Control predictivo para satisfacer la demanda de agua en un invernadero mediante un sistema de desalación solar

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Resumen

El déficit de agua en el área mediterránea es un problema que afecta de forma severa a la agricultura. Entre las opciones para evitar la sobreexplotación de los acuíferos se encuentran los procesos de desalación térmica que tienen la ventaja de poder ser alimentados térmicamente mediante el uso de la energía solar, garantizando así la sostenibilidad a largo plazo. En este artículo se muestran simulaciones de un caso de estudio en el que una planta solar con una unidad de destilación multi-efecto produce agua para el riego de un invernadero. Con el fin de operar adecuadamente dicha planta y garantizar el agua demandada por los cultivos, se propone un controlador predictivo que hace uso de los distintos modelos que forman el conjunto desalación-invernadero.

Palabras clave: Control de Proceso, Modelado, Energía Solar, Simulación Dinámica, Desalación Multi-efecto

Predictive control applied to a solar desalination plant connected to a greenhouse with daily variation of irrigation water demand

Abstract

The water deficit in the Mediterranean area is a known matter severely affecting agriculture. One way to avoid the aquifers exploitation is to supply water to crops by using thermal desalination processes. Moreover, in order to guarantee long-term sustainability, the required thermal energy for the desalination process can be provided by solar energy. This paper shows simulations for a case study in which a solar multi-effect distillation plant produces water for irrigation purposes. Detailed models of the involved systems are the base of a predictive controller to operate the desalination plant and guarantee the water demanded by the crops.

Keywords: Process Control, Modelling, Solar Energy, Dynamic Simulation, Multi-Effect Desalination.

Introduction

Modern agricultural systems are characterized by the intensive and optimal use of land and water, turning agricultural exploitation into a semi-industrial concept. Greenhouses are systems suitable for zones with unfavorable climatic conditions - allowing crop growth regardless of the ambient temperature, and for regions with less restrictive weather - with the aim of increasing crop productivity and improving fruit quality. Crop growth is primarily determined by climatic variables of the environment and the amount of water and fertilizers applied through irrigation. Therefore, crop growth can be controlled through these variables. Productivity optimization through efficient and adequate irrigation is a basic objective in those countries with water limitations. The water deficit has been progressively depleting the aquifers in the southeast of Spain

(Sánchez-Martos et al., 1999). Eighty per cent of the irrigation water used in Almería (Spain) comes from underground sources, leading to localized over exploitation of aquifers (Fernández et al., 2007). Over the last few years it has been promoted the use of alternative water sources such as purified water, rain and condensed water collection as a secondary source, the reuse of drainage water, the development of new technologies related to water-use efficiency such as advanced irrigation controllers, and seawater desalination. This paper deals with the combination of a greenhouse and a solar multi-effect distillation (MED) unit. The aim is to take advantage of the water produced in the MED unit to feed a greenhouse, being both systems located in the southeast of Spain. The challenge is to properly operate the desalination plant to produce the daily water demanded by the crop.

Case Study

The case study explored in this paper is a micro-grid framework in which two interconnected plants must be managed; a greenhouse and a solar desalination plant (Roca et al., 2014). On one hand, the greenhouse daily demands fresh water for irrigation purposes and, on the other hand, a solar desalination plant produces distillate water in a MED unit. An intermediate distillate storage tank is assumed to be located between the production process and the consumer system. The greenhouse data used in this research was acquired from the Cajamar Foundation Experimental Station greenhouses in El Ejido, Almería Province, Spain. The crops grew in a multispan “Parral-type" greenhouse with 877 m^2 and polyethylene cover. All data are recorded every minute with a personal computer and all the actuators are driven by relays designed for this task. The desalination plant used in this study is the AQUASOL system that is located at Plataforma Solar de Almería in southeast of Spain. This pilot plant includes a MED unit coupled with a solar collector field. A detailed description of the MED unit and the AQUASOL facility can be found in (de la Calle et al., 2015).

System Model

The greenhouse dynamic behavior is obtained with an energy balance that takes into account convective heat fluxes, heat losses and latent heat effect from crop transpiration (Rodriguez et al., 2015). The model of the solar desalination plant is divided in three main components; the solar field (Roca et al., 2008a), the storage system (Roca et al., 2008b) and the MED unit (de la Calle et al., 2015).

Control Scheme

The controller aim is to maintain a desired volume of distillate, D_{ref}, taking into account the quantity of water demanded by the greenhouse. The proposed scheme (see Fig.1) includes a state machine, a reference layer (with model predictive controllers, MPC) and a regulatory layer (with feedback linearization, FLC, and PI controllers). The greenhouse model is used to estimate the future water consumption, $\hat{C}$, depending on ambient temperature, T_a, humidity, H, and irradiance in the horizontal plane, I_{horiz}. The solar desalination model estimates solar field, tanks and MED temperatures, $\hat{y}$, that are used by the reference layer to evaluate optimal setpoints for the temperatures at the inlet of the

MED heater, $T_{iM,ref}$, and at the outlet of the solar field, $T_{oF,ref}$. These two variables can be regulated, in the regulatory layer, by means of a control valve V_t and the solar field water mass flow rate, $\dot{m}_F$, respectively. Both layers are activated when the MED unit is running, CM=1, state that is defined by the State Machine in base of the rules explicitly imposed. This State Machine requires three inputs: solar field outlet temperature, T_{oF}, hot water tank temperature, T_h, and titled solar irradiance, I_{titled}.

Simulation Results

With the aim of scaling the greenhouse water consumption to the solar desalination production, 10 greenhouses have been considered in the simulation. Therefore, the real consumption values obtained from the greenhouse have been multiplied by 10. The setpoint in the distillate tank has been established to 36 m^3 in order to store water for three days in case of cloudy days. As Fig. 2 shows, during the first 5 days, the distillate volume is maintained around the setpoint, with the higher deviation at day 3. During the following four days, the low solar irradiance level causes a severe fall in the distillate volume and 2 weeks with good solar irradiance will be required to recover the desired level. This situation reveals the necessity of considering an auxiliary system to feed the MED unit.

In order to observe the benefits of using the reference layer, these results have been compared with a case without reference layer (see Table 1). The advantages are: lower control performance index IAE, lower electrical energy consumed in the solar field, P_F, and higher storage energy in the tanks, E_a. The disadvantage is that the MED unit must be operated more hours, increasing then the electrical energy consumed in the plant.

Conclusions

The use of an appropriate control scheme in a solar desalination plant for greenhouse irrigation purposes could assure the water demand, reduce electricity costs in the solar field pump and maintain more thermal energy in the storage system. Future works will deal with a hybrid solar MED scheme and the minimization of the global costs. Simulations along the whole year will be included.

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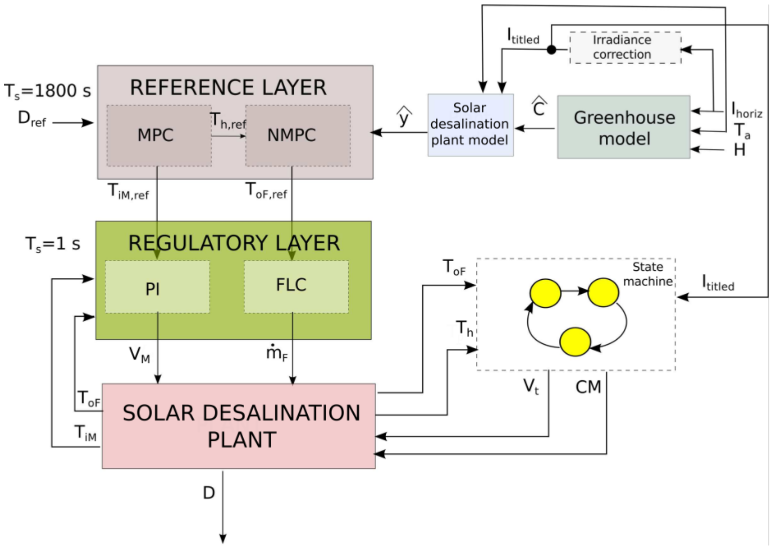

Figure 1. Proposed control scheme to obtain a desired volume of distillate

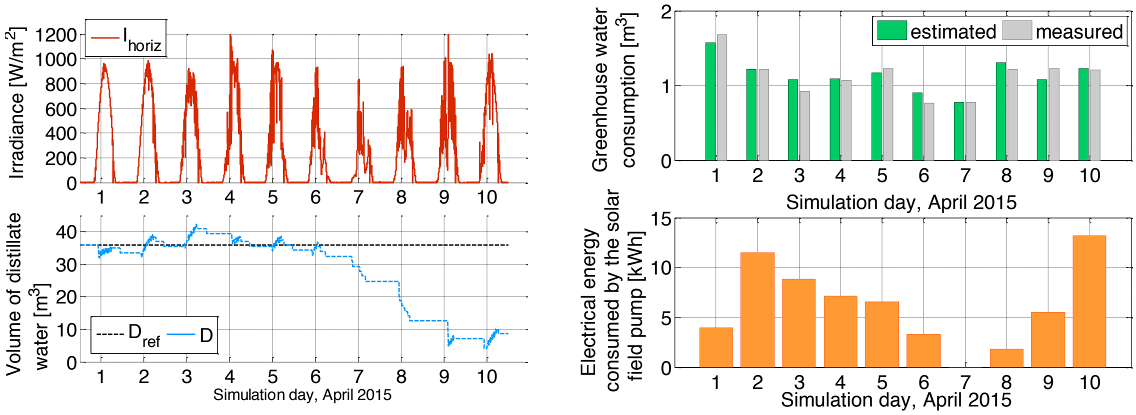

Figure 2. Solar irradiance and simulation results during ten days

Table 1. *Results obtained for ten days and comparison without using the reference layer.*

Reference Layer	IAE [m^3]	P_F [kWh]	E_a [kJ]	MED operating hours
Yes	7.3524e+06	61.7	2.4018e+07	42.5
No	7.7793e+06	64.4	2.3985e+07	38.5