An Average Current Control for SEPIC LEDs Driver with Unit PF and Low THD

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***Abstract*— In this paper, an average current controller (ACC) is proposed to control the input current in a single ended primary inductor converter (SEPIC). The single stage DC-DC converter is chosen to drive light-emitting diodes (LEDs) operating in continuous conduction mode (CCM). This controller is composed of two cascade loops PI regulators. The inner loop ensures the DC input current control and the outer loop for DC output voltage control. A simulation model, of a SEPIC converter connected to a 200W LEDs Lamp for wide AC input voltage from 90V-230V rms, has been developed in Matlab Simulink. The simulation results prove that the average current control is a good method to improve the power factor correction (PFC) and to reduce the total harmonic distortion (THD).**

***Keywords*— Average current control, SEPIC, DC-DC converter, PFC, THD, CCM, LED driver.**

I. INTRODUCTION

Worldwide, LEDs have been widely used for many industrial applications such as street lighting, liquid crystal display television, traffic lights, signage lights and greenhouse lighting. Owing to the various advantages of long life more than 100000 hours, small size, high luminous efficiency, a good optical performance and low pollution, LEDs it can be the most suitable solution for lighting systems [1]. LED Lamp requires a suitable power supply because any variation in the LED voltage implies a large variation of the LED current. Hence, the large variation of LED current affects the efficiency of LEDs. LEDs are more efficient in direct current operation. Therefore, it's necessary to develop a DC power supply for driving LEDs taking advantages of their aforementioned characteristics.

Single stage DC-DC converters are the best candidates for LEDs drivers [2-3]. They offer the easiest way to power LEDs and to control their luminance. Also, they guarantee a high power factor and low total harmonic distortion. There are several DC-DC converter topologies of the PFC for lighting system such as Boost [4], Buck [5], Buck-Boost [6], Cuk [7], Flyback [8] and SEPIC.

SEPIC is chosen by many authors as a suitable power supply for lighting LEDs due to the various advantages of the device compared to the other topologies [9]. It can be designed to operate with a range of supply in the continuous conduction mode (CCM) [10] and in the discontinuous conduction mode (DCM) [11]. SEPIC can be stepped up/down converter and keeps the same polarity of input and output voltage. With this topology, the EMI filter can be eliminated due to the intrinsic low input current distortion [12].

There are several operations modes for PFC such as critical conduction mode, discontinuous conduction mode and continuous conduction mode. The control of PFC can be achieved using many methods for current control such as hysteresis control [13], average current control [14], and peak current control [15].

The proposed topology is controlled using average current control. This technique requires two cascade proportional integral (PI) regulators loops to ensure a suitable line current wave shaping and an output voltage regulation.

In the first section, the impacts of the harmonic distortion are presented and the types of power factor correction. Section II describes the topology of SEPIC converter. The controller designer is presented in section III. Section IV presents the simulation results. Finally, section V concludes the advantages of the proposed average current control technique for the optimal PFC for SEPIC converter.

II. POWER FACTOR CORRECTION

A. Impact of Harmonics on Power Quality of LEDs

All of the electrical systems with nonlinear loads present a current and voltage harmonics. These harmonics are defined by the total distortion harmonic (THD) [16]. They can reduce power quality, affect system efficiency, create thermal problems, and cause an electromagnetic interference. The THD is expressed by the following function:

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1} \tag{1}$$

where I_n is the rms value of the n-th harmonic of the input current and I_1 is the rms value of the input current of the first harmonic.

B. Types of Power Factor Correction

PFC is very important in electric power transmission in order to improve stability and efficiency. The power factor can be defined by the equation (2).

$$PF = \cos\phi = \frac{P}{V_{rms}.I_{rms}} \qquad (2)$$

where, P is the average power; Vrms and Irms are the rms values of the input voltage and the input current; ϕ is the phase between the current ant the voltage.

There are two types of PFC, an active power factor correction and a passive power factor correction. The difference between the PFC topologies is the method of their implementation. DC-DC converters are used for active PFC with PWM technique, and for passive PFC, it uses the passive circuits such as capacitors and inductors.

1) Active PFC

Active PFC is the suitable technique to control the line current and guarantee a high PF using the switch in DC-DC converter. The control can be realized by two ways: continuous conduction mode and discontinuous conduction mode. This topology is characterized by:

- simple design.
- without EMI filter.
- low number of components.
- low harmonic distortion.

2) Passive PFC

This technique uses just passive elements to achieve PFC. In passive PFC, it's not necessary to use a control circuit. This topology is characterized by:

- difficult design.
- requires a large filter at the input to achieve a high PF.
- slow dynamic response.
- high harmonic distortion.

III. POWER STAGE DESIGN OF SEPIC CONVERTER

The single stage DC-DC SEPIC converter is shown in Fig. 1a. It operates in CCM at 100 kHz. This converter required to operate a wide AC input voltage that's ranged from 90V to 230V rms for 200W White LEDs Lamp. Load has modelled using four strings of LEDs. Each string has contained 37 LEDs, and they have connected in series with supplying 143V with a current of 0.35A. The total current in the load is about 1.4A.

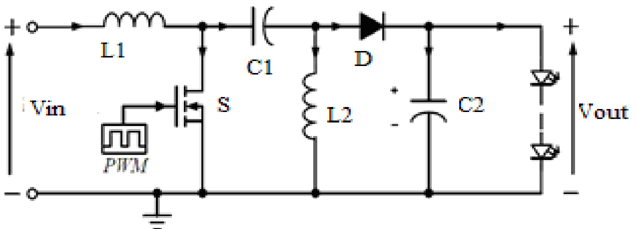

Fig.1a SEPIC converter

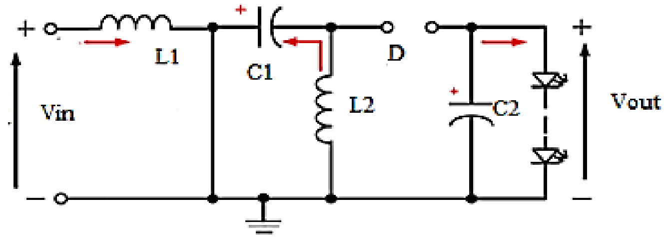

Fig.1b CCM mode when S is turn on

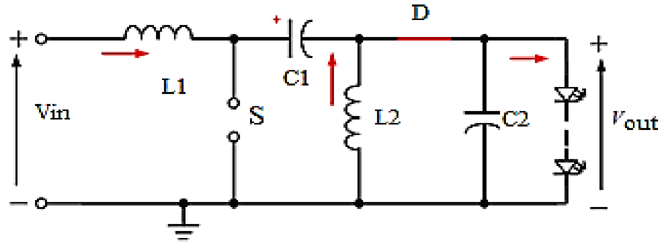

Fig.1c CCM mode when S is turn off

The device contains two capacitors C1 and C2, two inductors L1 and L2, a MOSFET switch S and a diode D. There is an exchange of energy between capacitors and inductors. The proposed device operates in CCM such that the inductor current never falls to zero. In CCM, there are two conduction states. The first state achieved when the switch S is turned on (Fig. 1b) and the diode D is turned off. During this state L1 is charged by the voltage source and L2 is charged by the capacitor C2. The currents through the inductors increase linearly. During the second state, the switch turn off (Fig. 1c) and the diode turn on. Both the inductors discharge. L1 and L2 release the energy to the capacitors and to the LEDs respectively. The currents through the inductors decrease linearly. In ideal SEPIC, the relation between the output voltage and the input voltage is given by the equation (3).

$$\frac{V_{out}}{V_{in}} = \frac{D}{1-D} \qquad (3)$$

V_{out}: output voltage
V_{in}: input DC voltage
D: duty cycle

Referring to equation (3), the output voltage can be controlled by the switching duty cycle.

A. Design of the SEPIC Converter

1) The Duty Cycle:

The maximum value of the duty cycle is defined by:

$$D_{\max} = \frac{V_{out} + V_D}{V_{out} + V_D + V_{in(\min)}} \qquad (4)$$

Where V_D is the threshold voltage of the diode and $V_{in\,(min)}$ is the minimum DC input voltage.

The minimum value of the duty cycle is defined by:

$$D_{\min} = \frac{V_{out} + V_D}{V_{out} + V_D + V_{in(\max)}} \qquad (5)$$

$V_{in\ (max)}$: the maximum DC input voltage

2) Design of the Inductors $L_1$and L_2:

The inductor L1 is defined by:

$$L_1 = \frac{V_{in(\min)} D_{\max}}{\Delta I_{L1} f_s} \tag{6}$$

ΔI_{L1} =10% I_{out} is the input current ripple and f_s=100 kHz is the switching frequency.

The inductor L_2 is defined by:

$$L_2 = \frac{L_1 L_{eq}}{L_1 - L_{eq}} \tag{7}$$

with:

$$L_{eq} = \frac{L_1 D_{\max} \Delta I_{L1}}{2} \tag{8}$$

3) The Capacitors:

The capacitor C_1 is defined by:

$$C_1 = \frac{I_{out} D_{\max}}{\Delta V_{in(\min)} f_s} \tag{9}$$

with $\Delta V_{in(\min)} = 10\% V_{in(\min)}$

The capacitor C_2 is defined by:

$$C_2 \geq \frac{I_{out}}{2\omega \Delta V_{c2}} \tag{10}$$

with $\Delta V_{c2} = 10\% V_{out}$

I_{out} : the output current

$\omega = 2\pi f$: the natural pulsation

ΔV_{C2} : the capacitor voltage ripple

IV. PFC USING THE AVERAGE CURRENT CONTROL

The proposed SEPIC LEDs driver used the average current is proposed for PFC. This technique requires two cascade loops. An inner loop (for current control) is used to ensure the wave-shaping of the input current and to improve the power factor. While, the outer loop (for voltage control) is designed to regulate and stabilize the output voltage of LEDs around a set point. In the inner loop, the inductor current is sensed, then it's compared with the reference current to generate the duty cycle for PWM control. The output of the external loop generates the reference current. In the outer loop, the load voltage is sensed and compared with the reference voltage in order to regulate the output voltage around the desired set point. The average current mode control is depicted in Fig.2 below.

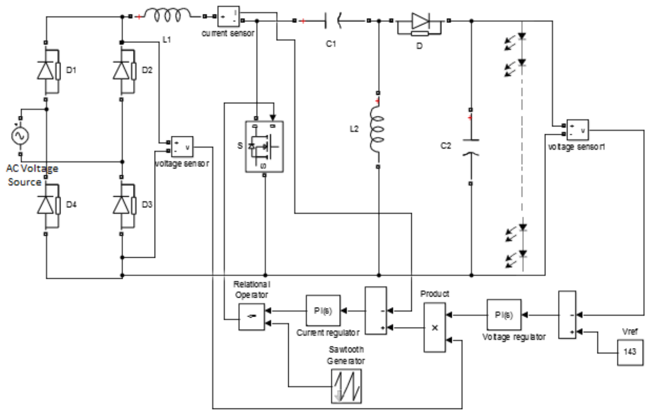

Fig.2 Matlab/Simulink Model of the SEPIC average current control

A. PI Controller for SEPIC Converter

This control is realized using cascade Proportional Integral (PI) control. The transfer function of PI regulator is defined by:

$$H(s) = K_p + K_i \frac{1}{s} \tag{11}$$

with:

K_i: the integral gain.

K_p: the proportional gain.

The parameters of the PI controller for both current loop and voltage loop are determined using Zeigler-Nichols (Z-N) closed loop method [17]. Hence, we define two transfer functions $H_i(s)$ and $H_v(s)$ to control the current and the voltage respectively.

$$H_i(s) = K_{pi} + K_{ii} \frac{1}{s} \tag{12}$$

$$H_v(s) = K_{pv} + K_{iv} \frac{1}{s} \tag{13}$$

Using Zeigler-Nichols method, the PI parameters are given by:

$$K_p = 0.45\ K_c \tag{14}$$

$$T_i = 0.84 T_c \tag{15}$$

where K_c is the ultimate gain and T_c is the ultimate period.

The parameters K_{pi}, K_{ii}, K_{pv} and K_{iv} are presented in Table 1.

TABLE I

PI PARAMETERS

K_{pi}	K_{ii}	K_{pv}	K_{iv}
4.8	0.006	1.5	0.09

V. SIMULATION RESULTS

The proposed SEPIC PFC converter was built using the MATLAB/SIMULINK toolbox. This device has designed of 200W White LED lighting lamp. The parameters of the SEPIC converter presented in Table 2 are calculated using the above equations. The suitable values of the cascade PI regulators are determined by the Z-N method. These parameters maintain the LEDs load voltage and the output current at constant values (143V, 1.4A) for wide AC voltage source range from 90V to 230V. The proposed model is shown in Fig. 2.

TABLE II
PARAMETERS USED IN SIMULATION

Parameters	**Values**
AC Input voltage	90V-230V rms
Supply frequency	50Hz
Capacitor C_1	0.95µF
Capacitor C_2	0.155mF
Inductor L_1	4mH
Inductor L_2	177.54µH
Switching frequency	100 kHz
Output voltage	143V
Output current	1.4A

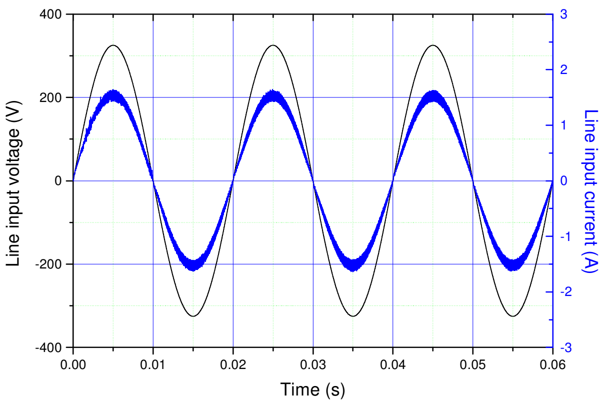

Fig.4: AC input current and voltage

Fig.4 shows the waveforms of the input current and voltage. In this figure the input current follows the input voltage without any phase and any distortion.

Fig.5 shows the waveforms of the output current and voltage. Around the set point, the output voltage is about 143V, while the average output current is 1.4A. In this figure it can be seen that the current in the lamp starts to appear only when the output voltage exceeds the threshold voltage of the LEDs in the vicinity of 123 V.

Fig.6 shows the curves of the PF and the THD of the input AC current. It can be observed that when we use the average current control method, the value of the power factor increases until 0.998 with reduced total harmonic distortion less than 3.2%. According to international Standard IEC 61000-3-2:2014, the obtained value of the current THD is in the standard limits for harmonic current emissions for Class C equipment input current ≤ 16 A per phase.

The simulation results given in this work, prove that the average current control using the cascade PI regulators is a good candidate to ensure the PFC.

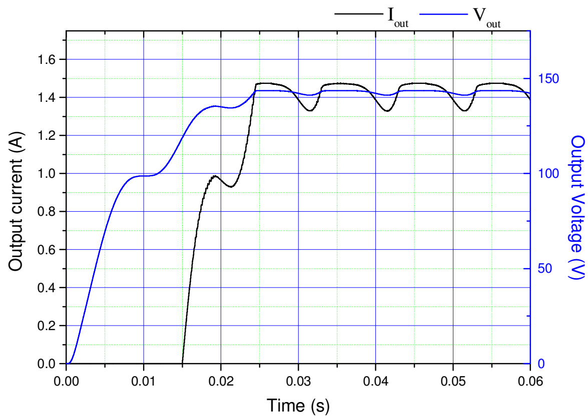

Fig.5 Output voltage (V_{out}) and Output current (I_{out})

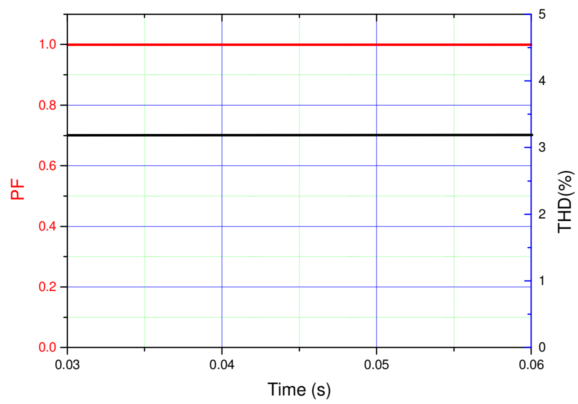

Fig.6 Power Factor (PF) and THD

VI. CONCLUSIONS

In this paper, an average current control design for a single stage SEPIC converter for a LEDs lamp is presented.

This approach consists of two cascade loops using PI regulators. The inner loop is used to ensure unity PF and to reduce THD, whereas, the outer loop is used to regulate and to stabilize the output voltage. The control scheme is simulated using MATLAB software. With this proposed control, the average current and voltage of the lamp are maintained constant around 1.4A and 143V respectively.

The simulation results prove that the average current control is a suitable way to improve the power factor correction (PFC) and to reduce the total harmonic distortion (THD).

This method of current and voltage regulation is necessary for electronic power supplies of white or multicolour LED lamps used in advanced lighting applications such as greenhouse lighting for horticulture.

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