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Theoretical and experimental analysis of a floating photovoltaic cover for water irrigation reservoirs

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ABSTRACT

The article presents the main design features and photovoltaic requirements of a FPCS (floating photovoltaic cover system) for water irrigation reservoirs whose purpose is to reduce the evaporation of water while generating electrical power. Also, a summary of installation costs and relationship with the yield performance is deeply analyzed. A prototype of 20 kWp was implemented, and given the success of the results observed, the whole surface reservoir was covered (4490 m^2 and 300 kWp). The paper analyses the first electricity productions of the system and from these data the CO_2 balance of the facility is calculated.

1. Introduction

Many irrigation systems have considerably increased its electricity consumption due to novel irrigation modernization plans. Therefore, nowadays, power costs mean a high proportion of the running costs of many farmers' irrigation associations. According to Corominas [1], the transformation of the traditional irrigation methods to pressurized systems, which has been going on in Spain since 1950, has reduced water consumption per hectare by 23% while power consumption has risen by 670%.

On the other hand, 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 [2].

In arid and semi-arid climates, water stored in reservoirs would be better managed if evaporation losses from the water surface were reduced. However, the practice of covering irrigation reservoirs is still relatively little used, although as water is becoming an even scarcer resource, interest in these systems is expected to grow in the future [3].

The different techniques available for this purpose can be divided into five main groups: (i) chemical, (ii) physical, (iii) biological, (iv) construction and exploitation, and (v) mechanical [4]. Of these, the last, involving fixed or floating mechanical and structural systems is the most important [5].

Bengoechea et al. [6] 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%. Water losses in the Segura Basin (Murcia, Spain) have been estimated in 60 h m^3, which means more than 8% of the available water supply for irrigation purposes [7]. Research in Australia suggests that 40% of open reservoir's water could be lost through evaporation [8]. Meanwhile, estimations performed from lakes and dams in Turkey give potential water savings of more than 20% [9].

Moreover, by shielding the water from solar radiation, photosynthesis and weed growth are reduced, thus improving water quality [10]. Based on the numerous studies on the subject that have been published, it can therefore be said that such methods provide more efficient irrigation systems [11].

Water and energy are coupled in an intimate way [12]. This relationship is starting to be called as the "water–energy nexus" and it is deemed to be a key strategic issue for future planning and

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policy considerations [13]. Besides, since water resources are becoming increasingly scarce, nations are obliged to use non-traditional water sources such as desalinated and recycled water; choices that need to be sensitive to the environmental impacts of the required electricity [14]. Finally, such water volumes are gradually stored in reservoirs along the year since its continuous production is normally outdated from the crop water needs. Thus, there is a growing interest in developing evaporation mitigation technologies to conserve and better utilize existing water resources [15].

As previously stated, water use performance for irrigation and its interdependence with energy has been deeply analyzed. Also, at the strategic level of management of the water resources stored in reservoirs and dams, some of them have assessed the economic impact of water evaporation losses from water surfaces [3]. Moreover, other studies have stressed the need to study the energy consumption and energy output of different fruit and vegetable crops [16,17].

However, until a few years ago, little effort has been developed in conceiving reservoirs, ponds and small lakes as a potential area to produce renewable energy. An interesting approach to this issue is the integration of photovoltaic into the water infrastructure [15]. Thus, emerges a new applied solar technology known as floating PV (photovoltaic). The main attraction of the PV systems is that they produce electric power without harming the environment, by directly transforming a free inexhaustive source of energy, the solar energy into electricity [18].The main motivation for the floating PV panels was the land premium and energy efficiency. Since water reservoirs are fully integrated in the irrigation and water supply network of geographical areas with profitable agricultural activity, land is deemed to be used for food production. The pre-mature stages of this technology application together with the propriety nature somewhat limit the literature available on floating PV installations.

The developed floating PV projects include conventional PV arrays, as well as concentrated PV arrays which benefit from the surrounding water body to prevent overheating of the solar cells [19–22]. Future concepts proposed for marine and large lacustrine sites are envisaged to incorporate laminated thin film PV [23,24]. Economics of the concept for floating PV arrays in irrigation reservoirs is developed by the author [15]. Also, economic analysis and the embodied carbon assessment for offshore (marine and lacustrine) PV environment are studied in Ref. [24].

This work is focused on the theoretical and experimental analysis of a FPCS (floating photovoltaic cover system) for water irrigation reservoirs. The floating technology has been developed seeking both to reduce evaporation of water and also generate renewable electricity. In such way, the irrigation system will move towards a more sustainable activity and thus, the whole agricultural sector will manage energy and water resources more efficiently.

Accordingly, the paper is organized as follows. The following section develops the requirements of design of the FPCS continuing with the description of the principal elements of the system. The study of the design factors is provided in Section 4 which is complemented in Section 5 with the economic analysis. Section 6 shows the real implementation of the FPCS together with a first approach to the CO_2 balance. This allows us to infer some recommendations in the Conclusion section providing some suggestions for further research.

2. Design requirements

The main objective of the floating photovoltaic cover (FPCS) is to improve the water–energy balance in irrigation reservoirs, as seen in Fig. 1. The surface is covered by a set of floating plastic modules that intercept solar radiation to generate power and are joined together by articulated couplings [20,25]. It can also be seen that the basic needs of the system are based on ensuring its structural integrity in accordance with the reservoir's characteristics while producing the maximum possible amount of electricity.

In order to meet the plant's solar and power requirements, the following factors were considered:

- Inclination and orientation of the modules to make the most efficient use of radiation.
- Dimensions of solar panels: basic geometry of 1.65 m long (h) by 1.00 m wide (b) was adopted (Fig. 3).
- Inter-panel separation to reduce shaded areas to a minimum, calculated according to the latitude of the site.
- Layout of servicing and maintenance walkways planned to facilitate operation of the photovoltaic plant. It is envisaged a minimum access way of 0.5 m between the rows forming the whole grid.

The floating deck placed above the top surface of the reservoir must also take into account the operational and design characteristics of the reservoir as a water storage and supply system. So that the following items were analyzed:

- Inclination of photovoltaic panels (α). The angle of elevation of the solar modules has a strong influence on the action of the wind on the cover.
- Geometry and characteristics of the reservoir. The geometric definition of the reservoirs is characterized by polygonal or irregular shapes searching to fit into the topography of the land to be set. Also, their principal alignments may or may not be optimal for maximum energy production as regards their degree of alignment with the cardinal points. Thus, in the physical environment or territory, there can be found multiple design layouts of reservoirs with varying agreement between the land

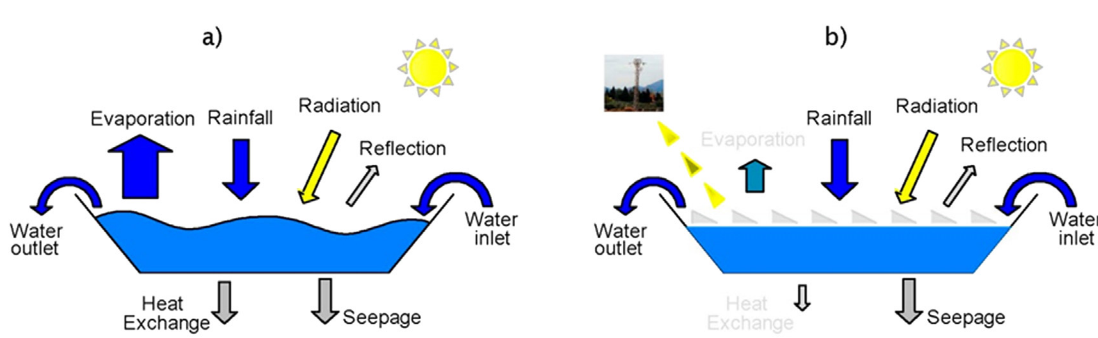

Fig. 1. Power balance. a) Uncovered reservoir. b) Floating photovoltaic cover system.