SIMPLE VALLEY-FILL FILTER SELF-OSCILLATING ELECTRONIC BALLAST WITH LOW LAMP CURRENT CREST FACTOR

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Abstract — **This paper presents an electronic ballast using the valley-fill modified filter as a passive power-factor-correction method. Pulse frequency modulation is used to reduce lamp current high crest factor, which is inherent of valley fill filter. Self-oscillating electronic ballast and resonant filter features are used with frequency modulation in order to avoid complex circuitry and to achieve a fluorescent lamp current low crest factor. The partial smoothing valley-fill dc-link bus voltage is used to control the switching frequency. The switching frequency changes in order to keep the lamp current crest factor lower than 1.7 and a modified valley-fill filter is used to meet IEC 61000-3-2 Class C requirements. Simulations and experimental results are presented to demonstrate the simplicity, and feasibility of the proposed system.**

KEYWORDS

Valley-fill; self-ocillating; electronic ballast; fluorescent lamps; power-factor-correction.

I. INTRODUCTION

Electronic ballasts supplying fluorescent lamps have become very attractive because of its well-known benefits, such as higher luminous efficiency (lm/W), no flicker, audible noise absence, lighter weight and volume.

Simple used electronic ballasts without power factor correction (PFC) with a large capacitor to filter the input rectified voltage presents good results of lamp current crest factor (lower than 1.7). However, it presents low power factor (PF<0.6), and a high input current total harmonic distortion (THD>130%). In order to overcome this drawback two power-factor-correction (PFC) methods have been used: 1) active [1],[2], and [3] and 2) passive methods [4] [5], [6], [7], and [8]. Second method using modified valley-fill filter to perform power-factor-correction can be used to meet IEC 61000-3-2 Class C requirement [6], and [8] which is shown in Table 1. However, it must use an appropriated circuit to obtain lamp current low crest factor. Although modified valley-fill filter is a simple structure, current lamp high crest factor (C. F.) is inherent. Solution to achieve low C. F. has been proposed using pulse frequency modulation [9].

In order to avoid complex circuits, additional components, and overcome the very high lamp current C. F., also meeting IEC 61000-3-2 Class C requirement, this work proposes:

1) to use self-oscillating electronic ballast (SOEB) with pulse switching frequency modulation;

TABLE I
Limits for Class C Equipment

Harmonic order (n)	Maximum Permissible Harmonic Current Expressed as a Percentage of the Input Current at the Fundamental Frequency %
2	2
3	30*Power factor
5	10
7	7
9	5
11≤n≤39	3

2) modified valley-fill filter, respectively to meet these requirements.

This paper is organized as follows. Section II presents a discussion about power-factor-correction techniques. In Section III is presented the lamp current crest factor correction principle. Section IV shows the design procedure for the purposed work. Section V and VI show simulation and experimental results respectively. Finally, a conclusion based on results obtained is carried out.

II. POWER-FACTOR-CORRECTION CIRCUITS

Two basic ways to perform power-factor-correction are described briefly.

A. *Active Power-Factor-Corection*

Active PFC is limited by high cost and circuitry complexity. The sharing of switch is a good alternative to overcome this drawback. However, it generally results in voltage and current stress in the active components.

B. *Passive Power-Factor-Correction*

Power-factor-correction using passive methods has some advantages compared over its active methods, such as low cost, simplicity, and low current and voltage stress. One of the simple methods of passive power-factor-correction is the traditional valley-fill filter shown in Fig. 1.

1) *Valley-Fill Filter Operation Principles*

Valley-fill filter operation principle to power-factor-correction is the increase of the time when electronic ballast consumes line current, approaching its waveform to a sinusoidal one, decreasing its THD. The disadvantage of using this valley-fill filter is the resulting DC bus voltage partial smooth of about 50%, resulting in a lamp current high C. F., reducing the lighting efficiency and lamp lifetime. Fig. 1 shows basic valley-fill filter and its operation stages. These operation stages show just half line-cycle, because the remainder is identical.

Stage 1) In this stage line voltage instantaneous value has its value smaller than its peak value divided by two ($V_p/2$), D_5

and D_7 are forward biased and further diodes reverse biased. In this case, filter capacitors (C_{f1} and C_{f2}), in parallel, are supplying the load, resulting in a determined voltage decrease (ΔV). Line does not provide current to the ballast.

Stage 2) When the line voltage instantaneous value overtakes stage 1 value ($V_p/2$ - ΔV), line starts to feed the load, because D_1 and D_4 (D_2 e D_3 in the next half line-cycle) are forward biased and further diodes reverse biased. In this stage, DC bus voltage will pursue line voltage waveform.

Stage 3) Diode D_6 becomes forward biased when line voltage reaches the value ($V_p/2$- ΔV). In this stage, besides line supplies the load, it will also charge both electrolytic capacitors in series, which will demand a peak current. DC bus voltage still pursues line voltage waveform.

Stage 4) When line voltage reaches its maximum value (V_p), each one of the filter capacitors (C_{f1} and C_{f2}) will be charged with $V_p/2$, and this stage will start. Stage operation is similar to operation of stage 2.

Fig. 2 shows the theoretical input line voltage and current and dc bus voltage waveforms. It can be seen, although increasing the period when electronic ballast consumes line current improving its THD and PF, it does not meet IEC 61000-3-2 Class C requirement. In order to overcome this drawback some structures have been reported [4], and [5].

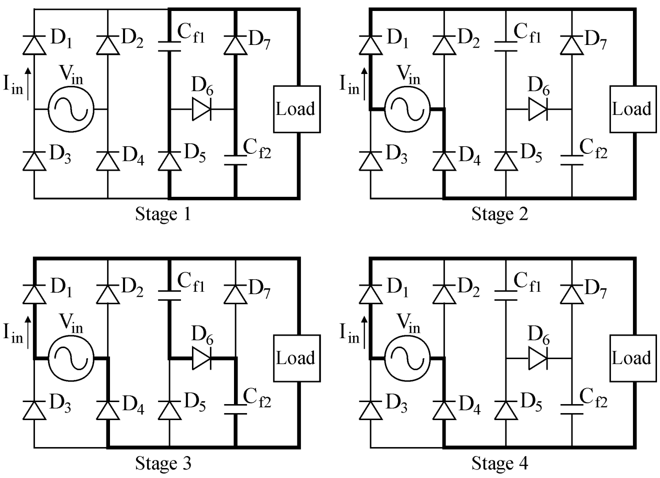


Fig. 1. Traditional valley-fill filter stages

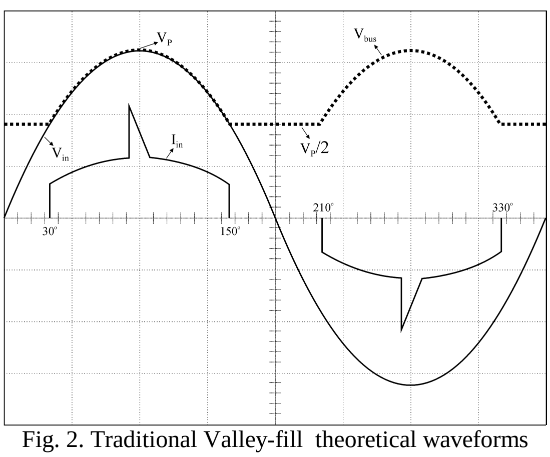


Fig. 2. Traditional Valley-fill theoretical waveforms

However, some configurations have lamp current high crest factor, due to the bus voltage ripple shown in Fig. 2. In this way, modified valley-fill filter is an alternative to be used with pulse-frequency modulation to meet the requirements of input (utility line) and output (fluorescent lamp current crest factor). The control technique used in this paper is based on frequency modulation, through the dimming technique proposed in [10], and an application proposed in [11]. Next section shows the principle of the proposed system.

III. LAMP CURRENT CREST FACTOR CORRECTION PRINCIPLE

The lamp current low crest factor is obtained through bus voltage ripple characteristic, which is shown in Fig. 3(b).

This bus voltage is used as reference signal to adjust the lamp current properly through the switching frequency control Fig. 3(a). This voltage is used to control the current i_C through a low power transistor, which makes the control of operation state when the bus voltage changes as can be seen in Fig. 3(b) and (c).

Fig. 4 shows proposed system with described technique. Self-oscillating gate-driver circuit, modified valley-fill filter and pulse frequency modulation (PFM) circuit are shown highlighted in this figure.

IV. DESIGN PROCEDURE

The design of the proposed system involves two main steps. First one is the resonant filter design [13], and second one is the pulse-frequency modulation circuit obtained through a similar technique proposed in [10].

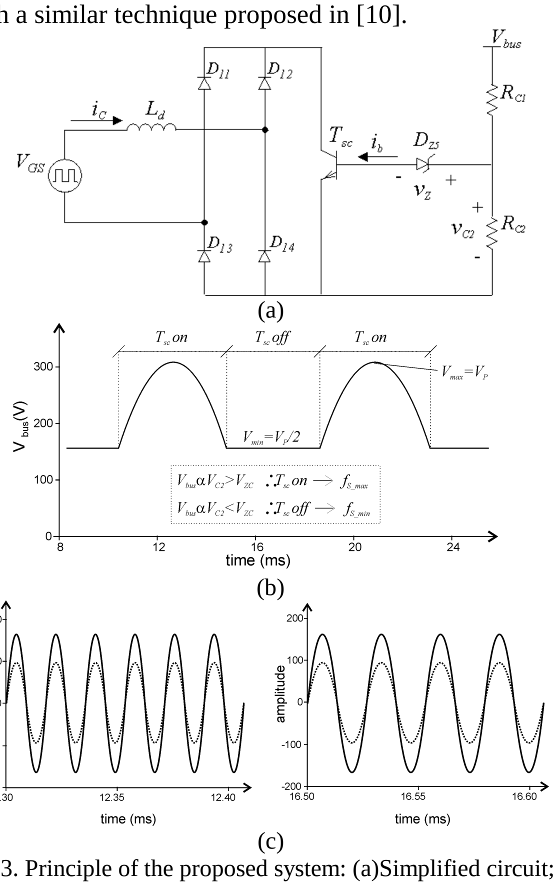


Fig. 3. Principle of the proposed system: (a)Simplified circuit; theoretical waveforms (b) bus voltage, and (c) fluorescent lamp

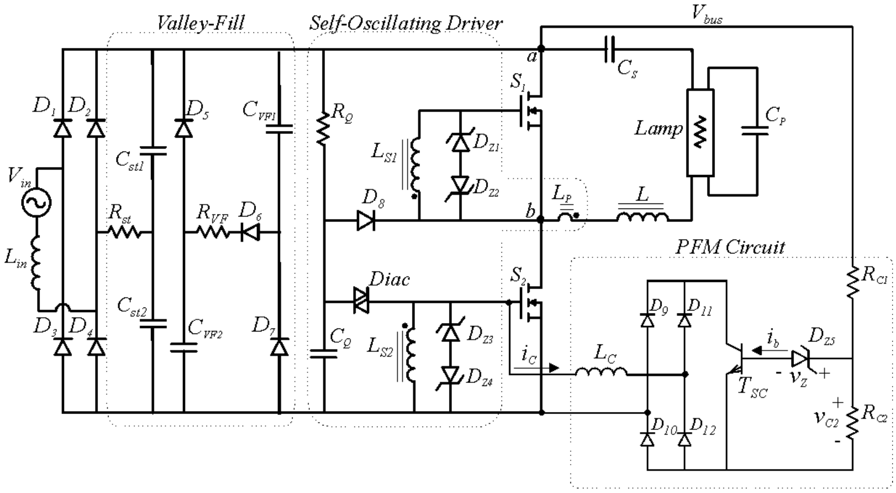


Fig. 4. Self-oscillating modified valley-fill pulse frequency modulation system

A. Resonant Filter Design

To determine the filter parameters, following approximations are considered:

- Fundamental approximation V_f;
- Fluorescent lamp is represented by its equivalent resistance in steady-state (R) and in the starting scenario (100*R);
- The components C_p, C_S and L are considered linear, and time invariant;

Following steps are used to determine the resonant components:

1) *Input Data:*

The operating switching frequency and voltage applied in the resonant filter is determined considering the bus voltage of the valley-fill filter.

2) *Resonant Filter Parameters:*

Resonant filter components (C_p, L, C_s) are determined though the following steps:

a) Phase Angle ϕ

The phase angle is determined in order to guarantee the starting, and the power in steady state of fluorescent lamp and ZVS operation of the switch.

Phase angle is

$$\phi=\arctan\left(\left(L\omega-\frac{1}{C_S\omega}-\frac{R^2C_P\omega}{(1+C_P^2R^2\omega^2)}\right)\cdot\frac{1+C_P^2R^2\omega^2}{R}\right),$$

where $\omega=2\pi f_s$, being f_s: switching frequency, and R: equivalent lamp resistance.

Fluorescent lamp power, represented through its equivalent resistance R is

$$P(\phi)=\frac{E^2\cdot 2}{\pi^2}\cdot\frac{\left(1+C_P^2R^2\omega^2\right)R}{R^2+\left(R\cdot\tan(\phi)\right)^2}, \qquad (1)$$

Being: E: bus voltage V_{min} and P: power in the lamp.

Thus, phase angle ϕ can be determined graphically according Fig. 5.

b) Paralel Capacitor C_p

Through the phase angle ϕ determined in Fig. 5 the capacitor C_p is determined by

$$C_P(\phi)=\frac{1}{\omega R}\sqrt{\frac{P(\phi)}{R}\left(\frac{\pi^2\left(R^2+\left(R\cdot\tan(\phi)\right)^2\right)}{E^2\cdot 2}\right)-1}. \qquad (2)$$

c) Resonant Inductor L

The resonant inductor is determined by

$$L(\phi,C_S)=\frac{R\tan(\phi)\omega^{-1}+C_P(\phi)R^2}{1+\omega^2C_P^2(\phi)R^2}+\frac{1}{C_S\omega^2}, \qquad (3)$$

being C_s a typical value to block dc component to the fluorescent lamp.

From (1), (2) and (3) the filter components are determined and summarized in Table II.

B. Crest Factor Correction Circuit Design

The parameters of the self-oscillating gate-driver circuit and crest factor correction circuit (PFM) are determined taken into account the following assumptions:

- Two voltage levels for input V_{ab} are considered, V_{min} and V_{max};
- Inductance L_d is determined to obtain the maximal frequency for the voltage level V_{max};
- Resonant filter parameters are determined previously considering voltage V_{min}.

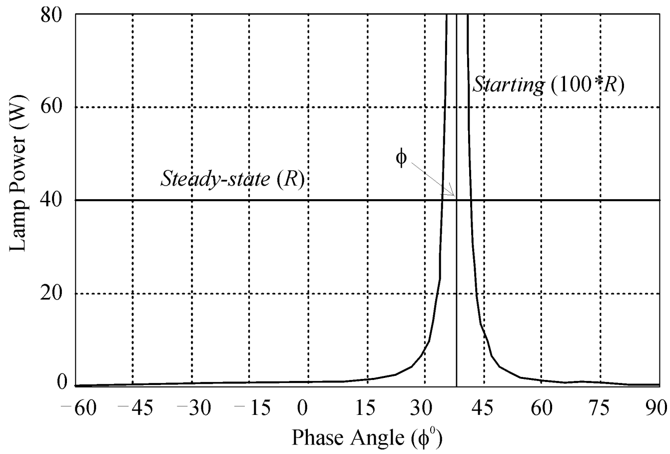


Fig. 5. Power in the fluorescent lamp in steady state (R) and starting (R=100*R)) versus phase angle ϕ)

1) *Self-oscillating:* Self-oscillating gate-driver circuit parameters are determined according the design methodology presented in [10].

2) *Crest Factor Correction:* Lamp current crest factor correction is performed through frequency variation obtained by means an inductor paralleled within the gate-driver circuit, controlled through a transistor that connects L_c in the circuit when the voltage V_{bus} becomes higher than V_{min}, as can be seen in Fig. 6(a) and (b). The behavior such as a control system allows the lamp current crest factor correction to be controlled changing the switching frequency of the converter. The parameters are defined considering the proposition shown in [10].

V. SIMULATION RESULTS

Fig. 7 shows simulation results in order to illustrate the performance of the proposed system. Fig. 7(a) shows the input voltage and current when the PFM circuit changes switching frequency at the fluorescent lamp. Fig. 7(b) shows the envelopment of the fluorescent lamp waveforms using an equivalent resistor. In Fig. 7(c) can be seen lamp current for two different frequencies in order to show the frequency modulation. In the same way Fig. 7(d) shows bus voltage and control current i_c. These simulation results illustrate the feasibility of this system.

VI. EXPERIMENTAL RESULTS

A prototype has been built with the components shown in Fig. 4. Table II shows the input data specification, resonant EMI filter parameters, and the main components of the implemented circuit. Fig. 8 shows the experimental results.

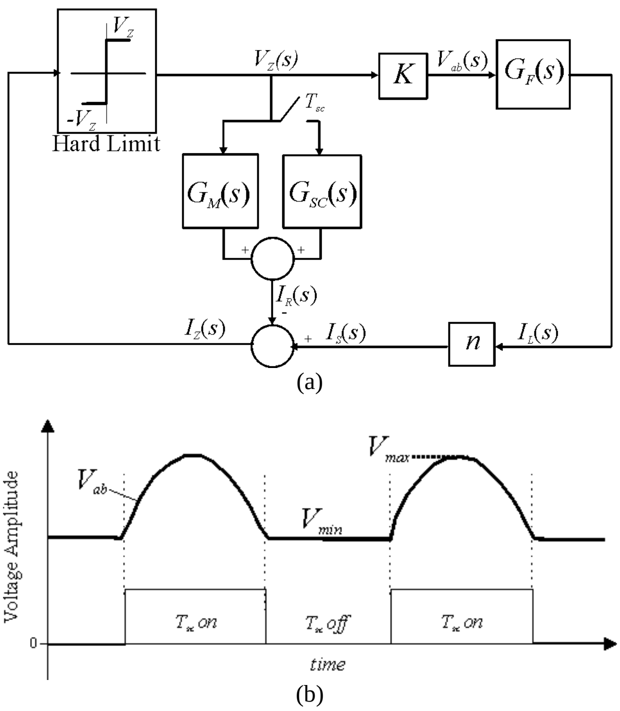


Fig. 6. Block diagram of the proposed system (a) (R=100*R)) versus phase angle ϕ) (b) Reference signal

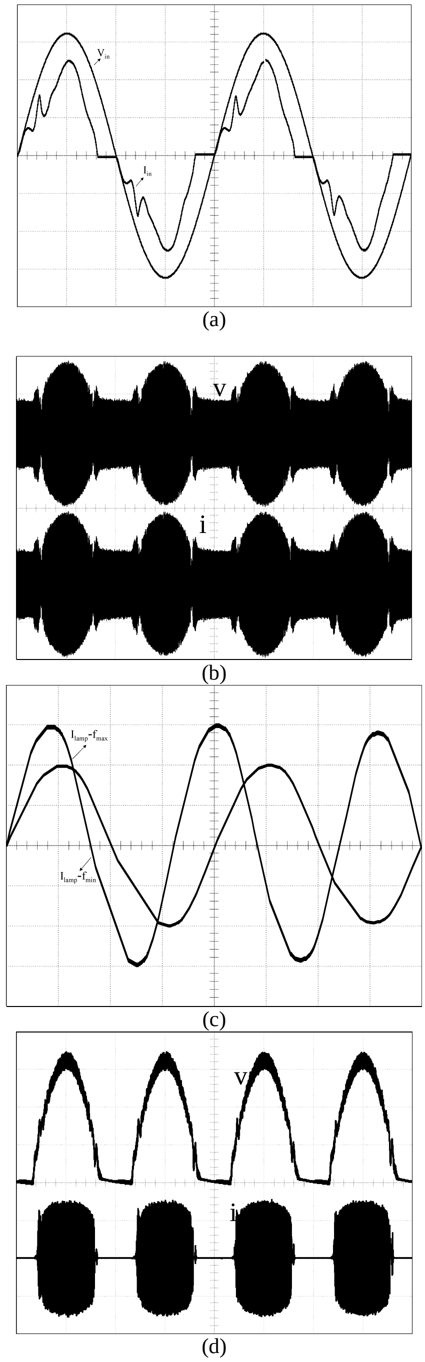
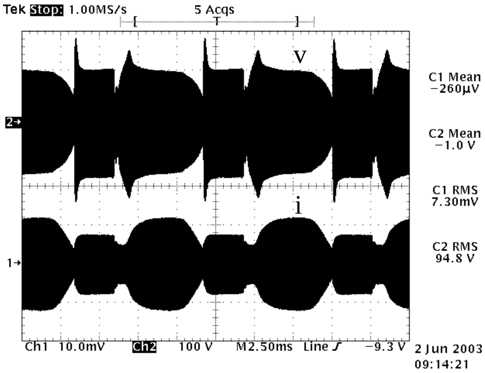


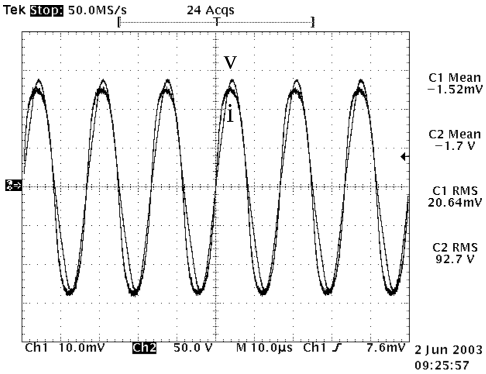
Fig. 7. Simulation results: (a) input voltage and current, (b)lamp voltage and current envelopment; (c)lamp current for lower and maximal frequency f_s; (d) bus voltage e current i_C.

Fig. 8(a) shows lamp voltage and current envelopment waveforms, where the lamp current C. F is 1.68 (lower than 1.7). Fig. 8 (b) and (c) shows the lamp voltage and current waveforms in the lowest (45 kHz) and highest (60 kHz) switching frequency, respectively.

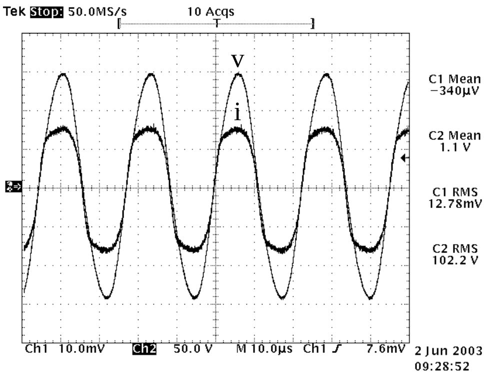
Fig. 8 (d) shows the bus voltage and control current i_C. Fig. 8(e) shows input voltage and current presenting a power factor of 0.96, and total current harmonic distortion of 15 % meeting the requirement of IEC 61000-3-2 Class C, as can be seen in Fig. 9.



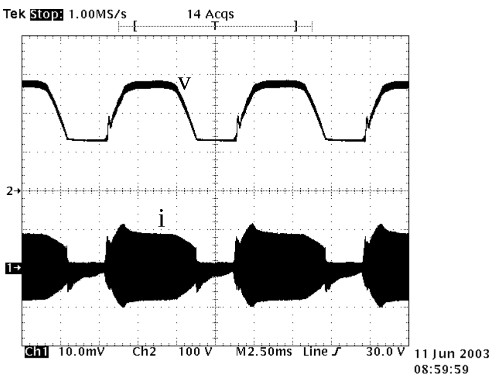
(a) 100V/div; 0.5 A/div; 2.5 ms/div



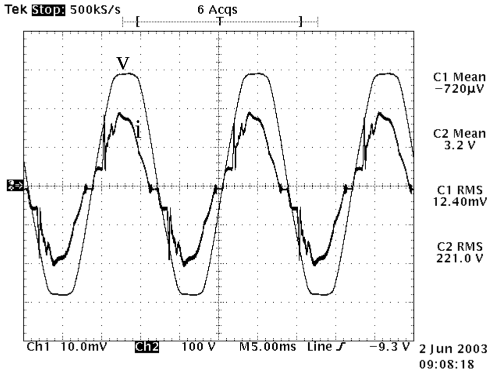
(b) 100V/div; 0.2 A/div; 10 µs/div



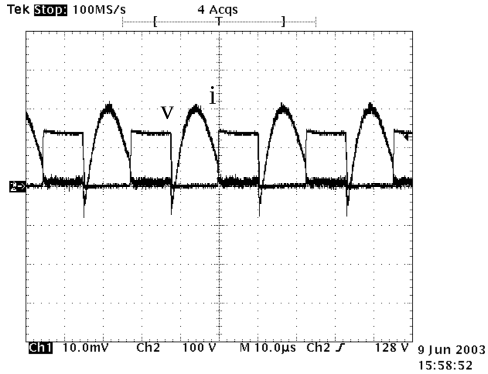
(c) 100V/div; 0.2 A/div; 10 µs/div



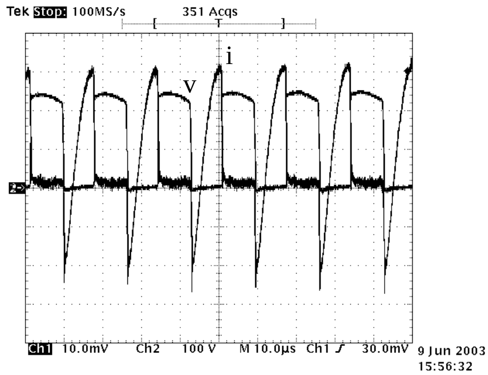
(d) 100V/div; 0.2 A/div; 2.5 ms/div



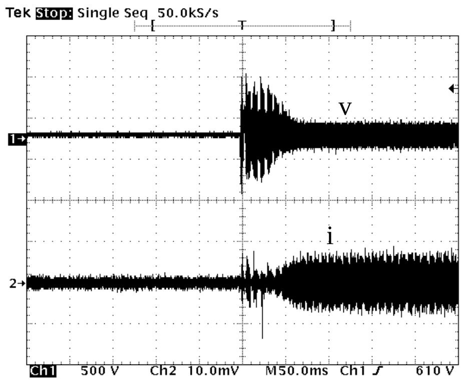
(e) 100V/div; 0.5 A/div; 10 µs/div



(f) 100V/div; 0.2 A/div; 10 µs/div



(g) 100V/div; 0.2 A/div; 10 µs/div



(h) 500V/div; 1 A/div; 50ms/div

Fig. 8. Experimental results: (a) lamp voltage and current envelopment; (b) lamp voltage and current f_s =45 kHz; (b) lamp voltage and current f_s =60 kHz; (d) bus voltage and current i_c; (e) input voltage and current; (f) switch voltage and current f_s =45 kHz; (g) switch voltage and current f_S =60 kHz (h) lamp starting voltage and current

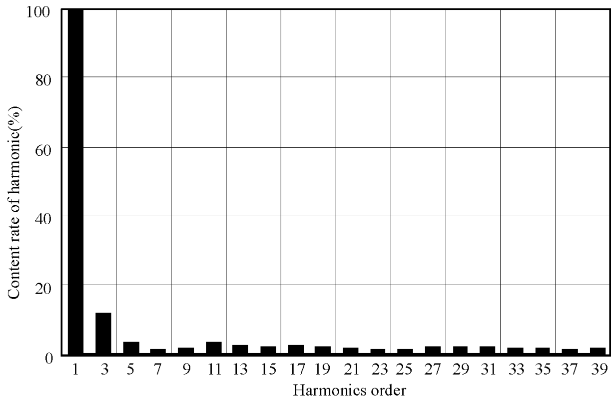


Fig. 9. Input current harmonic content rate

TABLE II
Summarized Parameters

Input Data	
Input voltage	V_{in}=220 V_{RMS}, 60Hz
Output Power	P=40 W
Equivalent Lamp Resistance	R=204 Ω
Switching frequency range	45 kHz-60 kHz
Self-Oscillating Electronic Ballast	
L_p,L_{S1},L_{S2}	2/10/10 Turns on core T15 IP6 – Thornton
D_{Z1}-D_{Z4}	Zener Diode 12 V ½ W
Diac	DB3
R_Q	Resistor 220 kΩ/1/8W
C_Q	Ceramic Capacitor 100nF / 63 V
R_M	Resistor 470 kΩ/1/8W
D_5	Diode UF4007
S_1, S_2	Power MOSFET´s IRF740
D_1 -D_8	Diode 4x1N4004
Lamp	Tubular Fluorescent Lamp 40W
Filter Parameters	
C_S	Series resonant capacitor, 147 nF, 250 V_{ac}
L	Resonant inductor, 800 µH
C_P	Parallel capacitor 22 nF, 600 V_{ac}
L_{in}	EMI filter 5 mH
Valley-Fill Modified Filter	
C_{st1}, C_{st2}	Polypropylene capacitor / 470 nF 200 V_{ac}
C_{VF1}, C_{VF2}	Electrolytic capacitor / 100 µF 250 V_{dc}
R_{VF}	Resistor 50 Ω / ½ W
R_{st}	Resistor 220 Ω / 2 W
PFM Circuit	
D_9 -D_{12}	Diode 4x1N4148
R_{C1}, R_{C2}	100 kΩ;10 kΩ /1/8W
L_C	Control inductor, 100 µH
D_{Z5}	Zener Diode 12 V ½ W
T_{SC}	Bipolar transistor, 2N2222

Fig. 8(f) and (g) shows ZVS commutation in the lowest and highest switching frequency. Fig. 8(h) shows lamp starting voltage and current.

VII. CONCLUSION

In this work, a simple alternative to improve the lamp current C. F. and power-factor-correction have been presented. A modified valley-fill filter has been employed to meet the IEC 61000-3-2 Class C requirements. This circuit is a passive power-factor-correction method presenting low cost, simplicity, and without active devices voltage and current stresses. A pulse frequency modulation circuit within the self-oscillating gate-driver circuit has been used in order to overcome the drawback caused by the dc bus partial smoothing, which is inherent from the valley-fill filter, maintaining the lamp current C. F. lower than 1.7. PFM circuit has been built with few low power components added to the self-oscillating electronic ballast, guarantying its well known reliability, simplicity and low cost.

Simulation and experimental results demonstrate the feasibility of the proposed system. The lamp current low C. F lower than 1.7, power factor of 0.96, and efficiency of 90 % indicate the potential application of the proposed system warranting the limits of the input (input line) and output (fluorescent lamp).

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