and taking also into consideration the dynamic response of groundwater. An analysis of the water savings is conducted.

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2. Description of the system

The control system allows the pumping unit to lift only the amount of water demand estimated on daily average or monthly average. The crop water requirement is estimated for a specific location and crop through dedicated software and set in the control system. If a more accurate assessment is required, the water demand can be dynamically estimated through a weather station connected to the control system. Then, the water supply can be calculated directly by the control system and controlled by setting the power-flow curve of the pumping unit or through dedicated water flow sensor. If the pumped water exceeds the water demand, the control system stops the pump. If the groundwater level drops below a certain depth, considered strategic for a sustainable management of the water resources, the control system adjusts the pump speed according to the water refilling rate. In the meantime, when the water demand is low, the surplus of power generated from the PV array can be used for other purposes, such as feeding electric grid. Fig. 1 describes the novel control system strategy.

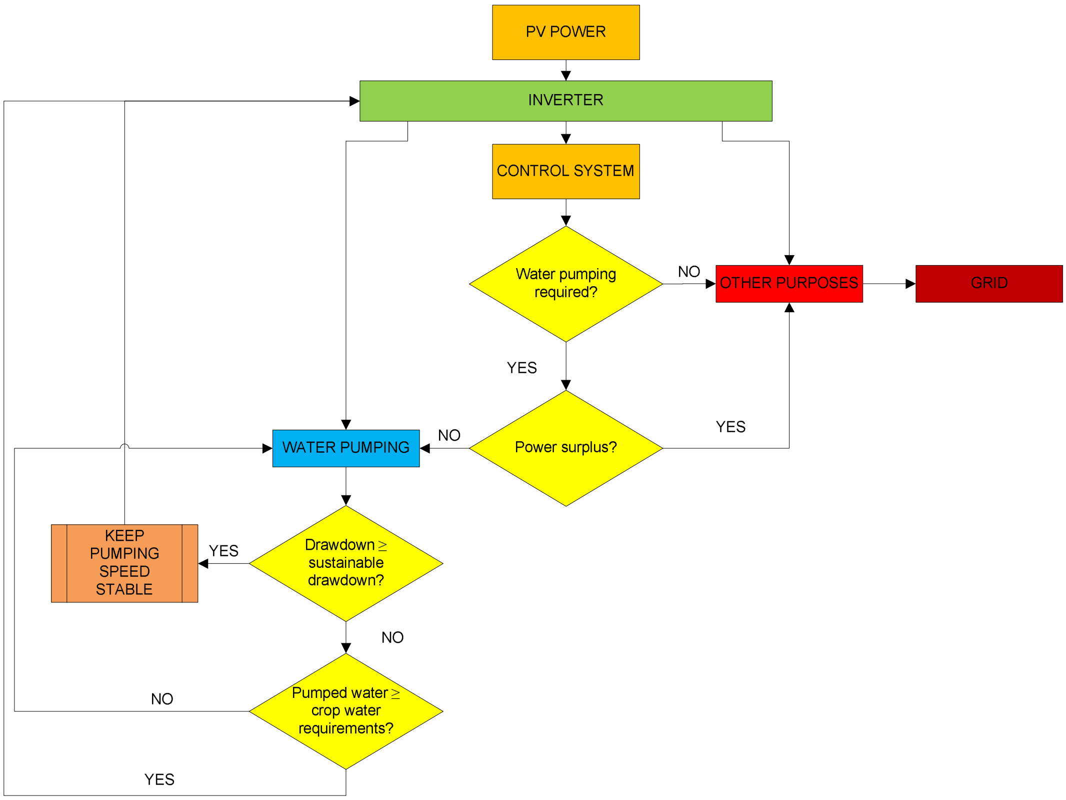

Fig. 1. Novel control system strategy.

3. Methodology

The simulated PVWP system has been designed to irrigate 3 hectares of Alfalfa (*Medicago Sativa*) in Dulan, a county in the east-central Qinghai Province, China (Latitude: 36°18' N; Longitude: 98°05' E; Altitude: 3194 m a.s.l.). The PV array power peak has been calculated with the approach used by [5]:

$$P_p = \frac{0.0027}{f_m[1 - \alpha_c(T_{cell} - T_0)]\eta_{MP}} \frac{IWR_p\, TDH}{E_S} \qquad (1)$$

Where, P_P is the array power peak (kW_p), *0.0027* is a conversion factor, IWR_p represent the peak of the daily irrigation requirements during the irrigation season (m^3/ha day), *TDH* is the total dynamic head assumed equal to 70 m, f_m is the matching factor equal to 0.9, α_C is the PV modules temperature coefficient equal to 0.0045 %/°C, T_{cell} is the cell temperature (°C), T_0 is the reference temperature equal to 25°C and E_S is the daily solar irradiation hitting the array (kWh/m^2 day) for the designing month. The irrigation water requirements have been estimated using the Penman-Monteith method [6]. The simulations of the PVWP system, and thus of the water pumped, have been conducted with PVsyst (v5.0) [7]. The simulations of the drawdown *s* have been carried out using the approach valid for sinusoidal pumping rate in confined aquifer [8].

4. Results

The designed PV array and pumping system are 12.8 kW_p and 9.5 kW, respectively. Fig. 2 shows both the supplied water and the water demand. During the irrigation season, the control system will control the pump to supply only the demanded amount; while during the non-irrigation season, the PVWP system can be turned off to avoid exploitation of unrequired groundwater resources.

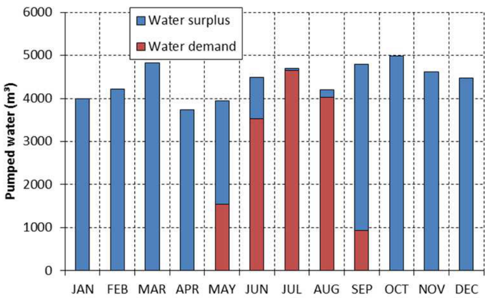

Fig. 2. Water demand and water surplus.

Fig. 3 shows how the system reacts when the pumped water cause a decline of the ground water level below a predefined sustainable level, which is assumed equal to 1.3 m in this work. The decline of the groundwater level can have different causes such as simultaneous pumping from different wells, aquifer overexploitation and drought. The control system keeps the water level above 1.3 m.

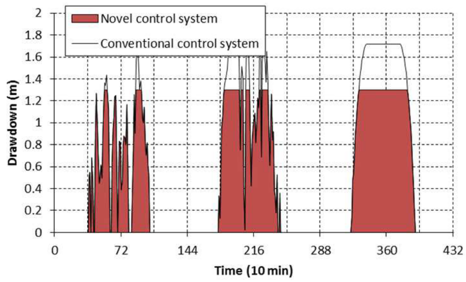

Fig. 3. Drawdown control.

Fig. 3 shows the control system operation highlighting the pumped water with and without control system for three irrigation days in May. The results are based on the monthly daily average crop water requirements, equal to 50 m^3/day. When the water pumped exceeds that amount, the pumping is shut down. For the PVWP system not equipped with control system, it operates all the time, resulting in a high water consumption. Comparing the results shown in Fig 4, 75% of water can be saved if the system is not turned off.

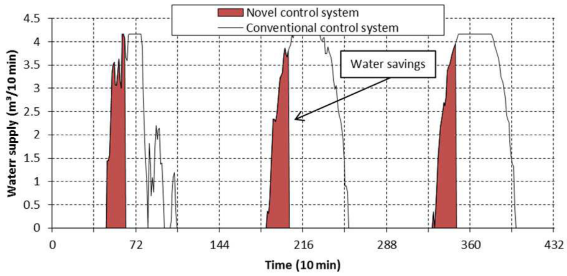

Fig. 4. Water savings based on the monthly average daily crop water demand.

5. Discussions

The conventional design strategy for PVWP systems results in an oversized installed systems in most of the time. By matching water supply and water demand, there exists a surplus of electricity production from the PV array, which can be used for other applications. Harnessing the surplus of electricity production can promote the economic feasibility of PVWP. If incentives such as feed-in tariffs for renewable energy production can be considered, there would be more benefits if the proposed control system is used for on-grid PVWP applications.

6. Conclusions

In this study, a novel control system for PVWP is proposed. The simulations carried out show how the novel control system allows optimizing the match between crop water requirements and water supply, which can achieve the sustainable management of the groundwater resources. The novel control system manages automatically the water supply on the basis of the ground water response and water demand. It can exploit the surplus power generated by PVWP systems both in on- and off-grid applications. The new control strategy results both in water savings and optimization of energy use.

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Biography

Pietro Elia Campana graduated in Environmental Engineering at the University of Perugia. Currently, he is PhD candidate in Energy and Environmental Technology at Mälardalen University.