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Analysis and Design of Sliding Mode Control for an Electronic Ballast

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***Abstract*— This paper presents the sliding mode control (SMC) of a low pressure discharge lamp and links the theory to practical power supply. Analysis and experimental study of boost converter, considered as variable structure system, is presented. The paper focuses on modeling and control circuit in Matlab/Simulink and implementing it to DC/DC converter. The efficiency of sliding mode control for variable structure systems is proven.**

***Keywords*— Sliding mode control - boost converter- DC/DC converter - electronic ballast.**

I. INTRODUCTION

The theory of variable structure systems with sliding modes is currently one of the most important research topics within the control engineering domain. Moreover, recently a number of important applications of the systems primarily in the field of power electronics, control of electric drives, robotics and position regulation of sophisticated mechanical systems have also been reported. Therefore, the objective of this paper is to present the sliding mode control of a discharge lamp powered by electronic ballast using a DC/DC boost converter.

Output voltage regulation is the general control objective in boost power conversion. The usual approach would design the action of the switch, the control action, based uniquely on the output voltage error called direct control. This approach will not be successful in general [15]-[19]. An indirect approach, based on lamp output current is needed to achieve robust regulation.

The paper is organized as follows. Section 2 states the sliding mode control strategy for variable structure systems. Section 3 presents the modeling of low pressure discharge lamp and electronic ballast. In section 4, we describe the steps implement sliding mode control for the low pressure discharge lamp. Section 5 gives results showing the effectiveness of the proposed method.

II. SLIDING MODE CONTROL

The control in sliding mode has the primarily role to obtain, in closed loop, of a dynamics largely independent of that of the process and especially of its possible variations. In this direction, it can be regarded to belong to a class of robust control [14]. On the theoretical level, it uses a discontinuous control to maintain the evolution of the system on a judiciously selected commutation surface, which fixes the desired performances. In other words, the control is only used to bring and maintain the evolution of the system on surface. On the practical level, the use of a discontinuous control can obviously pose, priori problems, since, ideally, the control beats in high frequency called chattering, which can be largely reduced by using a control law made up of two components: A continuous component called the equivalent control and a discontinuous component (of reduced amplitude) which maintains the evolution on the chosen surface in spite of the parameter variations of the process. Moreover, the discontinuous component can be replaced by a smooth function to avoid the obstructing phenomenon of chattering.

We consider the following state space model of a class of non linear systems:

$$\dot{x}(t) = A(x,t) + B(x,t)u(t) \qquad (1)$$

Where $A \in IR^{nxn}$ and $B \in IR^{nxm}$ are state matrices, $x \in IR^{n}$ is the state vector and $u \in IR^{m}$ is the control vector.

It is supposed that the trajectory of state reaches the sliding surface at the time t0 and that a sliding mode exists for $t \geq t0$.
The sliding condition is given by:
$s(x) = 0$ and $\dot{s}(x) = 0$.
Where s(x) is the switching function.
The substitution of (1) leads to write:

$$\frac{\delta s}{\delta x}\dot{x} = \frac{\delta s}{\delta x}\left[A(x,t) + B(x,t)ueq(t)\right] = 0 . \qquad (2)$$

Where ueq (t) is the equivalent control which solves the equation (2).
The calculation of the equivalent control is possible if $(\frac{\delta s}{\delta x}B(x,t))$ is invertible for any t and x. Then,

$$ueq(t) = -[[\frac{\delta s}{\delta x}]B(x,t)]^{-1}\frac{\delta s}{\delta x}A(x,t) . \qquad (3)$$

The preliminary mode with the sliding mode, on the basis of an unspecified initial condition to reach the sliding surface is called reaching mode. The complete definition of this mode requires the definition of a reaching condition as well as the definition of the nonlinear control law and its structure.

The reaching law approach of Gao [8] is easy to establish, and can be summarized in a differential equation which

specifies the dynamics of the switching function s(x) and represents at the same time the sliding condition.
The choice of the parameters of this equation makes it possible to control the dynamics of the system. The form of this law is:

$$\dot{s} = -K|s|^{\beta}\,\mathrm{sgn}(s) \qquad (4)$$

Where K and β (0<β<1) are a design parameters.
This law increases the commutation rate when the state of the system moves away from the sliding surface; it reduces it when the state approaches to this surface.

III. Modeling of a low PRESSURE discharge lamp

A. *Electric circuit of the lamp*

In discharge lamps, the power supply intervenes significantly in luminous efficiency and overall energy and defines the possibilities of the system time management.

In this context, the power supply produced, was designed to power an UV lamp using 24V battery. This power is an inverter which converts the DC voltage provided by the battery to a sine wave high frequency voltage needed to power a low pressure UV lamp.

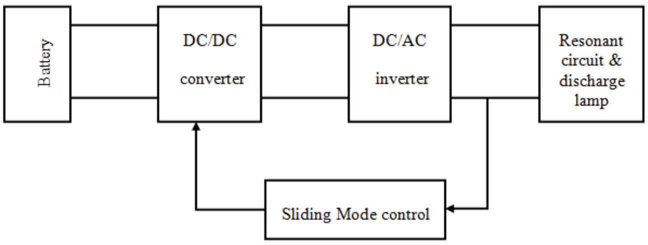

Fig. 1 Main circuit topology of SMC of a discharge lamp

The discharge lamps require a special circuit for their correct operation, which is carried out through the ballast which can be only structured by its traditional form with the passive components (reactive ballast) or by conduct sowings and passive components R, L, C (electronic ballast)[1]-[4].

The typical model of the electric circuit of a discharge lamp is given by the following figure:

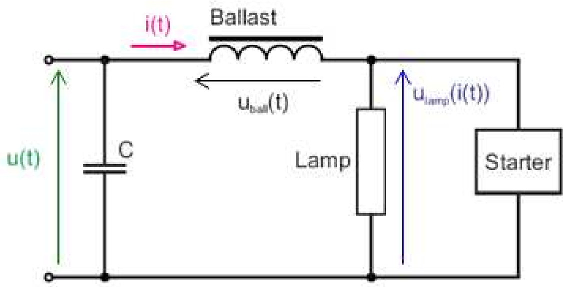

Fig. 2 Resonant circuit of a discharge lamp

The ballast is represented by a resistance R and an inductance L such as we can establish the equations:

$$\begin{cases} u_{lamp} = u - u_{ball} \\ u_{ball} = Ri + L\dfrac{di}{dt} \end{cases} \qquad (5)$$

The circuit of the figure (2) makes possible to write:

$$u(t) = Ri(t) + L\frac{di(t)}{dt} + u_{lamp}(t) \qquad (6)$$

Knowing that:

$$u_{lamp}(t) = \frac{i_{lamp}(t)}{g(t)} \qquad (7)$$

Where g(t) is the lamp conductivity expressed by the relation:

$$\frac{dg}{dt} = ai^2(t) + b_1 g(t) + b_2 g^2(t) \qquad (8)$$

Such as a, b_1 and b_2 are constants determined using many method. In this paper, we use the particle swarm optimization algorithm to identify these parameters.

B. *Parameters identification of the conductivity model*

Parameter identification problem is a problem to estimate the unknown parameters of the mathematical model based on a system of nonlinear equations by using experimental data obtained from well-defined standard conditions.

For a system with known model structure but unknown parameters, the parameter identification problem can be treated as an optimization problem. The basic idea is to compare the system output with the model output. The difference between the system and model outputs is minimized by optimization based on a fitness function. The fitness function is defined as a measure of how well the model output fits the measured system output [5]-[7].

The system's dynamics can be described using a differential equation such us:

$$\frac{dg(t)}{dt} = f(p, g(t), i(t)) \qquad (9)$$

Where g(t) is the lamp conductivity defined as its output and i(t) is the current which represent the lamp input.
P is the vector of three unknown parameters (P=[a b_2 b_1]) and f is a nonlinear function.
To formulate the problem equation (9) can be written with the next form:

$$\dot{g} = f(p, g, i) \qquad (10)$$

To identify p, a model of the system is introduced as:

$$\dot{\hat{g}} = f(\hat{p}, \hat{g}, i) \qquad (11)$$

From equation (10) and (11), the same input "i" is applied to the system and its model which has the same structure of the real system.

To evaluate parameters to be identified, the system output "g" is compared with each of the model.

The problem we consider here is to identify the optimum parameter vector as accurate as possible using the given experimental data, and this is a minimization problem which minimizes the fitness function defined by:

$$J(\hat{p}) = \min \sum [g(ti, p) - gi]^2 \qquad (12)$$

Where g(ti,p) ang gi are the numerical solution of the mathematical model and experimental data point for the i-th data point respectively.

The fitness function can be used to find the best estimation, so that the identification problem is then treated as an optimization problem.

The identification was held for a low pressure discharge lamp with the characteristics mentioned in the next table.

TABLE 1

CHARACTERISTICS OF THE LOW PRESSURE DISCHARGE LAMP.

Diameter	Length	Power	Nominal current
15 mm	400 mm	60 W	0.52 A

The PSO algorithm was coded in Matlab R2008b, and the simulations were run on an Intel Core 2 Duo CPU 2.67 GHz with 4 GB memory capacity.

The PSO algorithm gives model parameters:

a2= 93.33

b2= 582036.5

b1= 994.7

IV. SLIDING MODE CONTROL OF THE LOW PRESSURE DISCHARGE LAMP

The sliding mode control is used to maintain constant the lamp current with reference to an imposed value in order to keep a constant radiation.

The sliding surface being selected of the form:

$$s(x) = i(t) - iref(t). \qquad (13)$$

Where $i(t)$ is the lamp current, and $iref(t)$ is its reference current of the form:

$$iref(t) = irefmax \cdot \sin\omega t$$

During the sliding mode:

$$\dot{s}(x) = 0 \text{ and } s(x) = 0 \qquad (14)$$

$$\dot{s}(x) = \frac{di(t)}{dt} - \frac{diref(t)}{dt} \qquad (15)$$

To develop the sliding mode control of the low pressure discharge lamp we use next configuration of the electrical circuit of our system:

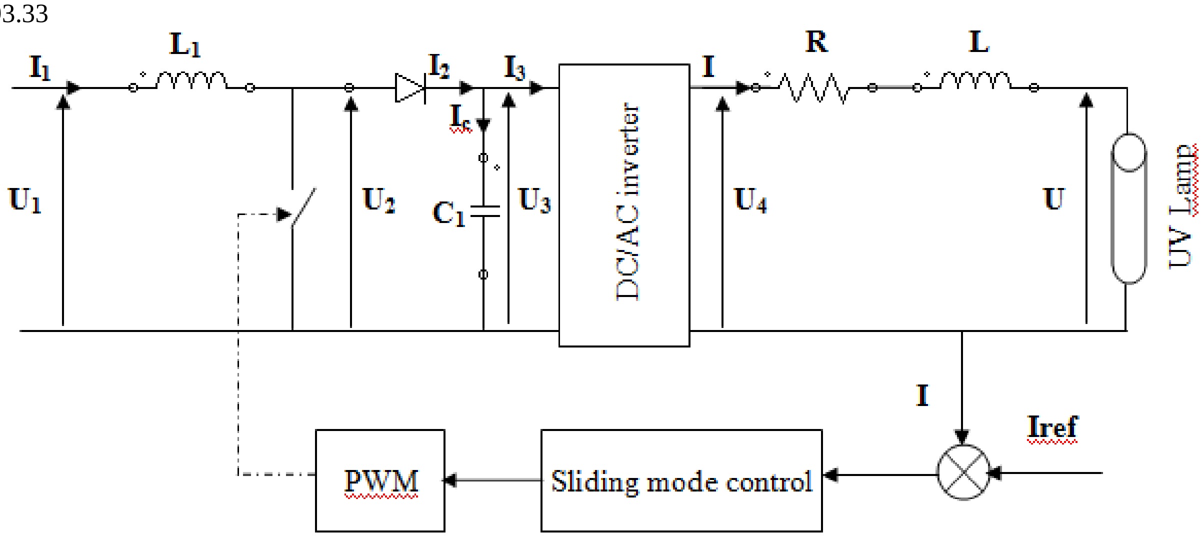

Fig.3 Sliding Mode Control implementation

The objective is to generate a control law for the switcher (boost converter) which can make the lamp current follows a reference value considered as a desired form.

To simplify the calculation of the control law, we suppose that all switchers are ideal:

$$\begin{Bmatrix} U_4 = \pm U_3 = \pm U_2 \\ U_4 = |U_3| \\ I = |I_3| \end{Bmatrix} \qquad (16)$$

The discharge lamp voltage is considered as nonlinear relation betwen its current I and conductivity g:

$$U = \frac{I}{g} \qquad (17)$$

The nonlinearity is coming from the conductivity model which is written:

$$\frac{dg}{dt} = a.I^2 - b_1.g - b_2.g^2 \qquad (18)$$

Where a and bi are parameters to be identified with particle swarm optimization.

$$U_4 = R.I + L\frac{dI}{dt} + U \qquad (19)$$

In the boost converter, the relation between input and output voltage is given as

$$U2 = \frac{U1}{1-\alpha} \quad (20)$$

Where α is the duty cycle of the dc/dc converter.

When we derive the sliding surface, equation (15) can be written as

$$\frac{dI}{dt} - \frac{dIref}{dt} = \frac{1}{L}\left(\frac{U1}{1-\alpha} - (R + \frac{1}{g})I\right) - \frac{dIref}{dt} = 0 \quad (21)$$

By solving equation (21), expression of the duty cycle α called the equivalent control is given by

$$ueq = \alpha = 1 - \frac{U1}{L\frac{dIref}{dt} + (R + \frac{1}{g})I} \quad (22)$$

The nonlinear component of the control law is given using the approach of Gao[8].

From where, the control law is given by:

$$u = 1 - \frac{U1}{L\frac{dIref}{dt} + (R + \frac{1}{g})I} - k|s|^{\beta}\,sign(s) \quad (23)$$

Where k is a properly chosen coefficient and β is less than1.

V. SIMULATION RESULTS

We carried out simulations by using the numerical values given in the table (2).

TABLEII

NUMERICAL VALUES OF MODEL PARAMETERS

irefmax	R	L	a2	b1	b2
0.52A	37Ω	0.2H	93.33	-994.7	-582036.5

The lamp conductivity is shown in the next figure.

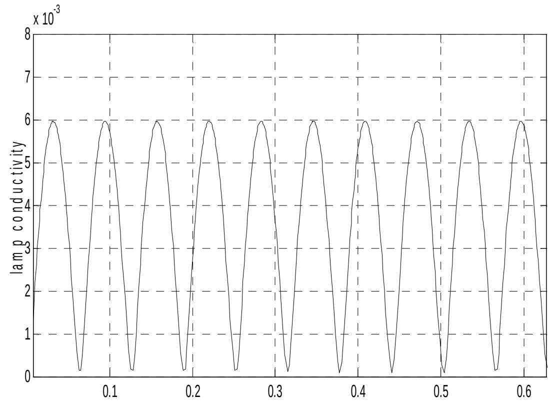

Fig.4 Lamp conductivity waveform

The waveform of lamp conductivity is exactly the needed form, so we can deduce that particle swarm optimization, makes as an intelligent optimization technique, is a very good method to identify nonlinear system parameters.

The following figure (Fig.5) illustrates, respectively, the evolution of the lamp current and the reference current as well as the sliding surface.

In the first part of this figure, we plot the desired current waveforms, and then we plot the lamp current waveform and the sliding surface which is the difference between these two waveforms.

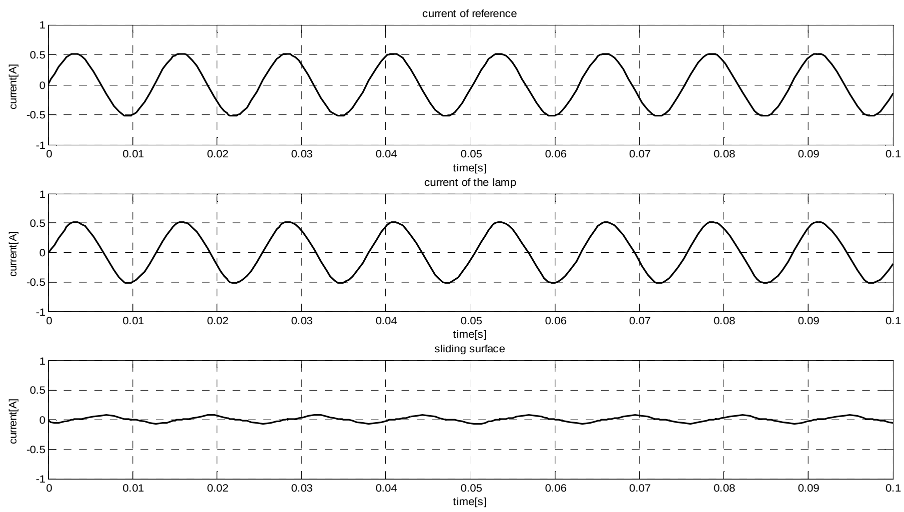

Fig.5 Waveforms of reference and lamp current and sliding surface

We deduce that the lamp current goes to the reference current so that the control attends its target which is to make the lamp current waveforms follows to a desired trajectory which is imposed to have an optimal power wave forms.

The lamp power waveforms is given as

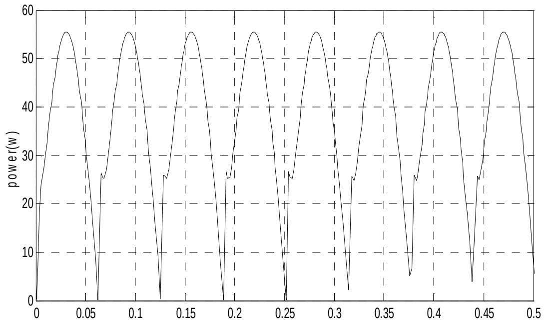

Fig.6 Lamp power waveform

The lamp power is nearly the same that desired lamp power. So we can assume that our strategy of the boost converter control, with sliding mode control, is very efficient and satisfy its objectives.

VI. CONCLUSION

A sliding mode control for DC/DC converter and a low pressure discharge lamp is presented. The application of the SMC is analyzed in details with respect to boost converter. Simulation results show that this control can stabilize the power supply and the lamp current. The efficiency of given control proves the increasing importance of the use of SMC tool for the robust control of nonlinear systems. The controller is simply implemented and for this reason, sliding mode control is usually used to control physical complex systems.

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