A μC Controlled Power Factor Corrected AC-to-DC Boost Converter with DCM Operation

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Abstract

This paper presents a boost-integrated, single-phase, pulse width modulated (PWM), fixed frequency ac-to-dc boost converter with active power factor correction. The boost inductor operation is maintained in the discontinuous current mode (DCM) so that natural power factor correction is obtained. As opposed to the two-stage rectifier-boost ac-to-dc converter the output current from the source of this converter is sinusoidal and in phase with the source voltage and filtering is superior. PWM control is used to control the output voltage at different load conditions and it is implemented using ATMEGA8 micro-controller (µC) from Atmel. A 110 V, 60 Hz to 150 V DC, 450 W, 100 kHz ac-to-dc converter is designed to explain design procedure. The designed converter is simulated for different load conditions using PSPICE to verify its operation. A laboratory prototype has been developed and tested. Simulation and prototype experimental results verify the DCM operation and high power factor. This converter is suitable for excitation field supply of a dc machine in electro-mechanics laboratory. This innovative design project work experience is very relevant to engineering research and education.

I. INTRODUCTION

With the advent of digital technology ac-to-dc converters are enjoying widespread applications [1-2]. As a result, in recent decades, ac-to-dc converter has formed an active area of research [3-5]. At the same time regulatory agencies are enforcing strict harmonics regulations such as IEC 1000, Std 500 etc. This is due to the high power factor and low line current harmonic distortion requirements. In addition to the high power factor, the advantages of high frequency switching are also being utilized for realizing ac-to-dc converter. These include high efficiency, smaller reactive components, easier filtering, reduced volume etc.

Conventional ac-to-dc converters consist of two stages: one ac-to-dc diode rectifier cascaded by a dc-to-dc converter. As a result the output current drawn from the ac source is non-sinusoidal and out of phase with the source voltage. This is shown in Fig. 1 (after transient) at steady state the current settles down but still non-sinusoidal and out of phase As a result the source power factor is low as can be seen from the total harmonic distortion (THD) in the current spectrum of Fig. 2.

To improve the power factor and thus reduce the THD active power factor techniques are used [3-5]. The objective of this paper is to present an embedded micro-controller based power factor corrected ac-to-dc boost converter. Boost converter when controlled properly can ensure high power factor [5]. On the other hand when the boost converter operates in DCM can ensure natural power factor correction with simplified control scheme. The proposed converter in this paper integrates a boost converter operating in DCM current mode.

The outline of this paper is as follows: Section II explains proposed converter operation with a schematic diagram. Design example is given in Section III to explain design procedure. Section IV presents prototype experimental results. This paper is concluded in Section V.

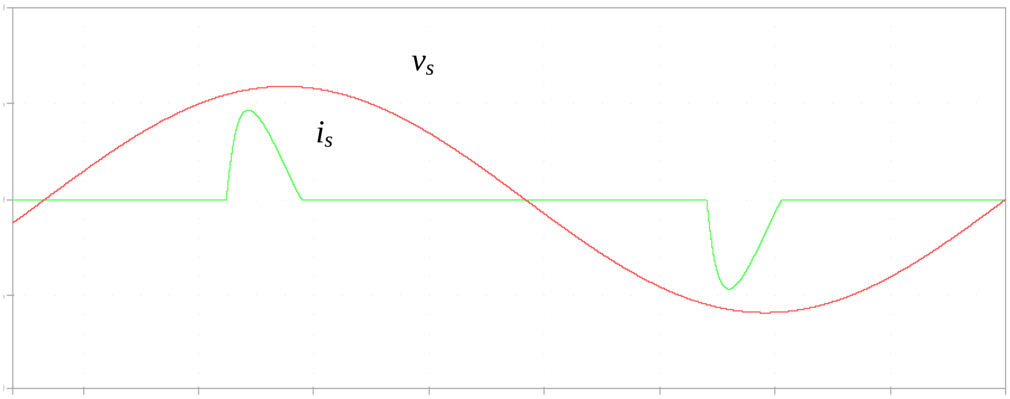

Figure 1 Source voltage, v_s (50 V/div) and current, i_s (1 A/div) in a diode rectifier at steady state.

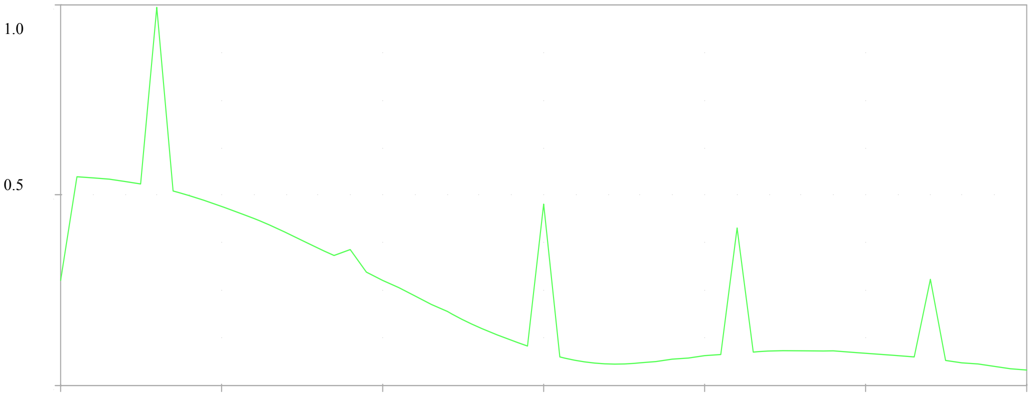

Figure 2 Normalized source current harmonic spectrum with THD = 71.68%

III. SCHEMATICS AND OPERATION

A detailed schematic diagram of the proposed ac-to-dc boost converter is shown in Fig. 3. The boost switch S_b is controlled from a gate pulse generated by the micro-controller. When S_b is closed the boost inductor stores energy from ac source and the source current increases as given by (1). When S_b is open the stored energy in L_b is released to capacitor C_b as current goes down from its peak value given by (2).

$$v_s = L_b \frac{di_{in}}{dt} \tag{1}$$

$$v_s - V_o = L_b \frac{di_{in}}{dt} \tag{2}$$

From (1) and (2) the increase and decrease ($V_o > v_s$) of current will be linear if v_s is constant and that is assured by making the switching cycle very small compared to the line cycle *i.e.* $f_{line} << f_s$. The high frequency current wave form is shown in Fig.4. Using (1) and (2) the output power can be expressed [4] as in (3).

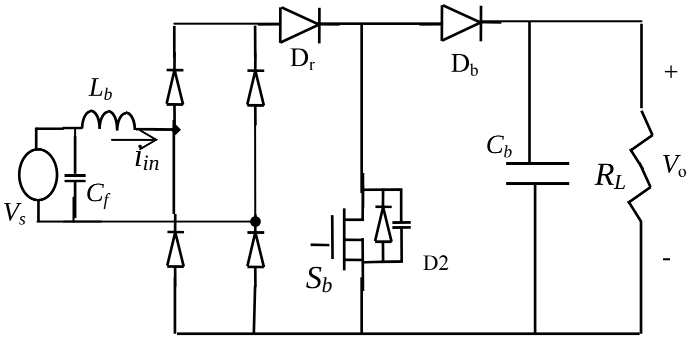

Figure 3: Proposed ac-to-dc boost converter

$$P_o = \frac{V_o^{\,2}}{(R_L)} = \left(\frac{V_{s,pk}{}^2 D^2 T K^2}{\pi L_b}\right)\left(\pi + 2\sin^{-1}\left(\frac{1}{K}\right)\right)\left(\left(1-\left(\frac{1}{K}\right)^2\right)^{1/2} - \pi - \frac{2}{K}\right)^{-1} \tag{3}$$

where $K = V_o / V_{s,peak}$

The output capacitor, C_b, is determined from the output ripple specification as in (4).

$$C_o = (I_{o,\,max} / 8 * f_s * \Delta V_{pk\text{-}pk}) \tag{4}$$

III. DESIGN

An ac-to-dc boost converter is designed, as a course project, with specifications: V_s = 110 V rms, 60 Hz, V_o = 150 V DC, P_o = 450 W, f_s = 100 kHz, efficiency, $\eta = 0.85$, $D = 0.4$, 10% output voltage ripple and $K = 2$. These specifications along with (3) and (4) are used to design the converter parameters. The designed parameters are: boost inductor, L_b = 100 μH, Load resistance, R_L = 50 Ω, and bus capacitor, C_b = 2000 μF.

IV. EXPERIMENTAL RESULTS

The converter designed in Section III is built and tested in laboratory using *n*-channel MOSFET switch IRF640 through student course project. The control gate signals for the switch was implemented using microcontroller ATMEGA8. The gate signals are shown in Fig. 5. As shown in Fig.6 output voltage is approximately 150 V with negligible ripple. It is obvious from Fig.7 that the power factor of this converter is close to unity.

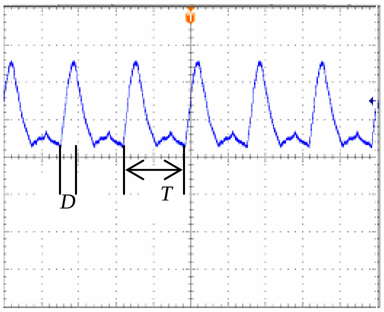

Figure 4 HF Boost inductor current

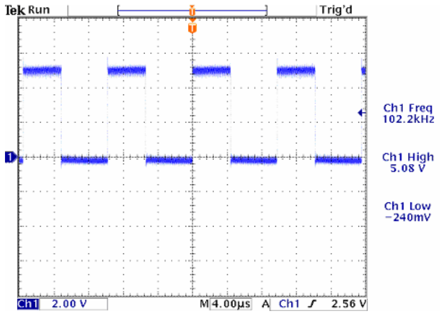

Figure 5 Gate pulse from µC

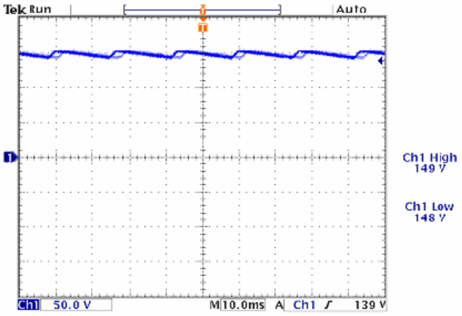

Figure 6 Output dc voltage waveform

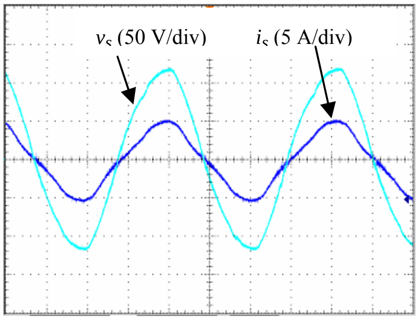

Figure 7 AC source voltage and current

V. CONCLUSIONS

A micro-controller based single-phase power factor corrected ac-to-dc boost converter has been presented. Operation of the boost converter is explained and analyzed. It is maintained in DCM mode and controlled with fixed frequency PWM from an I/O pin of the µ-controller. A design example is presented. A prototype laboratory model of the designed converter is built and tested. Some of the experimental results are presented in Section IV. Results show that the converter can maintain constant dc output voltage of 150 V for a wide (100 % to 10%) load range while power factor is improved with THD lass than 10%. Because of significant involvement in literature survey, design and testing processes, students were exposed to undergraduate research and hands-on experience. This converter is being used for excitation field supply of a dc machine in electro-mechanics laboratory.

BIBLIOGRAPHY

[1] I. Batarseh, “Power Electronic Circuits,” *John Wiley & sons, Inc.*, 2004

[2] Mohan, Undeland and Robbins, “Power Electronics – converters, applications and design”, *John Wiley & sons, Inc.*, 2003

[3] F.S. Hamdad, “Three-Phase AC-to-DC Soft Switching HF Transformer Isolated Converters with Power Factor Correction and Low Harmonic Distortion”, *PhD Thesis, University of Victoria*, 1999

[4] A. Rahman and A. Bhat, “A HF Isolated Single-phase Single-stage Soft-switched ac-dc Bridge Converter,” *IEEE Power Electronics Specialists Conference* 2001, Vancouver, Canada

[5] M.M.A. Rahman, “Single-stage Soft-switched HF Transformer Isolated ac-to-dc Bridge Converter and Extension to Multiphase Converter,” *Ph.D. Thesis, University of Victoria*, 2001

BIOGRAPHY

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