DIGITAL CONTROL OF SINGLE PHASE BUCK-BOOST CONVERTER BY PULSE AREA MODULATION

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ABSTRACT - This paper is described a digital implementation of a pulse area modulation (PAM) method for a unity-power-factor buck-boost converter. A digital controller is designed and implemented by a Digital Signal Processor(DSP) to replace the analog control circuit for PAM. Experimental results are presented and compared with simulations.

1. INTRODUCTION

The recent advance in Digital Signal Processor (DSP) technology has given better possibilities and advantages for using digital means in control of power converter. DSP digital controllers permit one to realize high speed high performance control, parallel operation, self-diagnose function and flexible control algorithms. Despite of the increasing number of application in 3 phase inverter system control such as Space-Vector PWM control scheme, relatively few DSP digital controllers have been built for PWM DC-DC converter[1]-[2].

In this paper, the design of DSP (TMS320C32-50) based controller for DC-DC converter is presented. Simulation and Experiment results of 1kW 20kHz single phase unity Power Factor Collection (PFC) buck-boost converter prototype by Pulse-Area-Modulation (PAM)[3]-[4] control scheme built on a DSP, but the controller is also applicable to the single phase full bridge converter.

2. DSP based controller for single phase PWM DC-DC converter.

The T.I. TMS320C32-50 is versatile 32-bit high performance CMOS floating point processor cable of 50MFLOPS and 275MOPS with a 40nS single cycle instruction execution time. A board, whose size is 218.4× 157.5mm is single. The board consist of A/D D/A converter, hardware protect signal, input-output signal isolated with photo coupler, interfacing with peripheral device, Electrical Programmable Logic Device (EPLD) which has reset, decoder boot-loader address interrupt controller. The DSP controller hardware configuration is as shown Table 1.

Talble 1 DSP controller hardware configuration

DSP Part				
DSP	TMS320C32-50 50MHz, 50MFLOPS. 275MOPS			1EA
MEMORY	SRAM(KM68257) EPROM(27CO20)	32K× 8bit 256K× 8bit	15nsec 150nsec	4EA 1EA
EPLD	EPM7160LC84 EPM7032LC44		12nsec 12nsec	1EA 1EA
Analog I/O Interface Part				
Analog Input 4ch	A/D Converter(MAX120) Multiplexer(ADG529)	12bit	1.6μ sec	1EA 1EA
Analog Output 4ch	D/A Converter(AD664)	12bit	4ch	1EA
Digital I/O Interface Part				
Optic Input	HFBR-1521	5MBd		4EA
OpticOutput	HFBR-2521	5MBd		8EA
Digital In/Out				6EA
RS485 RS232	AM85C30 MAX 211			1EA 1EA

3. DIGITAL CONTROL OF SINGLE PHASE BUCK-BOOST CONVERTER BY PULSE AREA MODULATION

3.1 Single phase unity PFC buck-boost converter

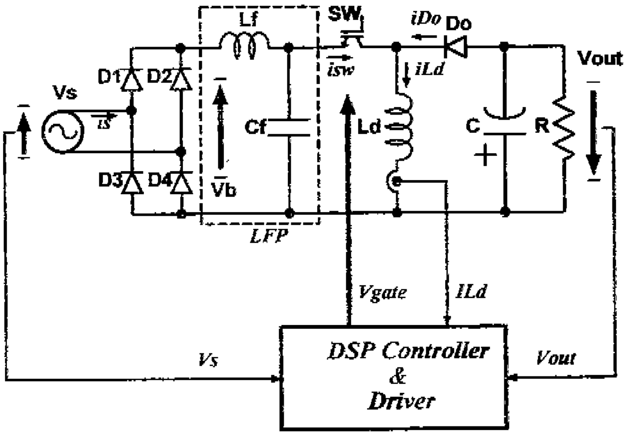


Fig. 1 A power circuits of the PFC buck-boost converter

Fig. 1 shows the power circuits of the single phase unity PFC buck-boost converter. The AC line input voltage v_s is rectified to a DC voltage by a diode bridge and low pass filter(L_f, C_f). The DC voltage is then applied to a buck-boost converter, which constitutes of inductor L_d, switch SW, diode D_o and Capacitor C. The output voltage v_o can be controlled less than or higher the peak value of the input voltage v_s with duty ratio.

If the inductance L is very large and the inductor current i_{Ld} has no ripples, that is, a very large inductance is required to avoid modulation errors caused by ripples of the inductor current in traditional PWM control scheme buck-boost converter. In case of small inductance L which caused inductor current i_{Ld} to have ripples, the buck-boost converter by replacing traditional PWM control scheme to PAM control scheme, is controlled to avoid the modulation errors.

The PAM converter regulates input instantaneous current is to its reference value in proportionate to sinusoidal input voltage v_s. The next describes PAM control scheme digital controller for a unity PFC DC-DC converter.

3.2 Pulse Area Modulation Control [4]

Fig. 2 show a principles of PAM control scheme. Carrier signal i_{car} can be determined by integrating the inductor current i_{Ld} in each switching period. We obtain

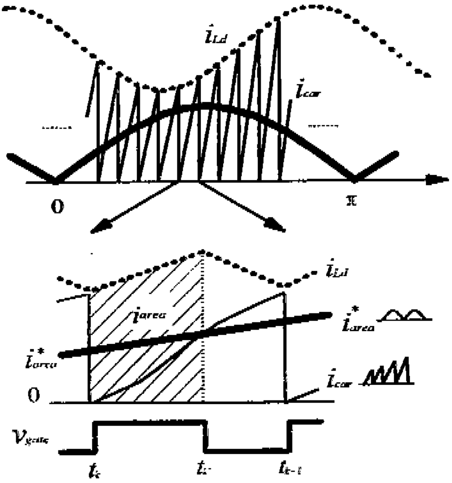


Fig. 2 A principles of PAM control scheme

$$i_{car} = \int_{t_k}^{t} i_{Ld}\,dt \qquad (1)$$

Thus, carrier signal i_{car} is a modulated sawtooth function, whose amplitude is determined in proportion to inductor current i_{Ld}. And we can write a pulse area reference i^*_{area} is as follows;

$$i^*_{area} = i^*_s \cdot T_{SW} \qquad (2)$$

where i^*_s is a current reference, whose absolute value is in proportion to input voltage v_s. T_{sw} is switching period.

Switching turn-off time t'_k is determined by carrier signal i_{car} and pulse area reference i^*_{area}. In a each period, current i_{sw} is equal to inductor current i_{Ld} in the turn-on switching time. Thus, we obtain

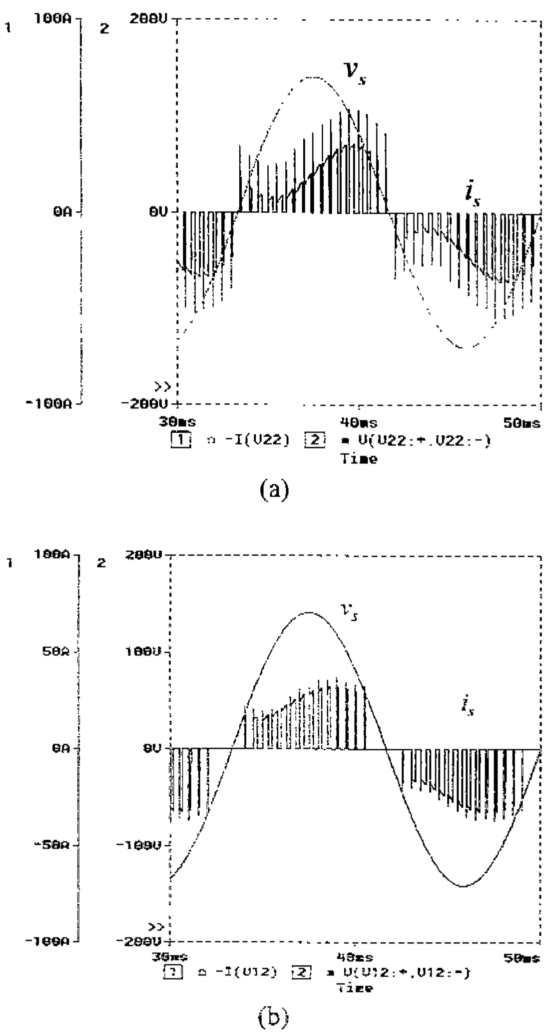
$$i_{area} = \int_{t_k}^{t_{k+1}} i_{sw}\,dt = \int_{t_k}^{t'_k} i_{Ld}\,dt = i^*_{area} \qquad (3)$$

3.3 Simulation

Fig. 3(a) shows input voltage v_s and input current i_s in case of traditional PWM control scheme. Fig. 3(b) shows in case of PAM control scheme.

In fig. 3(a), regardless of instantaneous magnitude of input current i_s, the pulse width in each modulation periods of current is proportional to input voltage v_s.

But, in fig 3(b), a pulse area in each modulation period of current, is proportional to input voltage v_s. A pulse width is determined by magnitude of input current. When inductor current i_{Ld} is very small about zerocrossing in case of PAM control scheme, it can appear overmodulation, which cause modulation errors.



(a)

(b)

Fig. 3 Simulation results (Input voltage and current)
(a) Traditional PWM control scheme
(b) PAM control scheme

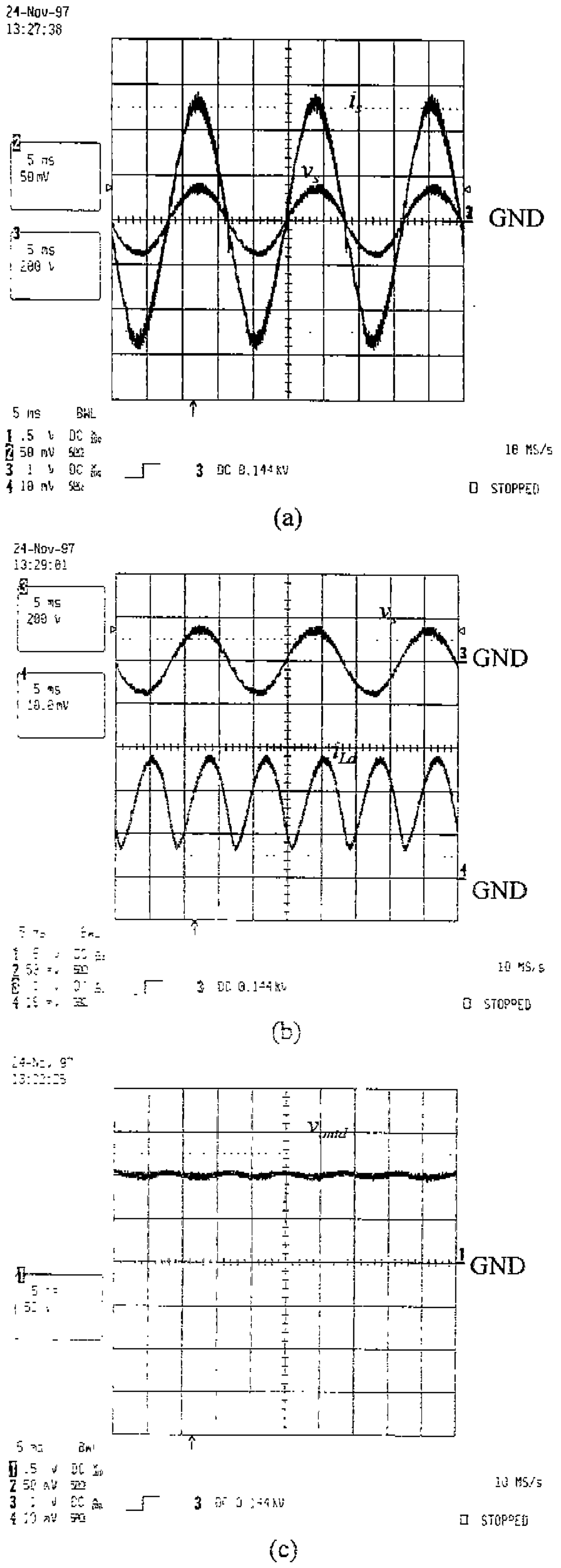
4. DIGITAL CONTROL ALGORITHMS

Let assume that inductor current i_{Ld} is constant in sampling period. From equation (3), we obtain

$$i^*_{sw} \cdot T_{samp} = i_L \cdot T_{ii} \tag{4}$$

where i^*_{sw} is PI controlled output. T_{samp} is sampling period. T_{ii} is turn-on switching time.From equation (4), we can write the turn-on switching time T_{ii} as

$$T_{ii} = \frac{i^*_{sw} \cdot T_{samp}}{i_L} \tag{5}$$



(a)

(b)

(c)

Fig. 4 PAM Control scheme(v_o = 110V, 5ms/div)
(a) Input voltage v_s and current i_s (200V/div, 5A/div)
(b) Inductor current i_{Ld} and Inductor current i_s (20A/div)
(c) Output voltage (50V/div)

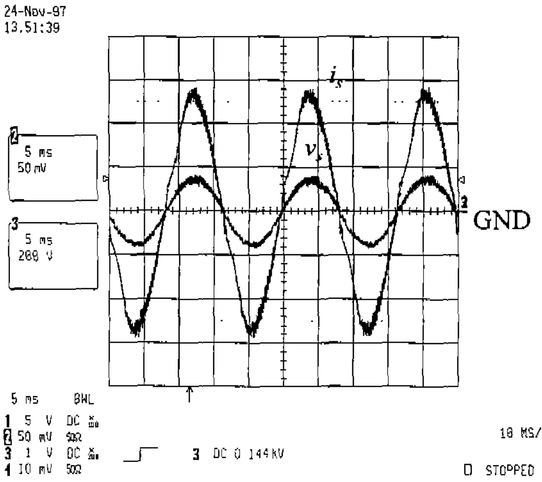
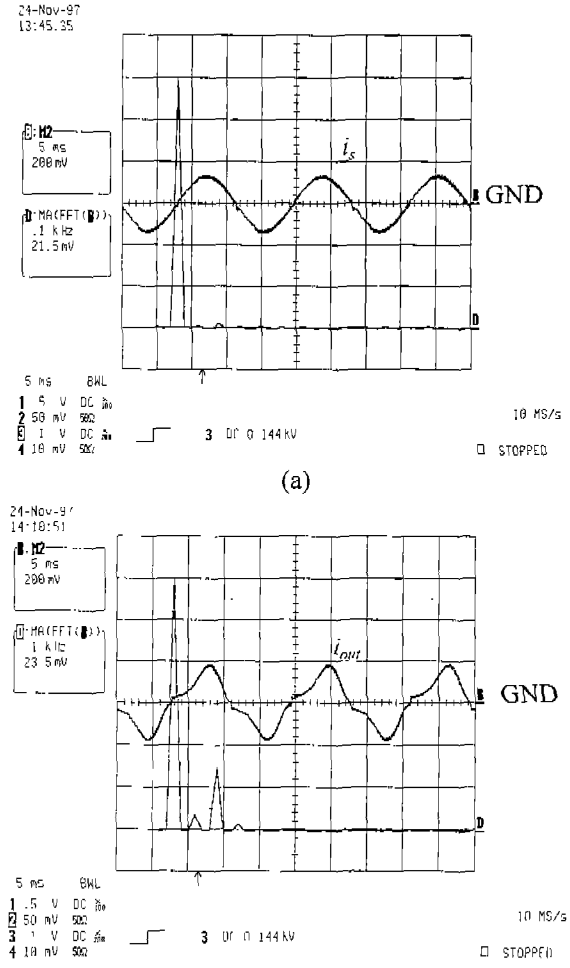


Fig. 5 PAM Control scheme
(v_o = 150V, 200V/div, 5A/div, 5ms/div)



(a)

(b)

Fig. 6 Input current i_s and its FFT
(20A/div, 100Hz/div, 5ms/div)
(a) Traditional PWM Control scheme.
(b) PAM Control scheme.

5. EXPERIMENTAL RESULTS

The operating conditions and circuits are as shown Table 2. Fig. 4 shows input voltage v_s, current i_s, inductor current i_{Ld} and output voltage v_o. Fig. 5 shows in case of output voltage is 150V.

Fig. 6(a)(b) shows input current i_s and its spectrum analyzer in cases of traditional PWM and PAM control scheme respectively. In Fig. 6(a), it appears that the low order harmonics, which cause the distortions seriously, are effectively suppressed. In fig.6(b),Specially 3th harmonics factor measured by the FFT analyzer is about 27%, but is 2.5% which is reduced to one-tenths in Fig. 6(a).

6. CONCLUSION

In this paper, we obtain simple digital control algorithms for single phase unity PFC buck-boost converter by PAM scheme. Experimental results, matching the simulation results have already proved control scheme. The DSP employed in the prototype is relatively inexpensive yet powerful. But with the decreasing cost of DSP and implementing more complex algorithms, digital controlled power converters appear well suited.

Table 2 Main parameter of buck-boost converter

Inductor L_d	7mH(60Hz)
Filter InductorL_f	300uH
Filter Capacitor C_f	4.7uF
Capacitor C	4700uF
Switching Freq. F	20kHz
Input Voltage V_s	110V, 60Hz
Output Power P_o	1kW

7. REFERENCES

[1] A.H.Mitwalli, S.B.Leeb, G.C.Verghese, "An Adaptive digital controller for unity power facter converter," IEEE Trans Power Electron, vol.11 no.2 Mar.1996.

[2] N.Mohan, S.S.Ang, "A digital signal processor based Controller for a switching converter" Int. J .Electronics, vol77,no.5, 1994

[3] S.Motegi, A.Maeda, "A Sinlge-phase Buck-Boost PFC Converter with Output Voltage-Ripple-Reducing Operation", T.IEE Japan,Vol 117-D, No.7, 1997

[4] K.Hirachi, Y.Nishida, K.G.D.Laknath, M.NakaokaA New Buck-Type Controlled AC-DC Converter with Input Current Harmonics Compensated Output Voltage Ripple Active Filtering Scheme", PEMC, P1/232-1/238,1997