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Identification and Control of a Light System Using the Phase-locked Loop Technique

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Abstract: In this study, we propose the application of the Phase Locked Loop (PLL) technique to the control of light system. This one is destined to test the light effect on the evolution of the plants and the production improvement inside an agricultural greenhouse. In light control using PLL technique, the loop operates around a central frequency of which it departs very little, what permits to study it by the approach of continuous linear systems. We have developed the modelling of the PLL light control and presented a comparative analysis of the phase control system results gotten by the experience, the theory and the simulation. The Performances of achieved system have been also tested experimentally.

Key words: Phase Locked Loop control, light system, modelling, continuous linear systems

INTRODUCTION

The Phase Locked Loop (PLL) is constituted essentially of a Phase-frequency Comparator (PC) a Low Pass-Filter (LPF) and a Voltage Controlled Oscillator (VCO) (Fig. 1). The loop operating Principle has been studying by Blanchard[1], Gardner[2], Enceslav and Kroupa[3]. The PLL is a phase-enslaved system.

Historically, the first applications of the PLL circuits were the reconstitution of the sweep TV signals synchronization in the bibs form and the demodulation from the satellite signals. The PLL principle is well used in frequency synthesis aria and in many arias of electronic[8], for examples:

- The modulation and demodulation of the modulated frequency,
- The synchronisation of an oscillator by an external signal,
- The multiplication and synthesis of frequency (frequency synthesizers design),
- the frequency translation,
- The demodulation of the modulated magnitude.

PLLs find then themselves in communication systems (wireless, telecom, data-com), in storage device, in noise cancellers, etc[4].

The PLL technique has proved its effectiveness in industrial control[6,7,9,10-12]: it ensures a high accuracy on the enslaved value (high stability of frequency). Recently, AL-Taha and Jassim[5] have introduced this approach in their works.

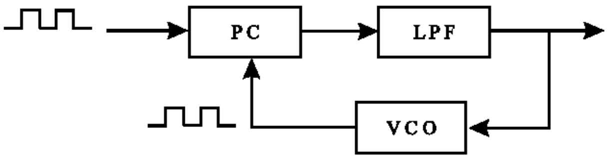

Fig. 1: Synoptic of a phase-locked loop

In this study, we propose the application of PLL technique to get an accurate control of a light system to test the effect of light on the evolution of the plants and on the improvement of the production inside an agricultural greenhouse.

In light control using PLL technique, the loop operates around a central frequency of which it departs very little. The theory of continuous linear systems has been used in this study.

LIGHT CONTROL BY PLL

Description of the process: The real process is constituted therefore mainly of a power spotlight 1 Kw, supplied under 220 V and commanded by an amplifier of controlled power to basis of thrusters. The sensor is a photodiode brought up in a circuit of conversion current-voltage (I/U), this voltage is amplified then. The Fig. 2 and 3 show, respectively, the different blocks of the process and the circuit of conversion (I/U).

Presentation of the light system using PLL technique: For the application of light control, the physical process (real system) that we conceived and achieved is the

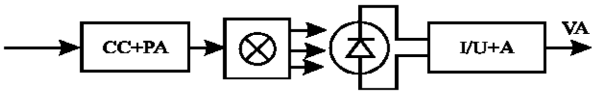

Fig. 2: Description of the process

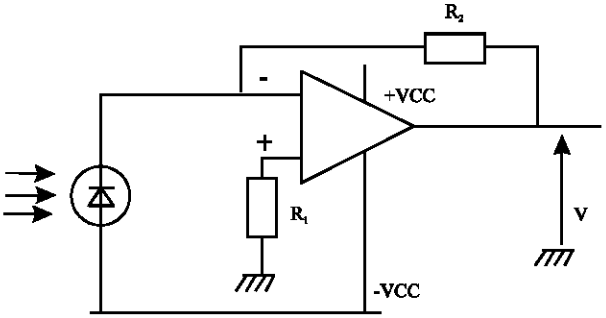

Fig. 3: I/U converter circuit

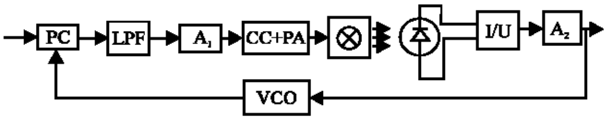

Fig. 4: Blocks of the light control loop

equivalent of the electronic VCO in the electronic control loop (used in modulation and demodulation). It is constituted by the set of the following circuits: A power amplifier to thrusters controlled by an integrated starting point circuit which allows to regulate the opening angle from 0 to 180° for a control voltage variation of 0 to +5v (CC+PA), a luminous source (lamp of 1 KW power spotlight), a light sensor (photodiode), a current-voltage converter (I/U) followed of its amplifier (A_2) and a voltage-frequency converter (VCO) of the CD 4046 integrated circuit. To close the loop, we use also the Phase Comparator (PC) of the CD 4046 followed by a Low Pass filter (LPF) and its amplifier (A_1).

The functional diagram-blocks of Fig. 4 represents the elements of the light control loop. We note that the use of a phase sensor permits to suppress the conversion of the signal descended of the sensor and to improve the accuracy considerably.

Identification of the process in open loop: One intends, in this subsection, to determine the transfer function that characterizes experimentally the process (power part and sensor) in open loop.

The Fig. 5, 6a and 6b showed, respectively, the static characteristic of the process (Vs according to Ve) and the static and dynamic step responses of the achieved and studied system.

From the obscurity (static response), the response in VA output Fig. 2 is the one of the Fig. 6a. The

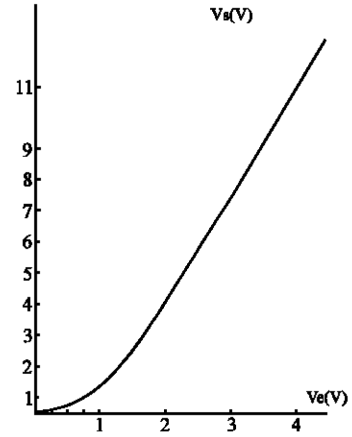

Fig. 5: The static characteristic

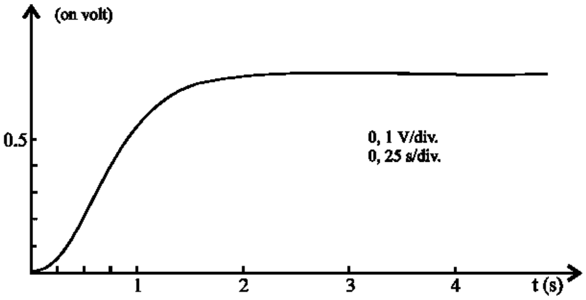

Fig. 6a: The static step response

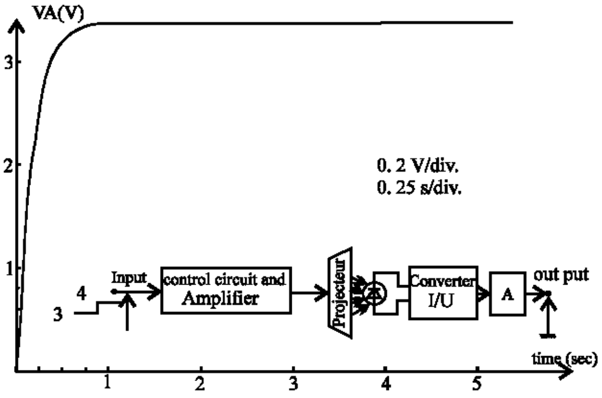

Fig. 6b: The dynamic step response

Strejec method allows us to succeed to the following transfer function:

$$H(S) = \frac{0.76e^{-0.06}}{1+0.4s}$$

From a light chosen experimentally (dynamic response), this transfer function can be more merely written as follows:

$$H(s) = \frac{3.4}{1+1.8s}$$

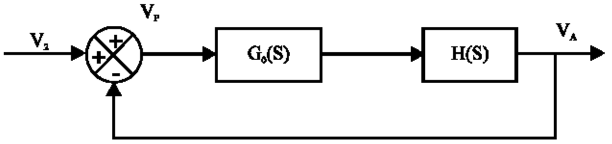

Fig. 7: The analogical internal loop

The analogical internal loop: In the goal to improve the response time of the system, we adopted the diagram of the Fig. 7 in which we conducted an analogical correction of the loop while choosing the operating point of the system. This last is fixed by the value of the V_p injected voltage.

MODELLING OF THE DIFFERENT BLOCKS OF THE CONTROL SYSTEM

The complete functional diagram of the light control is given by the Fig. 8. The approach of continuous analysis requires the knowledge of the transfer function of the different blocks of the system:

Phase comparator and low-pass filter: The response of the phase comparator is proportional to V_D Fig. 9, value of voltage taken by its output between two positive foreheads of the input signals. The shape of the characteristic of the phase comparator in the low pass-filter output, shown Fig. 10, brings a limitation to the system: indeed, for a gap of phase $\Delta\theta$ superior to 2π, there is overtaking and therefore risk of oscillation of the system.

For a gap of phase $\Delta\theta$, included between 0 and 2π, the middle value of the phase comparator output after filtering can be written as follow:

$$Vc = V_D \frac{\Delta\theta}{2\pi} \frac{K_f}{1+\tau_f s}$$

K_f and τ_f designate the static gain and the filter time constant respectively.

Process with intern analogical loop: For the chosen operating point, the transfer function is identified to:

$$T(s) = \frac{k_T}{1+\tau_T s}$$

with $K_T = 1.25$ and $\tau_T = 0.1$ sec

Frequency voltage-converter: The conversion function is assured by an electronic VCO of the CD4046 circuit whose transmittance is simply equivalent to a K_0 gain. The global system is described then by the diagram-blocks of the Fig. 11 where the PC inputs are pulsations.

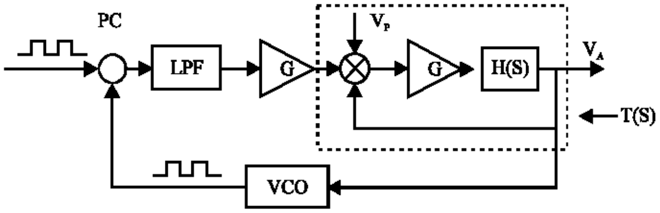

Fig. 8: The complete functional diagram of light control system

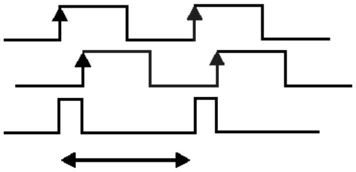

Fig. 9: Time diagram of PC

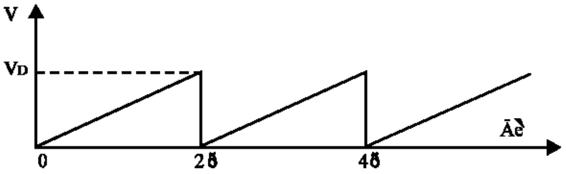

Fig. 10: Characteristic of the PC in the LPF output

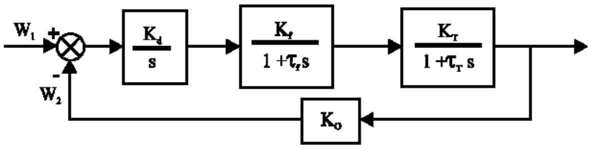

Fig. 11: Diagram-blocks of the modeled system

The transfer function of the system in closed loop is of the shape:

$$T(s) = \frac{K}{K_0} \frac{1}{[s(1+\tau_f s)(1+\tau_T s)+K)]}$$

with $K = K_0 K_d K_f K_t$

The term K_d represents the phase comparator gain.

The characteristic equation of the system shows that it is so much steady that the K_c criticizes gain is not reached.

COMPARATIVE SURVEY OF EXPERIENCE AND THEORY RESULTS

In this section, one intends to make a comparative survey between the theoretical and experimental results gotten in the case of the luminous source light control using the PLL's technique. We recorded the system responses to a frequency modulation for different values of the k_f filter gain. In the developed survey, we opted for a simplified theoretical analysis. We confronted the results of the experience to the theory while taking account, on the one hand of the system response characteristics (first overtaking, time of peak), and on the other hand on the width of the loop lock (capture) range.

Simplified theoretical survey of the control loop: The behavior of the system has been studied with the continuous diagram-blocks Fig. 11.

The transmittance in closed loop of the enslaved system is given by:

$$\frac{V_A(s)}{W_1(s)} = T(s)$$

Where,

$$T(s) = \frac{V_A(s)}{W_1(s)} = \frac{K}{K_0}\frac{1}{[s(1+\tau_f)(1+t+s)+K]}$$

with $\tau_f = 0.005$ sec, $\tau_T = 0.1$ sec and $K = 173.4K_f$

The computation of this function shows that we are, approximately, in presence of a second order system whose response depends on the value of K and therefore of K_f.

If one now considers the S filter output, the transmittance becomes then of the shape:

$$\frac{S(s)}{W_1(s)} = \frac{K_d K_f(1+\tau_T s)}{[\tau_T \tau_f s^3 + (\tau_T + \tau_f)s^2 + s + K]}$$

We can approximate this transfer function with a generalized second order. The presence of the derivative action to the numerator provokes an increase of the over takings: therefore the filter output response, for the same frequency step, is more oscillating than the one in the V_A amplifier voltage.

Responses in filter and voltage amplifier outputs: In this section, we present the experimental responses to a modulation of frequency in the filter and voltage amplifier outputs for increasing values of the K_f gain (0.03, 0.075 and 0.15). The system responses are represented in Fig. 12a-c (in the filter output) and Fig. 13a-c (in the voltage amplifier output), respectively. For the values of K_f gain, we have determined the lock (capture) range experimentally and theoretically:

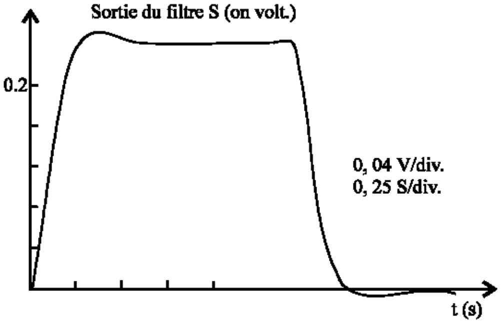

Fig. 12a: Frequency step response in filter output (K_f =0.03)

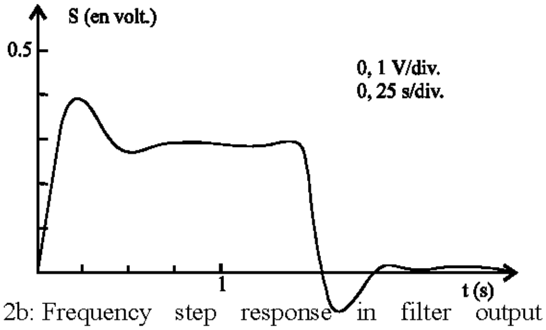

Fig. 12b: Frequency step response in filter output (K_f=0.075)

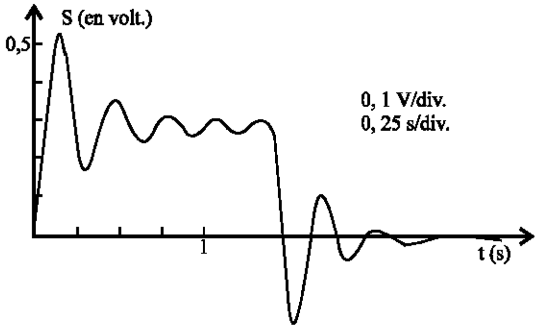

Fig. 12c: Frequency step response in filter output (K_f = 0.15)

Experimental determination of the lock (capture) range
We have studied the behavior of the control loop using P.L.L technique for the 3 values of the filter gain (0.03, 0.075 and 0.15). We have then determined experimentally the lock (capture) range.

Theoretical lock (capture) range: The theoretical survey of the light control system shows that the lock range (or capture range), for a f_0 fixed central frequency and a f_r given reference frequency, is determined by the following relation: $[f_r-f_0]<K$
Where, K represents the loop global gain.

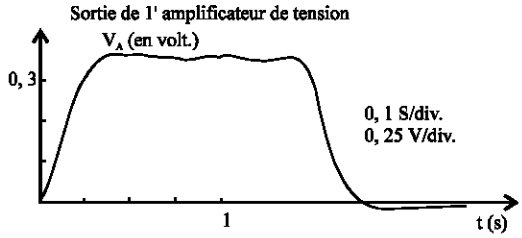

Fig. 13a: Frequency step response in voltage amplifier output ($K_f = 0.03$)

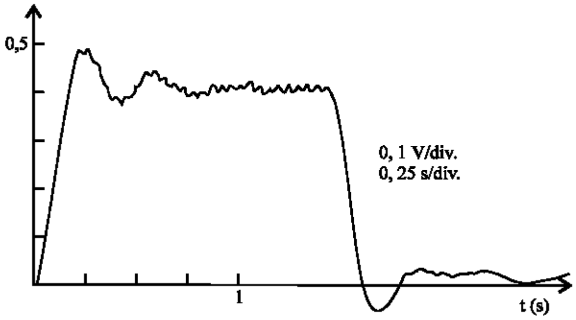

Fig. 13b: Frequency step response in voltage amplifier output ($K_f = 0.075$)

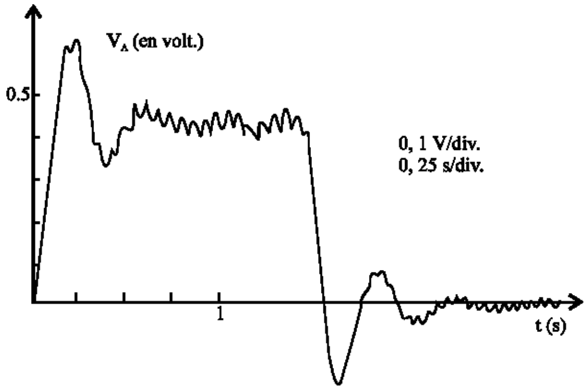

Fig. 13c: Frequency step response in voltage amplifier output ($K_f = 0.15$)

Table 1: Lock range width values in theory and experience

Lock range in Hz	Theory	Experience	Filter gain K_f
	5.2	5	0.030
	13.0	10	0.075
	26.0	20	0.150

Table 2: Transient regime analysis (time of peak and first over taking

Filter gain K_f	Time of peak in seconds Theory	Experience	Simulation	First over taking in percent % Theory	Experience	Simulation
0.030	0.6	0.43	0.70	5.8	4	3
0.075	0.3	0.25	0.35	22.4	20	15
0.150	0.2	0.21	0.23	37.0	44	30

The width of the lock range depends therefore solely on the gain of the system in open loop (filter gain). The wanted response type determines this gain. We summarized in Table 1 the theoretical and experimental results.

Experimental and theoretical results: The analysis of the curves of the system response to a step of frequency has the following remarks taken out again.

When the filter gain of the loop increases, the system becomes more and more oscillating, the lock range is increasing function of the filter gain as it has been announced previously.

When the system response is to the limit of an a periodic system, the time of peak is considerably high (the system becomes slow enough); but some against part, one wins on the stability of the system.

While the system response to a step of frequency includes two over takings (while increasing the value of the K_f filter gain), one loses a little on the stability, but one wins on the speed of the system (the system becomes fast).

The theoretical study of the light control system has been explored consequently for the computation of transient regime characteristics.

Table 2 showed a comparative survey of such results given by the theory and the experience.

In conclusion, for this study, we can note that in order to get a better phase-frequency control, it is necessary to adopt a compromise between stability, speed and accuracy. The good concordance between the theoretical and the experimental results watches that the analysis of the continuous type is sufficient to study a system operating around a frequency of which it departs very little. In the goal to strengthen the results of the experience and the theory, it is recommended to conduct also the survey, in simulation, of the system.

SIMULATION RESULTS

The simulation, that we did, permits to study the influence of the different characteristic parameters of the loop. Indeed, because of the modular character adopted for the simulation, it is possible to consider the action of different compensators on the behavior of the loop.

General organization chart: The general program of the simulation is essentially constituted of four main subroutines:

- the first subroutine permits the generation of the reference signal,

- the second subroutine has the goal to simulate the behavior of the PC,
- the third subroutine describes the behavior of the analogical process,
- the last subroutine permits the generation of the signal back from the frequenter sensor.

Generation of the reference signal: The simulate reference signal is a periodic square signal of + V magnitude, of frequency f_r whose value can be modified at will.

Phase-frequency comparator: The three states sequential behavior of the phase-frequency detector have been studied extensively in the literature[6-8]. One notes that this comparator is only active on the fronts of rise of the command and reaction signals (the cyclic report doesn't have an effect).

It is to notice that the lock range is equal to the capture one for this type of comparator. When no signal is present to its input, the VCO is adjusted then to the limit low frequency (permitting to get synchronism).

Analogical process: The analogical process (filter and light process controlled) is governed by differential equations that have been transformed in equations to the finished differences using the increment of integration designated by T_e. The temporal integration has been replaced directly by a numeric one. This approach proved to be sufficient in our case, because the filter and the process have models of first order. Other more, elaborate methods can be considered for a more high order.

Frequenter sensor VCO: The VCO plays the role of sensor delivering a frequency linearly proportional to the value of the command continuous voltage (this frequency is function of the power of light).

The characteristic of frequency-voltage conversion of the VCO determined experimentally shows that the oscillator presents a doorstep of operating neighboring of 1.2 V. While having a correct operating of the spotlight lamp (linear zone), The operating point is chosen in the manner that the value of the VCO control voltage will be superior to this limit.

Simulation results: To conduct a comparative analysis of results, we have also simulated the V_A voltage amplifier responses under the experiment conditions.

Determination of the system lock range: The enslaved system in phase operates around a central frequency of

Table 3: Results about locr range width in theory experience and Simulation

	Lock range in Hz		
Filter gain	K_fTheory	Experience	Simulation
0.030	5.2	5	>4
0.075	13.0	10	>8
0.150	26.0	20	>18

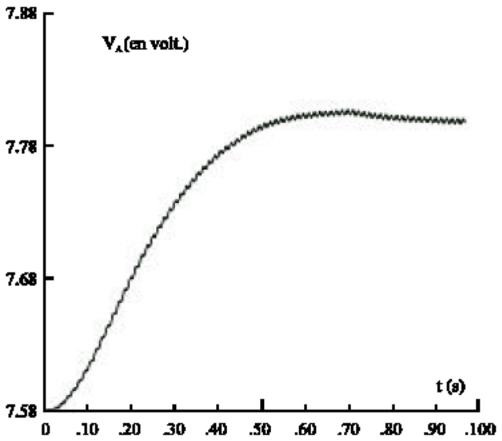

Fig. 14a: Step response (K_f=0.03)

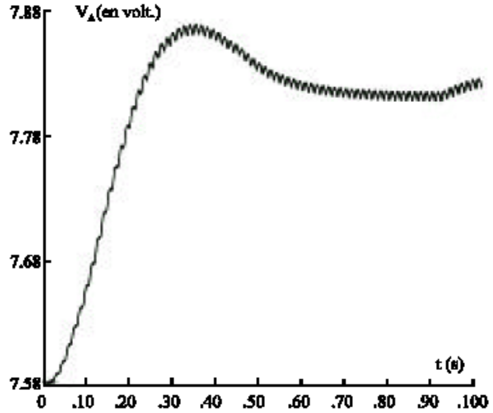

Fig. 14b: Step response (K_f=0.075)

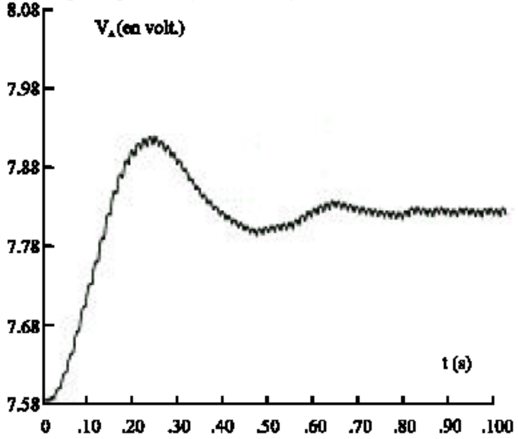

Fig. 14c: Step response (K_f=0.15)

the order of 80 Hz corresponding to the chosen operating point in the comparative experimental survey presented in the previous section. In the goal to determine the width of the lock (capture) range, we have simulate the various signals of the PC for increasing values of the K_f filter gain and the steps of frequency permitting to get roughly the limit of the PLL system lock (gap of phase $\Delta\theta$ neighbor of 2π). Table 3 summarized the obtained results concerning the lock (capture) range.

Table 3 shows that the results of the simulation are in agreement with the experience. Besides, the numeric simulation gives values of lock range less than those given by the theoretical model for high values of the filter gain.

Phase comparator behavior (for an increasing filter gain): The operating central frequency is maintained constant (of the order of 80 Hz). We have simulate the registrations describing the behavior of the phase comparator in the case where the filter gain becomes more and more higher for a fixed reference to 76 Hz. The simulation results permit us to note that the gap of phase in permanent regime decreases when the loop filter gain increases (the locking range is enlarged then). This kind of results has been verified during the experimental tests. Voltage amplifier responses to a step of frequency (for an increasing filter gain)

The Fig. 14a-c showed the evolutions during the time of the V_A voltage amplifier output for increasing values of the filter gain (central frequency of 80 Hz) in response to the same step of frequency used in the practice.

Comparative survey of results: We present in this section the results of the comparative analysis of the characteristic sizes, characterizing the proposed control system, given by the theory, the experience and the simulation (first overtaking, time of peak and locking range).

Table 3 has summarized the results of the survey. Compared to the results of the experience, the registrations of the simulation nearly plan the same dynamic behavior for a given filter gain (fixed).

It is to note that the experimental, theoretical and simulate results remain in good agreement, except for the values of overtaking where one notes that the simulation results depart a little the experience.

This simulation allowed us to illustrate the behavior of the phase comparator for an operating weak frequency in the whole lock range.

CONCLUSION

We have described, in this study, the realization of the light system control of a power luminous source for applications in research on the production improvement in an agricultural greenhouse. In the goal to have an accurate and robust control, we thought a system using the PLL technique for its qualities of accuracy and stability.

In this contribution, we have identified and modeled the components of the light control system functioning in the neighbourhood of a central frequency. In this case, it was shown that the use of the continuous linear systems theory is quite efficient to study the stability, the lock (capture) range and to inquire about the state of the transient regime according to the loop gain (K_f filter gain).

The comparative analysis presented in this paper permitted to underline the good concordance between the results gotten in the practice, the simulation and the theory. The simulation, capable to act as tool of validation of the experience and permitting to foresee the behavior of the studied system, seems again very interesting (thanks to its modular character) in the case where one conducts the survey of the appropriated compensators (correctors) in a phase-frequency control.

We plan now to examine the case where the reference frequency varies in very large ranges (like the case of speed control systems for example). A fine analysis shows that we are faced to width modulation sampled systems where the sampled time is variable (non-linear systems). In this case, it is quite necessary to use the non-linear sampled systems theory to resolve efficiency the control requirements.

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