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A New Control Strategy of Indoor Air Temperature in an Photovoltaic Greenhouse

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Abstract— **This paper presents the application of the photovoltaic energy to supply electrical power for a temperature controlling system of a greenhouse. A linearizing algorithm is applied to the physical model of the greenhouse in order to calculate the needed air flow to cool down the temperature if it exceeds a wanted level. The control of the temperature is ensured by a fan ventilation system through a DC/AC converter and an asynchronous machine.**
The model of the PV system and the greenhouse has been implemented in the Matlab/Simulink software and simulations have been presented to show the efficiency of the proposed system.

Keywords-component; Photovoltaic Energy; DC/AC inverter; Asynchronous Machine; Greenhouse; physical model; Linearizing algorithm..

I. INTRODUCTION

The renewable energy technologies represent an alternative solution for the fuel and gas sources. Compared to the decrease and the environmental effects of traditional energy sources, the renewable energy are eco-friendly and nonfinite sources. The technology of the photovoltaic energy is more and more investigated in different industrial fields and diverse applications such as rural agriculture.

Cooling a greenhouse during the summer when the internal temperature exceeds nominal value of the growth of plants is very important for a better productivity and to protect plants from different diseases.

In this work, a PVG is used to supply electrical power to a ventilation system which is used to introduce fresh air inside the greenhouse when the internal temperature is relatively high. MPPT algorithm based on the variable reference voltage and a rotor field oriented vector are investigated to ensure the control of the ventilation system

II. MODELING OF THE VENTILATION SYSTEM

The ventilation system is based on the three components; the PVG, a DC/AC converter and an asynchronous machine.

A. Modeling of the PVG

The model of the considered solar cell is given by the figure 1 where the characteristic I=f(V) is written as below [1],[2]:

$$I = I_{ph} - I_{d1}\left[e^{\frac{q(V+IR_s)}{n_1KT}} - 1\right] - I_{d2}\left[e^{\frac{q(V+IR_s)}{n_2KT}} - 1\right] + \frac{V + IR_s}{R_p}$$

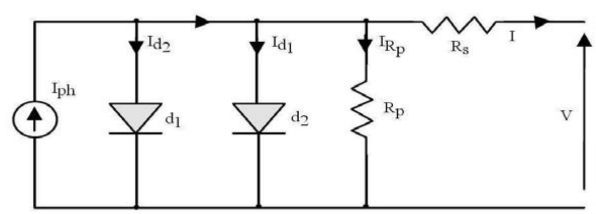

Figure 1. Equivalent electrical model of a solar cell

Where:
I_{ph} : photocurrent
q : electron charge (1.6 10-19 C)
k: Boltzmann's constant (1.38 10-23 J/K)
R_p : parallel resistance or shunt resistance
R_s : serie resistance
n_1 , n_2 : ideality factor of p-n junction
T: cell's working temperature

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B. Modeling of the DC/AC inverter

The DC/AC inverter consists on a three–voltage source inverter based on three arms containing, each one, complementary switches based on pulse width modulation PWM [3],[4].

The inverter's current is given by:

$$I_{inv} = K_1 I_a + K_2 I_b + K_3 I_c$$

Where;

I_a , I_b , I_c are the output current from each arms.

K_1,K_2,K_3 are the controller signals of the switches.

C. Modeling the asynchronous machine

The model of the asynchronous machine in the case of a rotor field oriented vector control is given by the given by[5],[6]:

$$\begin{bmatrix} \frac{dI_{ds}}{dt} \\ \frac{dI_{qs}}{dt} \\ \frac{d\Phi_{dr}}{dt} \\ \frac{d\Phi_{qr}}{dt} \end{bmatrix} = \begin{bmatrix} a_1 & \omega_s & a_3 & a_4\omega_r \\ -\omega_s & a_1 & -a_4\omega_r & a_3 \\ a_5 & 0 & a_6 & \omega_s-\omega_r \\ 0 & a_5 & -(\omega_s-\omega_r) & a_6 \end{bmatrix} \begin{bmatrix} I_{ds} \\ I_{qs} \\ \Phi_{dr} \\ \Phi_{qr} \end{bmatrix} + \begin{bmatrix} b_1 & 0 \\ 0 & b_1 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix}$$

Where:

$$\begin{cases} a_1 = -\frac{1}{k_s}\left[R_s + \frac{M^2}{L_r T_r}\right], a_3 = \frac{M}{k_s L_r T_r}, a_4 = \frac{M}{k_s L_r}, a_5 = \frac{M}{T_r}, a_6 = -\frac{1}{T_r} \\ b_1 = \frac{1}{k_s} \\ k_s = \sigma L_s \end{cases}$$

Dispersion's Blondel Coefficient

$$\sigma = 1 - \frac{M^2}{L_s L_r}$$

The rotor and stator time coefficient are:

$$\begin{cases} T_r = \frac{L_r}{R_r} \\ T_s = \frac{L_s}{R_s} \end{cases}$$

ω_S : Pulsation of reference d_q

$$\omega_r = p\Omega = p\frac{d\theta}{dt}$$

The electric pulsation:

R_s ,R_r: Stator and rotor resistance;

L_s, L_r : Stator and rotor inductance;

M: mutual inductance;

p: number of pole-pair

III. MODELING OF THE GREENHOUSE

A greenhouse is characterized by different thermal and water exchanges with the external environment [7],[8]which are shown in figure.2

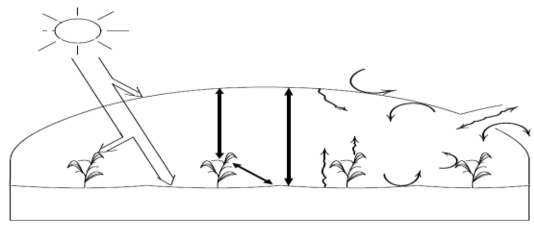

Figure 2. Scheme of different thermal and water exchanges in a greenhouse

(⇒): radiation exchanges short-wavelength, (↔) radiation exchanges long-wavelength, (↺): Exchange by conduction and convection, (↝): water exchange

A greenhouse constitutes is a complex dynamic system. Different approaches are investigated to describe the evolution of the internal environment versus the variation of the solar radiation and the ambient temperature.

Considering different thermal and water exchanges, an approximated physical model describing the evolution of the inside air temperature could be written [9],[10],[11],:

$$\begin{aligned} m_a C_a \, {}^{dT_a}\!/_{dt} = \Big(& k_1 \alpha_c S_c \\ & + \left(\left(k_2 \alpha_{pl} + k_4 A^*\right) S_{pl} + k_3 \alpha_s S_s\right) \tau_c \Big) R_s \\ & + \left(\frac{\lambda_c}{e_c} + h_{ce}\right) S_c (T_e - T_a) \\ & + \rho_a U C_a (T_e - T_a) + B^* S_{pl} (W_a^* - W_a) \end{aligned}$$

Where:

$$\frac{\delta}{\delta + (1 + r_t/r_a)} = A^* \qquad \frac{\rho_a C_a}{r_a(\delta + (1 + r_t/r_a))} = B^*$$

C_a: Specific heat of the air (J.Kg-1 .K-1)

T_a: Temperature of inside air (K-1)

α_c, α_{pl}, α_s:Coefficients of radiation absorption, consequently by the cover, the plants and the soil (-)

S_c,S_{pl}, S_s: Consequently represents the surface of the cover , soil and the plants (m2)

τ_c : Transmission coefficients of the cover (-)

R_s : Solar radiation (W.m-1)

λ_c: Conductivity of the cover (W.m-1.K-1)

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e_c: Thickness of the cover (m)

h_{ce}: Coefficient of convection cover-outside air (W.m-2.K-1)

T_e: Outside air temperature (K-1)

ρ_a: Air density (Kg.m-3)

W_a: Absolute Humidity of inside air (Kg-1.Kg-1)

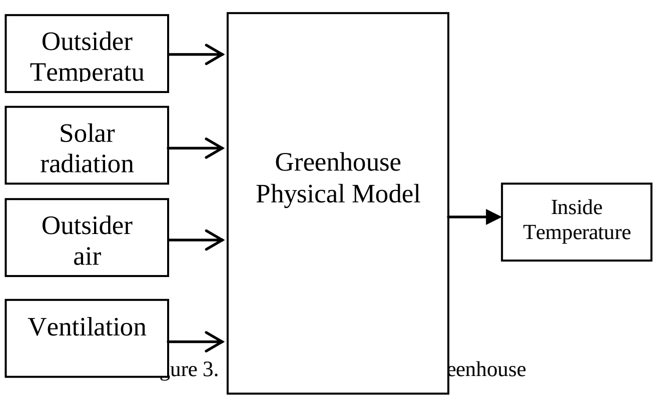
W_a^*: Absolute saturated humidity of the inside air (Kg-1.Kg-1)

r_a: Resistance of the upper layer to the heat transfer (S.m-1)

r_t: Resistance of the plants to the heat transfer (S.m-1)

δ: Curve slope of the saturated air pressure versus T_a (-)

The physical model is presented in the figure.3



ure 3. eenhouse

IV. Control of the Inside Temperature of the Greenhouse

The control of the inside temperature of the greenhouse is ensured by a linearizing algorithm, expressed by the following formula:

$$u_c = 1/\, g(x, v)\ .\ (u_e - f\,(x, v))$$

f(x,v), g(x,v) are non-linear functions.

This algorithm allows is applied to the physical model of the greenhouse expressed in 3, where:
x : state vector : inside temperature of the greenhouse
v: external perturbation :outside temperature , solar radiation
u_c : varibles in the linearizing algorithm : speed of the ventilation
u_e : dTa/dt : finite variation of the inside temperature

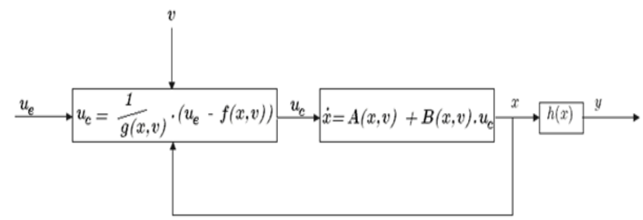


Figure 4. Linearizing algorithm

V. Results and Discussion

A. Validation of the physical model of the greenhouse

Under the same climate conditions (external temperature, humidity, solar radiation) the inside temperature of the physical model is compared to the inside measured temperature.

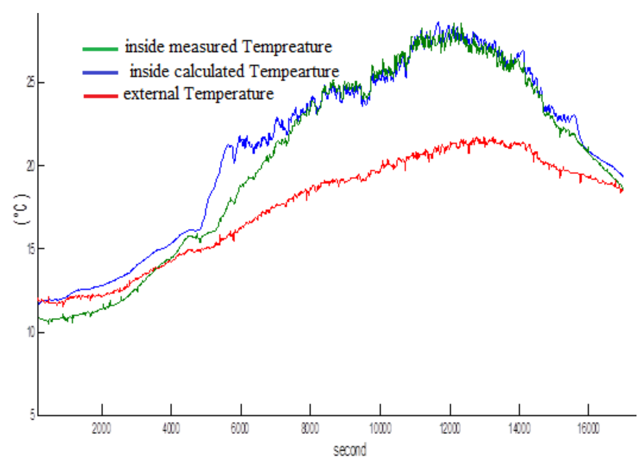


Figure 5. Comparison between the calculated and the measured temperature of a greenhouse

The figure 5 shows a good correspondence between the measured and the calculated inside temperature of a greenhouse, the evaluation of the absolute error present a maximum of 3°C.

B. Simulation of the linearizing algorithm

The inside temperature of the greenhouse is controlled by the linearizing algorithm, the simulation result under Matlab/Simulink of the physical model for a wanted value of temperature is shown in figure 6.

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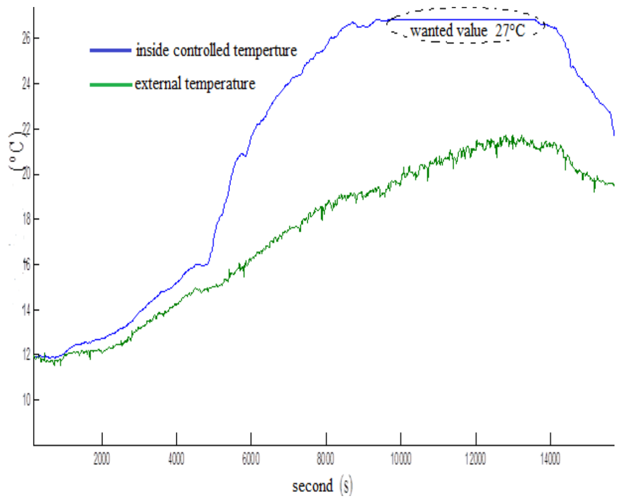

Figure 6. Simulation of the linearizing algorithm

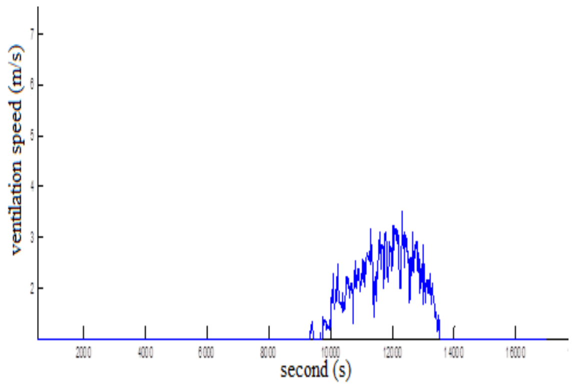

Figure 7. Ventilation speed

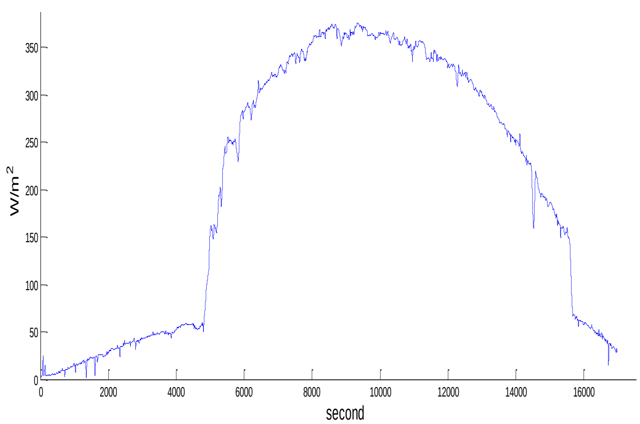

Figure 8. Solar radiation

The figure 6 show that for the controlled temperature of the physical model don't exceed a limited level of 27°C. When the inside temperature of the greenhouse tends to exceed 27°C, the ventilation is started and the linearizing algorithm calculate the needed air flow to be introduced to stabilize the temperature surrounding the limited value.

The ventilation speed, function of the air flow to be introduced, is ensured by the asynchronous machine. The speed of ventilation start to increase proportionally to the effect of the solar radiation on the inside temperature of the greenhouse.

VI. CONCLUSION

This work first aims to model a ventilation system of a greenhouse powered by the photovoltaic energy. Different parts of the system were modeled; in particular the physical model of the greenhouse was validated by a comparison with measurements, to study its efficiency. Computational simulations were carried within Matlab/Simulink and results were found to have a good correspondence with the measurement. The physical model could describe the evolution of the greenhouse temperature with a good satisfaction.

A linearizing algorithm was applied to the greenhouse model in order to control the temperature from exceeding a wanted value. The results of simulation have shown the efficiency of the algorithm to calculate the needed fresh air, so the speed of the ventilation, which is introduced by the ventilation system.

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