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Modern Control of a Power Supply Based on a Matrix Converter for Water Disinfection by UVC Radiation

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Abstract: Water, an essential resource, has been facing gradual deterioration in quality over an extended period. Water treatment has emerged as a critical concern, with a long-standing acknowledgment of the importance of preserving and appreciating this precious resource. UV-C technology has proven to be an ideal solution that effectively addresses these twin needs. The core principle of UV bactericidal treatment revolves around generating ultraviolet rays within a treatment chamber filled with water. Consequently, ensuring a dependable power source for low-pressure mercury-argon discharge lamps has become imperative to guarantee the efficiency of UV-C disinfection.The primary goal of this study is to supply our discharge lamp with a current source that produces a sinusoidal current at its output, featuring a frequency of 50 kHz and an effective value of 0.65 A. Electronic ballasts enable lamps to enhance radiation quality by operating at high frequencies, and the selection of a power supply is a response to this specific challenge.The aim of this research centers on the utilization of a single-phase matrix converter. The bidirectional switching cells within this converter offer frequency-related advantages. To achieve the desired magnitude and frequency, we employed a PWM control strategy. Subsequently, we implemented a linear current adjustment approach using two controllers: a Proportional-Integral (PI) controller and a Generalized Predictive Control (GPC) in the RST polynomial form. This was done to ensure a high-quality current source with the desired waveform and low Total Harmonic Distortion (THD).The research outcomes have led to environmental simulations conducted using Matlab/Simpower system and Matlab/Simulink.

Keywords: Disinfection, UV-C Lamp, Electronic ballast, Matrix converter, Predictive control (GPC).

Introduction

Ultraviolet radiation at a wavelength between 100 and 400 nm has germicidal properties highlighted from the end of the 19th century. These properties specific to UV-C (200-280 nm), result from an action on the nucleic acids of micro-organisms which show variable sensitivity to this radiation depending on their composition. UV radiation is produced by generators: UV lamps, discharge lamps, made up of rare gas (argon, galium, etc.) and mercury vapor (Costache, 2000). These lamps, intended for the purification and sterilization of air and water and

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for the disinfection of small surfaces, have an electrical operating point, characterized by a voltage/current couple, which depends on their geometry and the gases used, but also of the electrical source that supplies them. Each operating point is therefore linked to the couplings between the power supply and the electrical discharge. Power supplies are studied in electronics and electrical engineering laboratories in order to characterize their electrical behavior and carry out their design. These power supplies are well modeled and their development relies heavily on simulation (Aissa Bokhtache et al., 2016), (Aissa Bokhtache et al., 2015). The models used make it possible to simulate the electrical behavior (on the basis of voltage and current quantities). We have endeavored to tackle the problem of the study of a "discharge lamp intended for sterilization, powered by electronic ballast" system. We contented ourselves with studying the modeling and control of the electronic ballast supplying the low-pressure mercury-argon discharge lamp under the best conditions in order to generate the maximum UV radiation at 253.7 nm with high germicidal power (Toumi et al., 2013). The main objective of the use of the matrix converter, in this work, is the replacement of conventional converters with DC intermediate circuits, for the power supply of the lamp, by a converter carrying out the direct AC/AC conversion. The article is therefore organized in such a way as to deal successively with the different points of the problem. it develops two axes: modeling and control. In order to study the behavior of the lamp-converter association, we simulate and visualize the current and the arc voltage of the lamp as well as their harmonic spectra for the desired frequency which is 50KHz (by increasing the frequency of power supply, a better luminous efficiency is obtained) The effective value of the arcing current will be 650 mA, a value which will later constitute the reference in the regulation loop. The switch control signals are obtained by the PWM control. We will simulate the "converter-lamp" system in open loop, first in order to study the dynamic behavior of the system, and then in closed loop for the regulation of the lamp current. In this context, this article is the subject of a comparison of the results of simulation in particular on the plan "rate of harmonic distortion (THD)" with a traditional regulator (PI) and a GPC regulator in the polynomial form RST, in the purpose of improving the performance of the converter.

Discharge Lamp-Electronic Ballast Description and Modeling of the System

The electric circuit model of the discharge lamp consists of two main components: the arc resistor "Rarc" and the filament resistors "*rf*" for each cathode. In the model, the arc resistor "*Rarc*" represents the electrical characteristics of the lamp's arc, which depend on the arc power and temperature. This resistor is used to simulate the behavior of the discharge within the lamp (Aissa Bokhtache et al. , 2021) .

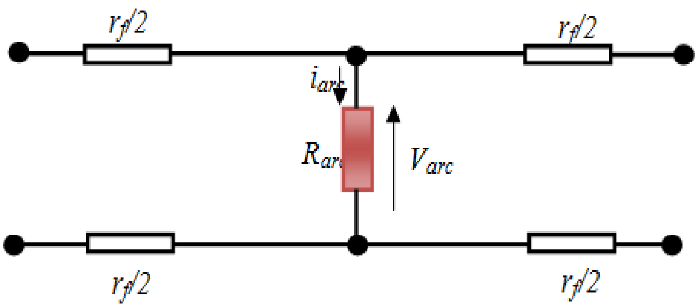

Figure1**.** Model of the electric circuit of the gas-discharge lamp.

Figure 2 summarizes the system studied: Discharge lamp-electronic ballast powered by a converter.

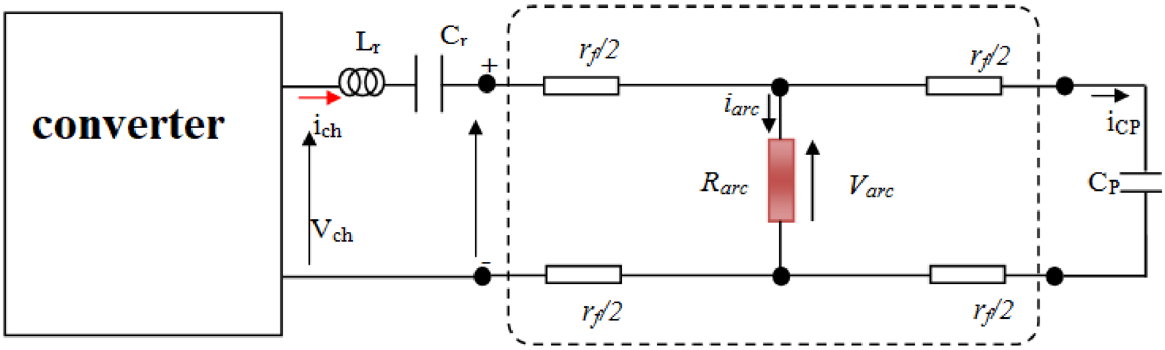

Figure 2. Equivalent circuit of electronic ballast-discharge lamp with converter.

Characteristics of the Load Used

The load used in the simulation is a specific discharge lamp described in references (Aissa Bokhtache et al. , 2017). The table below presents the main characteristics of the lamp:

Table 1. Characterıstıcs of the dıscharge lamp-electronıc ballast assembly (Aissa Bokhtache et al., 2021)

Variables	values
C_r	147 nF/ 250 V
C_P	8.2 nF/ 600 V
L_r	1.08 mH
P_{Lamp}	65 W
f	50 KHz
R_{arc}	170.769 Ω
r_f	5 Ω
L_{tube}	150 cm
I_{arcrms}	0.65 A

With : r_f: filament resistor, R_{arc}: arc resistance, Z_{cp} : starter impedance,i_{arc}: arc current, V_{arc} :arc voltage, i_r: load current, i_{cp}: starter current, and V_{lamp} :lamp voltage, L_r , C_r: resonant circuit parameters, C_p: starter capacitor. Transfer function of the system Discharge lamp-Electronic ballast(Aissa Bokhtache et al., 2017). The total impedance of the discharge lamp-electronic ballast system is given by:

$$Z(s) = \frac{(R_{arc}+r_f)L_r C_r C_p S^3 + \left[\left(2R_{arc}+r_f\right)L_r C_r C_p + L_r C_r\right]S^2 + (R_{arc}+r_f)(C_r + C_p)S + 1}{\left[(R_{arc}+r_f)C_p S + 1\right]C_r S} \quad (1)$$

Where "*s*" is the Laplace operator. As a result, the transfer function of the open loop system is:

$$\frac{I_{arc}}{V_{ch}} = \frac{r_f C_r C_p S^2 + C_r S}{(R_{arc}+r_f)L_r C_r C_p S^3 + \left[\left(2R_{arc}+r_f\right)L_r C_r C_p + L_r C_r\right]S^2 + (R_{arc}+r_f)(C_r + C_p)S + 1} \quad (2)$$

The Structure of the Electronic Ballast Based on Matrix Converter

The single-phase matrix converter is characterized by a matrix topology of four bidirectional power switches connecting the input voltage to the load. The schematic diagram of the SPMC (Single-Phase Matrix Converter) is shown in Figure 4. The power switches (supposedly ideal) of the matrix S1, S2, S3, S4 are bidirectional, they allow the current to be conducted in both directions, as well as to block the voltages of two polarities (Bouhani, 2012; Hanafi et al.,2006).

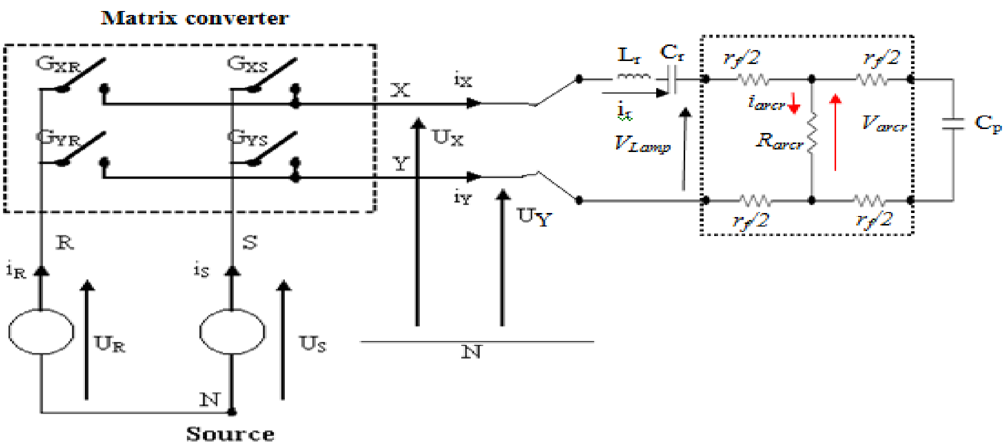

Figure 3. System representation discharge lamp-electronic ballast powered by a matrix converte.

Figure 4. SPMC Structure, bidirectional switch module (Abrous, 2008)

Method

The switches are controlled by natural PWM with a modulation ratio r = 0.86 and a modulation index m = 21, which makes it possible to obtain the rms current value of the desired (I_{arcrms} = 0.65A).

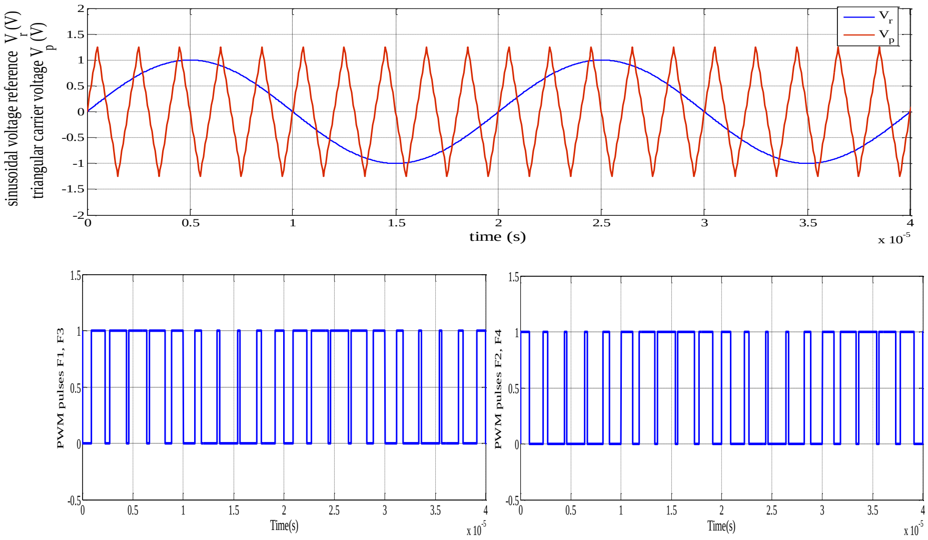

Figure 5. Control sequence of the switches made by the natural PWM.

Simulation in Open Loop

The simulation results of the system matrix converter - electronic Ballast- discharge lamp in open loop are given by the following figures:

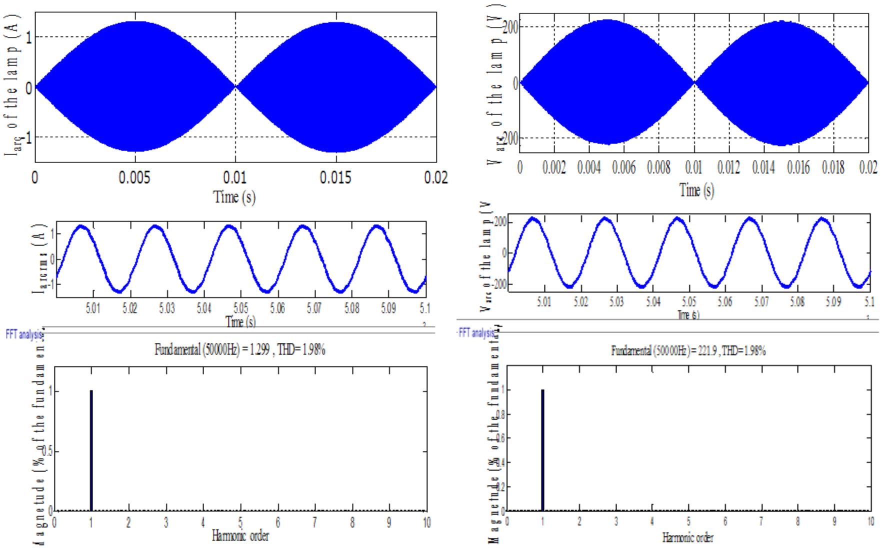

Figure 6.Current and arc voltage of the lamp and their harmonic spectra in open loop

Figure. 6 shows the waveforms of the current and arc voltage of the lamp. Note that the envelope of the voltage and the arc current oscillate at a frequency of 100 Hz. It shows that the current and the arc voltage oscillate at the desired frequency which is 50 kHz with a rate of 1.98% distortion for current and arc voltage. We find that the current and the voltage are totally in phase with the same THD. This is explained by the fact that the electric arc of the lamp is characterized by a resistance Rarc. The waveforms of voltage and current are perfectly sinusoidal in steady state of operation. Figure 7 shows that the effective arc current is stabilized at 0.65A (the desired value) after a transient regime of about 0.0195s.

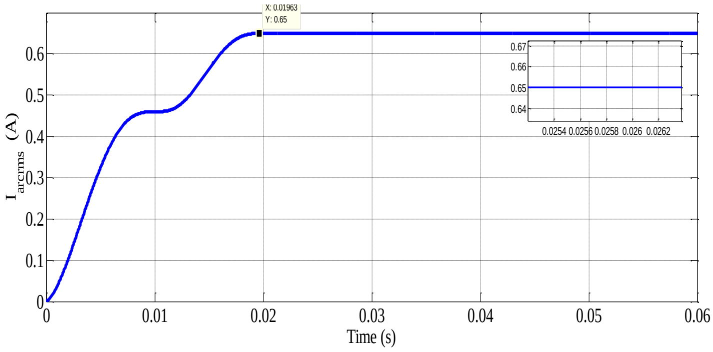

Figure 7. RMS arc current of the lamp in open loop

Simulation in Close Loop

To ensure good performance of the discharge lamp in terms of radiation, i.e. maximum UV radiation at 253.7 nm (a good germicidal effect), we must keep the arc current of the lamp strictly stable around a constant value close to 0.65A we must therefore impose regulation of the arc current with a reference of 0.65A. The difference will be transformed into the switching frequency of the switches.

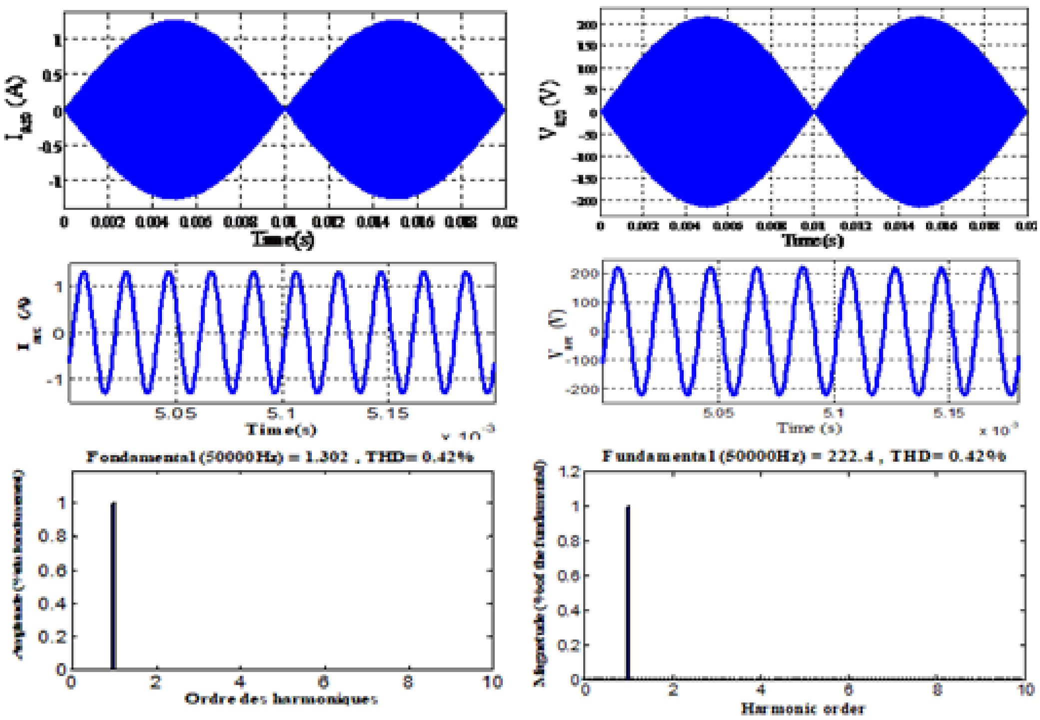

Figure 8. Current and arc voltage of the lamp and their harmonic spectra in close loop

We see from Figure 8 that the arc current and voltage are completely in phase with the same THD. The voltage and current waveforms are perfectly sinusoidal in steady state with a frequency of 50 KHz. The THD is improved (0.42% with introduction of PI in the regulation loop compared to 1.98% in open loop). From Figure 9 the effective value of the regulated arc current stabilizes at 0.65 A after a transient regime which lasts 0.0095 s compared to 0.0195 s in open loop, we therefore notice a considerable improvement.

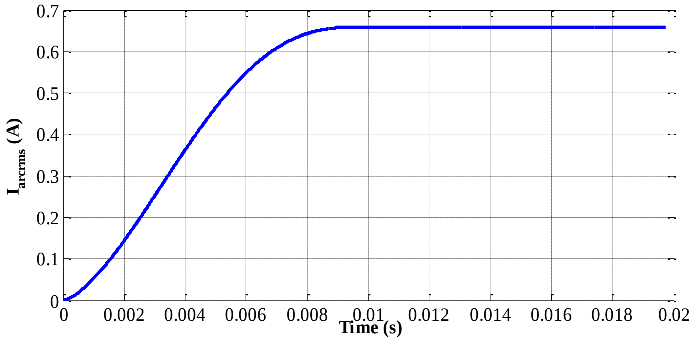

Figure 9. RMS arc current of the lamp in close loop

Summary of the GPC Regulator for the ARC Current Loop

Starting from the transfer function of the lamp model given by equation 2, take a sampling period Te = 10 $^{-7}$, we obtain the discretized transfer function of the model 3 (Khati et al. , 2020):

$$\frac{I_{arc}}{V_L} = \frac{6.554e-006q^{-2}-4.312e-006q^{-1}-2.242e-006}{q^{-3}-2.883q^{-2}+2.768q^{-1}-0.8849} \quad (3)$$

According to 3, we obtain the following polynomials $A_i q^{-1}$ and $B_i q^{-1}$ of the CARIMA model:

$$\begin{aligned} A_i q^{-1} &= q^{-3}-2.883q^{-2}+2.768q^{-1}-0.8849 \\ B_i q^{-1} &= 6.554e-006q^{-2}-4.312e-006q^{-1}-2.242e-006 \end{aligned} \quad (4)$$

The current regulator is synthesized for the following setting: N1=1; N2=10; Nu=1 and λ = trace ($G^T G$). RST polynomials are calculated by the general program (Benallou , 2009)

Results and Discussion

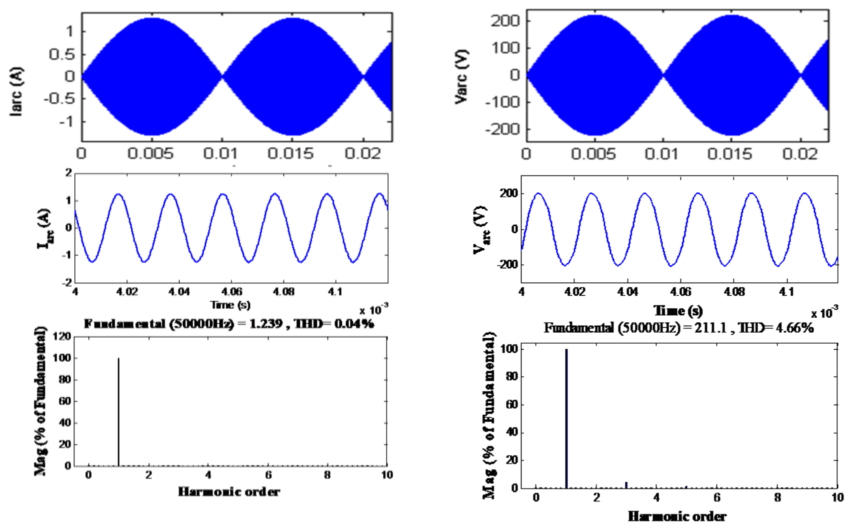

Figure 10. Current and arc voltage of the lamp and their harmonic spectra for GPC regulator.

The GPC regulator provided very good performance to the lamp. A remarkable reduction in terms of THD (0.04%) compared to that obtained with PI regulator (0.42%). The current and voltage waveforms are sinusoidal.

Conclusion

The implementation of discharge lamps for most industrial oriented applications (processing of finished products), makes use of diverse knowledge: electrical engineering, optics, plasma physics, and chemistry. We have put in place the foundations of the study of the power of our discharge lamp (electronic ballast). The first part was devoted to the presentation of the general structure of an electronic ballast (using a half-bridge inverter and direct matrix converter), choice of switches and their characteristics, the model of the electrical circuit of the discharge lamp as well highlighting the relative influences of the various parameters of the electronic components constituting the electronic ballast. The electrical behavior of the fluorescent lamp powered by an electronic ballast with HF can be modeled by a power dependent resistor and the temperature. The second part of this article was devoted to the MATLAB simulation of the electronic ballast circuit, two regulators were separately used to regulate the arc current: the classic PI regulator and the GPC regulator in polynomial RST form. These two control techniques made it possible both to control the effective value of Iarc and to improve the waveform of currents and voltages since the THD was reduced to 0.42% with PI and to 0.04% with GPC against 1.98% open loop.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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