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A new photovoltaic floating cover system for water reservoirs

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ABSTRACT

This paper describes a new photovoltaic floating cover system for water reservoirs developed jointly by the company CELEMIN ENERGY and the Universidad Politécnica de Valencia. The system consists of polyethylene floating modules which, with the use of tension producing elements and elastic fasteners, are able to adapt to varying reservoir water levels.

A full-scale plant located near Alicante (Spain) was built in an agriculture reservoir to study the behaviour of the system. The top of the reservoir has a surface area of 4700 m^2 but only 7% of such area has been covered with the fixed solar system.

The system also minimizes evaporation losses from water reservoirs.

1. Introduction

Nowadays, farmers' income is strongly affected by the electricity costs. High production costs, small farm size, competitive international markets and the water deficit are the main causes that characterize the difficult situation of the Spanish agriculture.

The demand for energy is to increase in the agriculture industry as a consequence of the greater use of the water resources and the modernization plans carried out in the last decades. The installation of more efficient irrigation systems has led to water savings; however, power consumption has grown because of increasing pumping needs and filter operations. So, although water efficiency has improved in the agriculture sector, electric power demand has increased substantially. Upward revisions of the electricity rates and uncertain future scenarios adversely affect the price of water.

The solutions to these problems come not only from setting special electricity rates for irrigation but also from improving the energy and water efficiency of the irrigation systems. Renewable energy sources emerge as a way to counter-balance such situations.

The new irrigation plans involve the transformation of traditional systems into pressurized systems. In most cases, this modernization has demanded the construction of water reservoirs. Among the different storage systems available, earth reservoirs waterproofed with geomembranes are the most widely used solution.

In arid and semi-arid climates, water stored in reservoirs would be better managed if evaporation losses from the water surface were reduced.

In this sense, Bengoechea et al. [1] studied the water evaporation rate in agricultural water reservoirs in the south of Spain (Almeria) and estimated that water losses by evaporation in farms amounted to 17 percent. Martinez et al. [2] estimated water losses of 60 hm^3 for the Segura Basin (Murcia, Spain), which means more than 8% of the available water supply for irrigation purposes. Craig et al. [3] suggested that evaporation phenomena in agricultural reservoirs in Queensland (Australia) were the cause of a total water loss of 1000 hm^3, i.e. about 40 percent of its total storage capacity. Gökbulak et al. [4] made similar studies from lakes and dams in Turkey and estimated potential water savings of more than 20%.

The above results highlight that the evaporative losses from water storages at both the farm and the regional scales can be large. Thereby, the assessment of such losses and the development of evaporation mitigation techniques are crucial for preserving the limited water resources [5–7].

In the last decades, several evaporation control products were developed to control evaporation losses from water reservoirs [8]. These products range from floating covers, modular covers, shade structures, chemical monolayer covers and biological and design methods. Craig et al. [3] highlighted the good performance of mechanical methods, either floating systems or suspended shade structures. The evaporation reduction achieved with such systems is around 80%.

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Moreover the use of floating covers provides other benefits like:

- lower filtering costs (by controlling sunlight and water temperature),
- much longer duration of the geomembranes,
- reduced silt accumulation.

But there is a lack of technical studies about cover systems for irrigation reservoirs. Although in Spain a standard for reservoir covers has been recently published [9], its scope is for systems based on geomembranes (not on floating ones) and it focuses on the execution process, not on system design.

However, latest trends show an increasing interest for developing membrane and spatial structures to minimise water evaporation [10,11].

The Photovoltaic Floating Cover System (PFCS) described in this paper is the synergic response to the issues mentioned above and is highly innovative in today's agriculture sustainability. On the one hand, an evaporation mitigation technology is applied into agricultural water reservoirs. On the other hand, the production of clean energy is envisaged as a means of balance the electricity costs either exporting the electricity back to the grid or enabling to generate power for self-consumption [12].

The solution consists of a continuous platform placed above the water level by replicating a floating module which acts as the support of the photovoltaic panels. To our knowledge, no detailed studies assessing the performance of a photovoltaic covering system for reservoirs have been published to date. Also, a distinguishing element of the present system is that covers the whole area of the reservoir (bottom surface and upstream slope areas).

2. Key design elements

The primary purpose of the PFCS is to improve water and power efficiency of agricultural irrigation reservoirs as illustrated in Fig. 1. The water surface is covered with a number of floating modules which are joined together by means of pins. Incident solar radiation is used to produce renewable energy. Additionally, properly designed reservoir cover systems prevent fluid loss due to evaporation and by blocking off sunlight they prevent algae bloom.

The key design factors affecting the performance of the system are:

- Good structural performance of the floating platform as a partially submerged body.
- Good structural behaviour of the reservoir and floating cover as a whole.
- Ability to adapt to varying reservoir water levels and reservoir layouts.
- Meeting the PV installation requirements.
- Minimizing in-situ work during construction and exploitation.

In summary, the primary purpose of the system is to meet the water requirements of the reservoir while maximizing power production.

2.1. Suitability assessment of the reservoir layout

Floating cover systems require site specific planning and design to be successful. Most reservoir designs are irregular in order to better fit land topography. Moreover, both the reservoir's walls and the different design layouts for the internal 3D geometry of the reservoir are highly variable. As a consequence, the geometry of the floating module has to be versatile enough to properly adapt to different internal geometries of the water reservoir.

2.2. Geometry of the floating module

The floating module's geometry was designed taking into account two main issues. First, the dimensions of the module must be adapted to commercial photovoltaic panels. Second, the modules must cover the maximum possible water surface to prevent water evaporation.

The solar issues under analysis were: photovoltaic panel dimensions and tilt angle, number of units to be installed, distance between panel rows to prevent shade effects and access ways to ease operational maintenance.

Several configurations and geometries of the floating module were studied before selecting the design presented in Fig. 2, which comprises two 1.6 × 1.0 m/200 Wp panels and a 0.5 m access way.

For the latitude of the field site (Agost, Alicante province, Spain), 30° is the optimal tilt angle for the fix solar panels to maximize energy production. However the shade analysis for the prototype installed in the reservoir named "El Negret", revealed (Table 1) that lower tilt angles not only provided better electrical performance but also a more regular module geometry. As the tilt angle of the FV array decreases, it is needed a shorter distance between row lines of PV panels to prevent interactive shadows. As a result, a more homogeneous module grid was obtained. Besides, low tilt angles significantly reduced the effects of wind uplift and drifting. Since wind forces play an important role in the structural behaviour of the system, the use of low tilt angles will improve the global performance of the system. Also, Table 1 shows the energy yield obtained from meteorological data and a global performance ratio of 0.75.

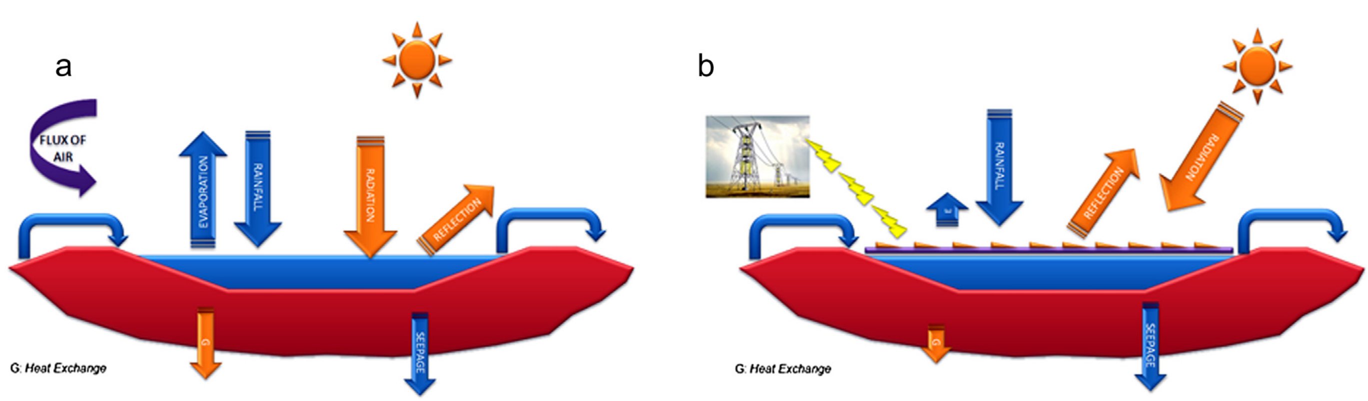

Fig. 1. Water & energy balance: a) Uncovered reservoir. b) Photovoltaic Floating Cover System.