

Optimal design of a standalone direct pumping photovoltaic system for deficit irrigation of olive orchards



R. López-Luque^{a,*}, J. Reca^b, J. Martínez^b

^a Department of Applied Physics, University of Córdoba, Room C21E030, Albert Einstein Building, Campus of Rabanales, 14071 Córdoba, Spain

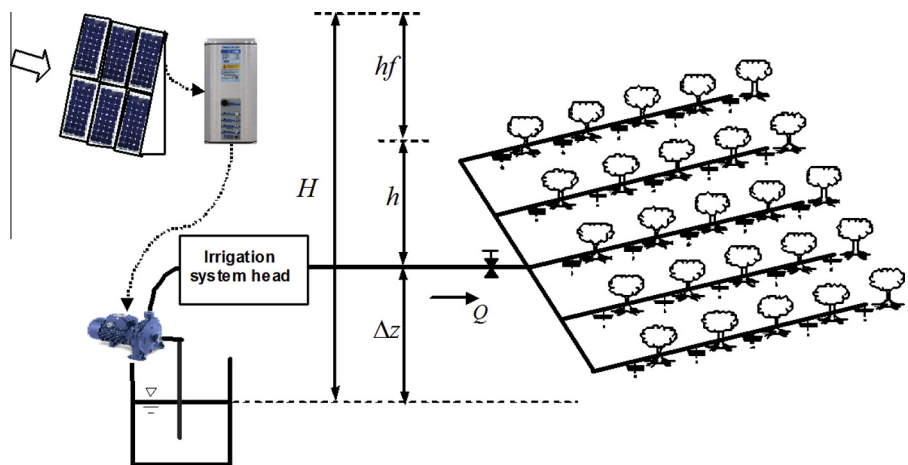
^b Department of Engineering, University of Almería, 04120 Almería, Spain

HIGHLIGHTS

- The new concept called Photovoltaics Opportunity Irrigation (PVOI) is introduced.
- A standalone PVOI system is proposed for the irrigation of olive trees.
- A simulation model of a PVOI system is developed to optimize its design.
- The optimal design of the PVOI system was achieved under deficit irrigation.
- The PVOI approach provided reductions in the investment costs and water savings.

GRAPHICAL ABSTRACT

Scheme of the proposed PV direct irrigation system.



ARTICLE INFO

Article history:

Received 9 January 2015
Received in revised form 20 March 2015
Accepted 21 March 2015
Available online 7 April 2015

Keywords:

Photovoltaics Opportunity Irrigation (PVOI)
Solar energy
Photovoltaic energy
Olive orchard
Deficit irrigation
PV optimal design

ABSTRACT

In this work, an optimal standalone direct pumping photovoltaic irrigation system is proposed for the deficit irrigation of olive orchards. A simulation model of the system was developed in order to obtain the economically optimal design of this system. This model is composed of different sub-models: the photovoltaic power generation capacity sub-model, the direct pumping management sub-model and the sub-model that evaluates the economic and productive response of the crop to the application of water. The model simulates for increasing values of peak power of the photovoltaic system, the water and energy balance in the photovoltaic irrigation system and the crop yield. It also calculates the investments and operational costs of the system and, finally, the net economic returns to the farmer. The model enables us to select the optimal design of the system that achieves its maximum economic profitability.

The economically optimal designs provided by the model are not achieved for a completely full irrigation of the crop but rather for deficit irrigation. In this way, we propose a new approach to PV irrigation systems design and management that we call PV opportunity irrigation (PVOI). PVOI makes use of the ability of many crops to undergo some water stress without experiencing a significant yield loss in order to reduce the size of the PV irrigation system. The operational strategy in the PVOI approach is to irrigate as long as enough power is supplied by the PV array. Unlike any other conventional design method available in literature, the total amount of water applied to the crop depends on the energy provided by the PV

* Corresponding author.

E-mail addresses: fa1lolur@uco.es (R. López-Luque), jreca@ual.es (J. Reca), jumartin@ual.es (J. Martínez).

Nomenclature

D	soil water depletion	q	emitter discharge
ET_d	actual evapotranspiration of the crop (mm)	Q	total discharge of the pumping system (m^3/s)
ET_c	crop evapotranspiration (mm)	r_h	ratio of the minimum working pressure of the emitter (h_m) to the maximum (h_M)
ET_o	reference evapotranspiration (mm)	R_n	net irrigation depth (mm)
F_w	fraction of soil wetted by the emitter	R_s	equivalent resistance coefficient of the irrigation network
H	total energy head (m)	S	slope coefficient for silicon cells $^\circ\text{C}/(\text{W m}^{-2})$
h	working pressure head at the emitter (m)	T_a	air temperature ($^\circ\text{C}$)
hf	overall head loss in the distribution network (m)	T_{cell}	temperature of the cells in the module ($^\circ\text{C}$)
$I(t)$	irradiance on the inclined collector plane (W m^{-2})	T_{STC}	cell temperature under standard test conditions ($^\circ\text{C}$)
$I_b(t)$	solar direct irradiance as a function of time t (W m^{-2})	x	pressure-discharge exponent of the emitter
$I_d(t)$	solar diffuse irradiance as a function of time t (W m^{-2})	Y_a	actual crop yield
I_m	irradiance minimum threshold value (W m^{-2})	Y_M	potential crop yield
I_{STC}	irradiance under standard conditions (W m^{-2})	β	performance decay coefficient due to the rising temperature of the cell
k	discharge coefficient of the emitter	Δz	elevation change (m)
K	overall inverse discharge coefficient of the emitters in the irrigation network	φ	tilt angle of the PV modules
K_c	crop coefficient	ρ	albedo
K_{ES}	crop coefficient due to the surface evaporation from the soil outside the wetted bulb	θ	direct solar radiation incidence angle with respect to the inclined collector plane
K_{EW}	crop coefficient due to the Surface evaporation from the soil wetted by the emitters	θ_z	direct solar radiation incidence angle with respect to the horizontal plane
k_s	water stress coefficient		
K_{TC}	crop coefficient due to the tree transpiration		
K_{TW}	crop coefficient due to the cover crop (or actively growing weeds) transpiration		
K_y	yield response factor		
N	pump speed (rpm)		
n_e	total number of emitters in the irrigation system		
P	net power transferred to the water (W)		
P_e	effective precipitation (mm)		
PP	peak power generated by the PV modules under standard conditions (W)		
P_{PV}	photovoltaic power provided by the PV system (W)		
$P_{PV,min}$	minimum value of utilizable photovoltaic power (W)		

Subscripts

d	refers to a specific day d
i	refers to the working conditions for the pump operating at any intermediate speed
M	refers to the working conditions for the pump operating at its maximum speed
m	refers to the working conditions for the pump operating at its lowest speed

array rather than on a strict fulfillment of the pre-established crop water irrigation requirements. The application of the PVOI approach implies not only a reduction in the investment costs of the system but also some water savings, which is very important in areas with water scarcity.

© 2015 Elsevier Ltd. All rights reserved.

1. Introduction

Solar energy has a very high potential in Mediterranean areas as this region's climate is characterized by a high number of sunlight hours. For this reason, the irrigation of many crops in these areas with photovoltaic (PV) energy systems is increasingly gaining interest.

Olives are one of the most widespread crops in the Mediterranean basin. Their contribution to the local economy of many areas is of paramount importance. Traditionally, olives are cultivated under rainfed conditions; however, many studies have shown that the application of irrigation water results in a significant increase in yield and a considerable reduction of the problem of alternate bearing [1,2]. For this reason, in recent years, there has been an enormous increase in irrigated olive land area using drip irrigation systems.

Controlled deficit irrigation has been proposed as a profitable technique in water stress tolerant crops like olive orchards. The objective of deficit irrigation is to apply less water than that

required to achieve a maximum potential yield. This technique is economically feasible for crops that are relatively tolerant to water stress and when the cost of the water applied is relatively high. The effect of different controlled deficit irrigation strategies on olive yield have been studied in different research works [3,1,4–7].

In spite of the abovementioned benefits of irrigation on the production of olive oil, many traditional olive orchards continue to be only rainfed as farms are located in outlying lands where other alternative crops are not feasible and, in many cases, far from electricity distribution facilities. The investment costs needed to electrify these farms can be excessively high. In addition, in many countries in the Mediterranean basin like Spain, the price of electricity has become increasingly higher in recent years. The increase in energy costs can jeopardize the economic feasibility of most of these olive orchards. The use of off-grid powering systems seems to be appropriate in cases like this one. At present, off-grid electrification is becoming an active field of research [8].

Standalone photovoltaic irrigation systems are being used for many types of irrigation systems throughout the world [9,10].

متن کامل مقاله

دریافت فوری ←

ISIArticles

مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات