SEPIC CONVERTER IN BOUNDARY CONDUCTION MODE FOR UNIVERSAL-LINE POWER FACTOR CORRECTION APPLICATIONS

Dorin CISMASIU

Catedra de Inginerie Electrica si Electronica, Facultatea de Inginerie,
Universitatea “Lucian Blaga” din Sibiu, Str. Emil Cioran Nr.4, ROMANIA

Abstract – SEPIC converter operated in boundary conduction mode (BCM) for power factor applications is analyzed and designed. Power factor correction under boundary conduction operation mode can be achieved conveniently using a simple commercially available control IC. Experimental results validate the circuit design.

Key words: Power factor correction, SEPIC converter, ripple steering.

I. INTRODUCTION

In universal line input ($85V_{rms}$-$264V_{rms}$) power factor correction (PFC) application, the Boost converter is commonly used. However the output DC voltage of the Boost converter has to be set to be greater than the input line peak voltage. In some applications where an intermediate output voltage level (e.g. 48V, 210V, etc) is required, converters with step-up and step-down conversion ratio, for example SEPIC, Flyback, and Cuk, are potential candidates.

At same power level and design considerations, the peak inductor current is smaller in a BCM converter than in a DCM converter.

SEPIC converter is suitable as a low harmonics rectifier. Fig.1 shows that a single controller chip can realize the BCM operation in a SEPIC single-phase rectifier. Compared to a flyback converter, the input current in SEPIC converter is continuous and thus the SEPIC rectifier needs smaller volume of input filter.

It is well known that inductors could be realized in same magnetic core, provided they are fed by similar voltage waveform [1,3]. The impedance characteristic of coupled inductors is found to be independent of the feeding voltages of both primary and secondary sides.

This leads to a simplified model of coupled-inductors, such that the analysis process of the coupled-inductor and uncoupled-inductor SEPIC can be unified. The ripple steering phenomenon can also explained in the same framework.

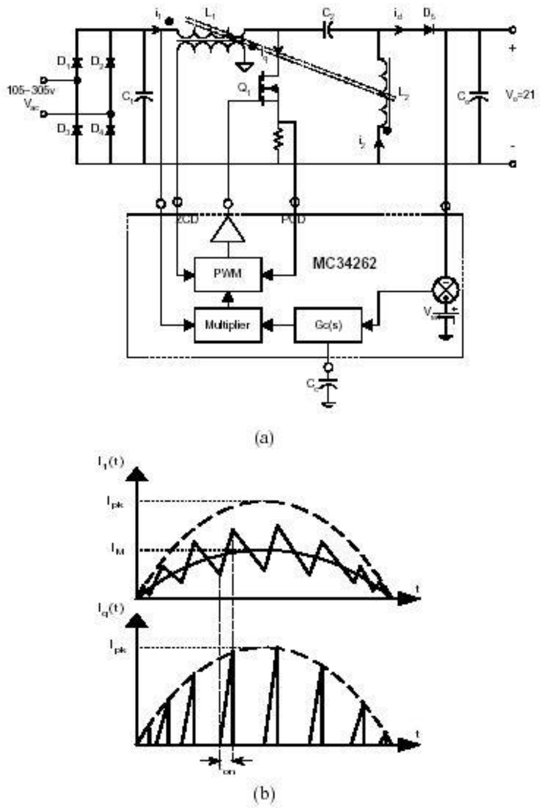


Fig. 1(a) BCM SEPIC converter, (b) ideal input inductor current and transistor current waveforms

II. ANALYSIS OF UNCOUPLED –INDUCTOR SEPIC CONVERTER give:

- Switching frequency

$$f_s(t) = \frac{1}{T_{on}\left(1 + v_1(t)/V_o\right)} \qquad (1)$$

where T_{on} is constant, $v_1(t)$ input rectified voltage, V_o output voltage

Switching frequency change along with line input voltage.

- Input line current

$$i_{in} = \frac{1}{2} I_{pk} \frac{\sin(\omega t)}{1 + K_v\left|\sin(\omega t)\right|} \qquad (2)$$

where $K_v = V_M/V_o$ is the input-output ratio.

The input waveforms of different values of K_v, plotted in Fig.2 show that current is sinusoidal for $K_v=0$ but will be distorted as K_v increases. This mean that the SEPIC at BCM can not achieve unity power factor performance except extreme condition.

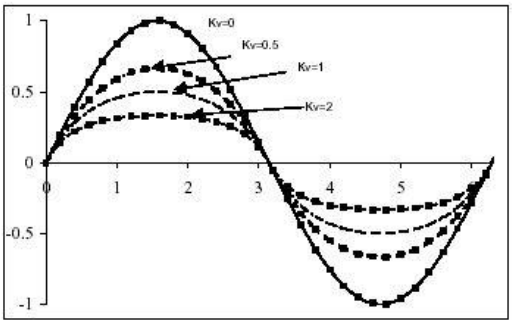


Fig.2 Input current waveform with different K_v

- Switching frequency can be expressed as a function of input voltage, regulated output voltage, output power and equivalent inductance.

$$f_s = \frac{\eta V_M^2 F(K_v)}{2P_o L_e \left(1 + K_v \left(\left|\sin(\omega t)\right|\right)\right)} \qquad (3)$$

where

$$F(K_v) = \frac{1}{T_{ac}} \int_0^{T_{ac}} \left[\frac{\sin^2(\omega t)}{1 + K_v \left|\sin(\omega t)\right|} \right] dt$$

III. COUPLED –INDUCTOR SEPIC CONVERTER

In the coupled inductors in SEPIC converter, both windings are fed by equal voltage which is $v_1(t) = v_2(t)$

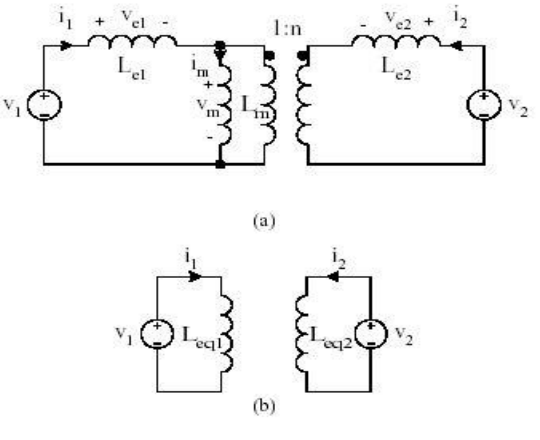


Fig. 3 Equivalent circuit model of coupled-inductor structure: (a) T-model, (b) simplified model

The simplified model[6] shows that coupled inductors fed by the same voltage (see Fig.3) waveforms will exhibit as two equivalent inductors, which only depend on the physical inductor structure instead of feeding voltages. So that, the analysis results from uncoupled inductors SEPIC converter can be extended to coupled inductor SEPIC converter.

Furthermore, if those two windings were wound symmetrily, the major factor that determines the difference between primary and secondary leakage inductance is turns ratio. The leakage inductors have following relationship:

$$L_{e2} = n^2 L_{e1} \qquad (4)$$

By defining the coupling coefficient $k_r = L_{e1}/L$ with $L=(L_m+L_{e1})$, the equivalent inductance and zero ripple condition can be written in compact forms:

$$L_{eq1} = \frac{nk_r(2-k_r)}{(n-1)+k_r}L \qquad (5) \qquad L_{eq2} = \frac{nk_r(2-k_r)}{\frac{(1-n)}{n}+k_r}L$$

Primary side zero ripple condition:

$$k_r = 1-n \qquad (6)$$

Secondary side zero ripple condition: $k_r = (n-1)/n$ (7)

IV. DESIGN CONSIDERATIONS

The switch voltage stress is $(1+K_v)Vo$, which shows that under maximum line input voltage, switches have the worst voltage stress. The worst-case current stress for both transistor and diode, shown in (8), happens at low-line input and maximum out power.

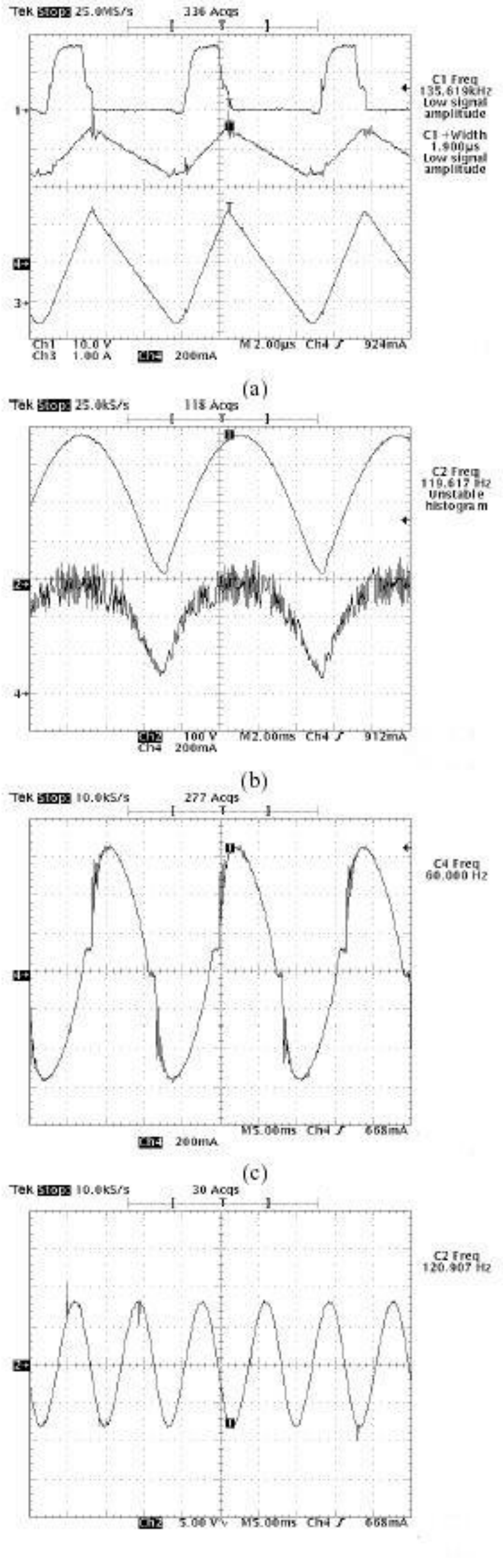
$$I_{q,pk} = \frac{2P_o}{V_{M,low}F(K_v)} = \frac{2}{K_{v,low}F(K_{v,low})}I_o$$

$$I_{q,rms} = \frac{2}{K_{v,low}}\sqrt{\frac{1}{3F(K_{v,low})}I_o}$$

$$I_{d,avg} = I_o \qquad (8)$$

V. EXPERIMENTS

A prototype at 100W output, was built to verify the circuit performance. The circuit diagram is given in Fig.1.Experimental waveforms are shown in Fig.8. Experimental results of two different line inputs are concluded in table I. The BCM SEPIC rectifier can achieve high efficiency, high power factor and acceptable THD at both high and low line inputs.



(a)

(b)

(c)

(d)

Fig. 4 Experimental result of SEPIC converter. (a) gate drive, primary and secondary inductor current (b) rectifier input voltage and current,(c) line current at high-line input. (d) output voltage ac ripple at twice line frequency

Table I

	V_{in}(V)	Efficiency	PF	THD	f_sMax kHz	$f_s$min kHz
Lowline	120	89.8%	0.990	4.9	217.5	112.3
High line	264	91.5%	0.924	18.1	426.1	142.6

VI. CONCLUSIONS

SEPIC converter operating in boundary conduction mode for power factor correction application is proposed, analyzed and designed. By developing a simplified equivalent circuit model for the coupled inductor structure, the SEPIC converter with or without coupled inductors (and ripple current steering) can be analyzed and designed in a unified framework. Power factor correction under boundary conduction operation mode could be achieved conveniently using a simple commercially available control IC

REFERENCES

[1] N. Jayaram and D. Maksimovic, “Power Factor Correction Based on Coupled-Inductors SEPIC and CUK Converters With Nonlinear-Carrier Control”, IEEE APEC98.
[2] R. Erickson, Fundamental of Power Electronics, Kluwer 1997, ch18.
[3] G. Spiazzi, L. Rosseto, “Coupled-inductor Analysis and Design”, IEEE PESC 86