Proceedings of the 17th Nordic Process Control Workshop
Technical University of Denmark, Kgs Lyngby, Denmark
January 25-27, 2012

Greenhouse LED lighting control

Torsten Wik * **Anna-Maria Carstensen** * **Tessa Pocock** **

* *Department of Signals and Systems, Chalmers University of Technology, Göteborg, Sweden*
** *Heliospectra AB, Göteborg, Sweden*

Abstract: Industrial scale greenhouses have, during the last decade, reached a high level of automation. However, lighting control is in general still controlled manually because of the type of lamps (High Pressure Sodium) that are used. With High Brightness LEDs about to reach the market today sufficiently high power for greenhouse grown crops can be achieved, and this opens up for advanced lighting control. Optimized control will, however, be a difficult task because the needs of the plants differ between individual plants, crops, time of the day, time of the growth cycle, temperature, and of course the natural ambient light. In this approach to this problem we distinguish four different control loops: growth control, ambient light compensation, light stress detection and recovery, and spectrum optimization, where the focus of this work is on the latter two. In particular it is shown here that light induced photoinhibition, decreasing photosynthetic yield and potentially damaging the plants, can be remotely detected in a light environment.

1. INTRODUCTION

Contrary to most people's belief, green house lighting is a major energy consumer in Europe. The current electricity consumption is estimated to be around 150 TWh per year, which is about the same as the total electricity consumption in Sweden. Modern Dutch green houses are built in two storeys, 10ha in size, and with an electricity consumption of 10 MW powered by gas turbines. A lowered electricity consumption would clearly have a significant environmental impact and also allow for crops grown closer to the consumer.

Today, almost all full scale green houses use High Pressure Sodium (HPS) lamps for their lighting. These lamps are more or less of the same type as those used for highways. They are highly efficient in the sense that they give a lot of light for a given power. However, what has not been commonly known is that the spectra they produce do not fit well to the absorption spectrum of the photosynthesis. In fact, the mismatch, with a lot of power in the far red, implies that approximately one third of the emitted light energy can never be used by the plants, and often the wasted light is even higher (see Figure 1). Another problem with the HPS lamps is that they are not adjustable and slow to start, and therefore they are in general not controlled even though most other processes in a commercial green house are.

Today there are high power LEDs available on the market and a company, Heliospectra AB in Göteborg, is developing LED-based lamps for green houses. These lamps contain several different groups of LEDs having different colors to better fit the absorption spectrum of the photosynthesis (Figure 1). In Figure 2 the first commercial installation for one of Santa Marias (Swedeponics) green house for basil is shown.

Since LEDs are easily adjustable in power this opens up for feed forward as well as feedback control. This control

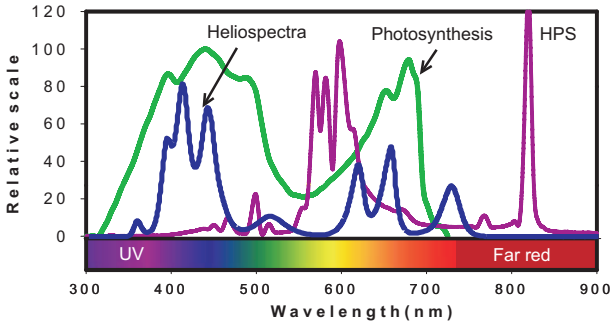

Fig. 1. The action spectrum of the photosynthesis, HPS lamps and the prototype LED-lamp.

Fig. 2. The first commercial installation of the Heliospectra lamp in a basil house at Swedeponic, Påarp, Sweden. (Photo: T. Pocock for Heliospectra).

possibility may cause potentially large energy savings through at least the following mechanisms:

- *Growth control.* Today the growers have poor possibilities to adjust the plant growth, which have the effect that a significant part of the harvest has to be thrown away because the demand does not match the produce. For this reason Swedeponic, for example, throw away 15% of their basil produced. Using variable light intensities we can control the growth rate within certain limits, hence minimizing this waste.

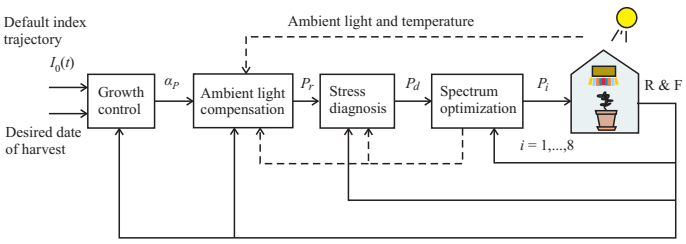

Fig. 3. The basic components of the LED lamp control system being developed.

- *Photoinhibition.* Excess light causes plant stress and the induction of photo protective mechanisms that lower the yield. The plants may even become damaged with a permanent decreased photosynthetic yield. (Note that the human eye cannot see when the light stress begins but only when the plants are actually being damaged!)
- *Light spectrum.* The intensities of the different LED-groups (colors) should be adjusted to the needs of the plant.

2. METHOD AND PRELIMINARY RESULTS

In this project we are aiming at a control system for a LED-lamp adjusting the LED intensities to the needs of the plants and the grower, based on sensors installed in the lamp. The system is characterized according to the above energy saving mechanisms (see Figure 3).

To determine the needs of the plant is a difficult task, but their status affects the light emitted (fluorescence) and the light reflected from the plants. A key research task is therefore how to use the measured emitted and reflected light to diagnose the plants.

2.1 Stress diagnosis

Analysis of fluorescence, using fluorescence indices such as F_v/F_m, from plants is a well established method for detecting plant stress. However, such standard methods require on leaf measures and a completely controlled environment. To be used in practice for automatic control, the stress has to be sensed remotely. Takayama et al. [2011] have remotely detected plant stress (draught) in tomato plants in a greenhouse using fluorescence. However, their method requires dark adaption (complete darkness for at least 20 minutes), and can thus only be used at night and not in daylight, which is the normal situation for our application.

In a series of experiments we have focused on diagnosing the signaling response to different light excitations with the purpose of finding when the plants become stressed by excess light. We have then found that the fluorescent light at 685 nm responded well to an excitation signal at 420 nm. As a first step we have investigated the responses to steps (Figure 4) and to slowly varying sinusoids (Figure 5). From the step responses it can be concluded that the plants exhibit different dynamics for increases in light intensity than for decreases. In particular it was found that the dynamics of the up-steps were significantly changed by excess light already at moderate (reversible) photoinhibition. A

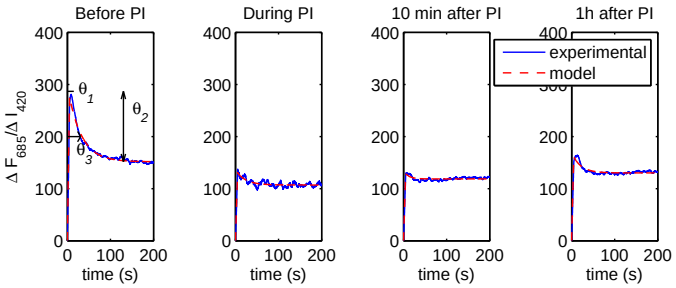

Fig. 4. First order transfer functions with direct term fit closely to the up-steps with clear parameter changes caused by the photo inhibition.

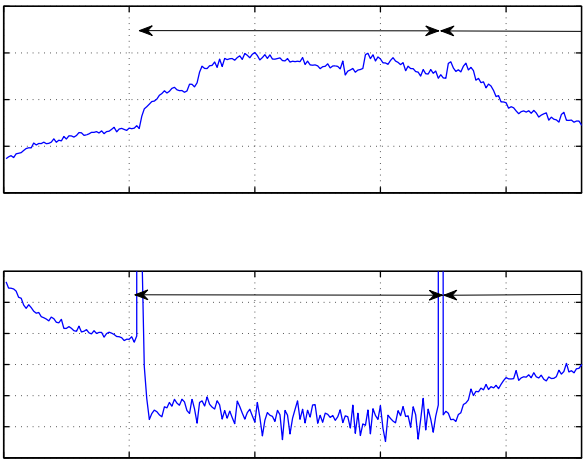

Fig. 5. The ratio between the amplitude of the variation at 60-1 Hz in the reflected light at 420 nm and the amplitude of the variation in the emitted light at 420 nm (top). The corresponding ratio between the variations in fluorescence at 685 nm and of the applied light at 420 nm (bottom).

relatively close fit of the responses to first order transfer functions on the form

$$G(s) = \theta_1 - \frac{\theta_2}{1 + s\theta_3}$$

to the measured responses could be achieved (Figure 4), with clear changes in model parameters (Figure 6), implying that photo inhibition can in fact be remotely detected in a light environment. In the next step, recursive identification of models having direction dependent dynamics (Rosenqvist [2004]) using a superimposed suitable binary excitation signal at 420 nm, for example, will be investigated as an approach to have a continuous online diagnosis.

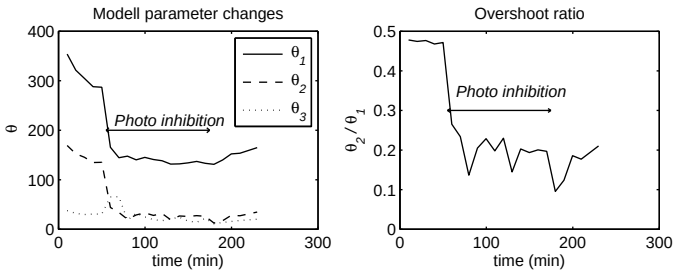

Fig. 6. Changes in model parameters (see Figure 4) during and after photo inhibition.

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