Digital Control of Switching Power Supply - Power Factor Correction Stage

Sangsun Kim and Dr. P. Enjeti

Power Electronics and Power Quality Laboratory
Department of Electrical Engineering
Texas A&M University
College Station, TX – 77843-3128
Tel: 979-845-7466
Fax: 979-845-6259
Email: enjeti@ee.tamu.edu

Abstract: Industry standard for the control of switch mode power supply (SMPS) systems has been analog control. Now with the advent of high speed, lower cost digital signal processing (DSP) ICs, digital control there has been an increased interest in digital control of SMPS. The Power Electronics & Power Quality Laboratory of Texas A&M University is currently exploring several implementation aspects of digital control of power factor correction (PFC) stage of SMPS. Two low cost digital controllers: TMS320LF2407 and ST52x420 are evaluated for implementing PFC function. Simulation and experimental results are shown to demonstrate PFC control of SMPS to meet IEC 1000-3 harmonic limits.

I. Introduction

Worldwide, the markets of internal and external switch mode ac/dc power supply (SMPS) have been growing at a faster rate for several applications such as communications, computers, instrumentation, Industrial controls, and military/aerospace area [1, 2]. According to resent estimates, the world wide SMPS market share for power supplies (notebook computer, cellular phone, modem, and telecommunication equipment) is expected to increase from about $20 billion in 2000 to $56 billion by 2005, for a compound annual growth rate 23.2 %. The majority of the present day SMPS employ analog control and are undergoing slow evolution. On the other hand, enabling technologies such as digital signal processors (DSP), integrated semiconductors, magnetics, improved power components, and cooling technologies are fast evolving. Tomorrow's SMPS is expected to be highly efficient, with near unity power factor, DSP control, 10W per cubic inch, and 400+A in the same size as 200A today. In response to the concerns, this article evaluates the feasibility employing state of the art digital control of power factor correction stage with fuzzy logic algorithm.

A conventional SMPS employs a diode rectifier for ac to dc conversion. This type of utility interface generates harmonics and the input power factor (PF) and total harmonic distortion (THD) are poor. IEC 1000-3 and IEEE 519 standards specify link as harmonic compliance and THD. To comply with the corresponding standards in Europe and North America several active solutions have been proposed [2] and widely studied in the literature, being most usually employed the boost converter. The design of the switching power supply requires many features such as:

1. Lower input current harmonics to meets the IEC 1000-3 harmonic limits.
2. High input power factor to minimize reactive requirements.
3. Minimum conducted EMI.

Up to now, the demands for digital processor have been increased due to its low cost, high speed operation, and flexibility. In this article, several implementation aspects of digital control of power factor correction (PFC) stage of SMPS are explored. 16-bit fixed point DSP, TMS320LF2407, is evaluated for implementing PFC function. To further reduce the cost and implement fuzzy logic control for PFC, 8-bit micro-controller, ST52x420, is employed. Simulation and experimental results are shown to demonstrate PFC control of SMPS to meet IEC 1000-3 and IEEE 519 harmonic limits.

II. Analog and Digital Control

Traditionally, the implementation of switching power supply has been accomplished by using analog power factor correction (PFC) as shown in Fig. 1 [3]. Analog PFC IC's which are manufactured by TI/Unitrode, Fairchild, and STmicroelectronics are available and have been able to provide improved power factor. Analog control can provide continuous processing of signal, thus allowing very high bandwidth. It also gives infinite resolution of the signal measured. Analog control, however, also posses some drawbacks such as a number of parts required in the system and their susceptibility to aging and environment variations, which lead to high cost of maintenance. Further, analog control once designed is inflexible and performance cannot be optimized for various utility distortions. In the view of these, this article explores digital implementation of switch mode power supply via digital control. Digital control provides advantages such as programmability, less susceptibility to environmental variations, and fewer part counts [2]. It also reduces the size of the power supply by containing the complexity of control system within the software. Therefore, since digital control is much flexible than analog control, is becoming lower cost, and applicable for

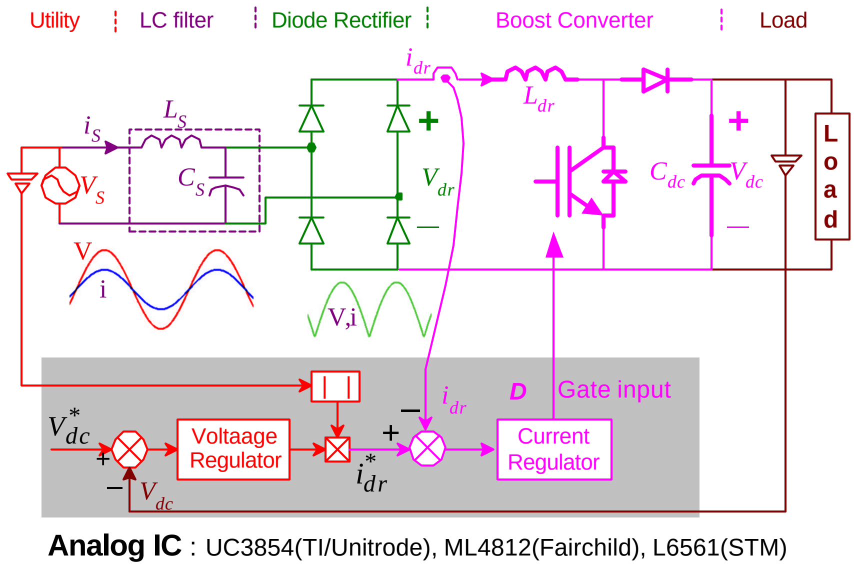


Fig. 1 Power factor corrected boost converter with analog control.

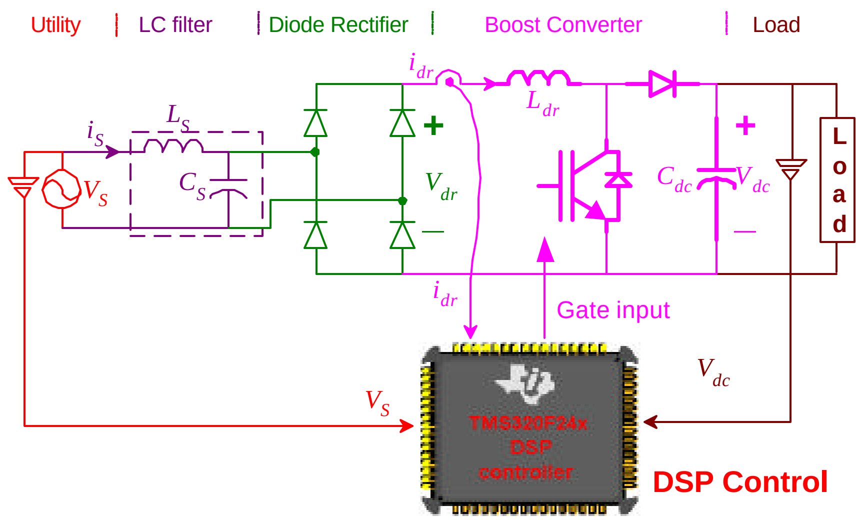


Fig. 2 Digital control of PFC Boost Converter.

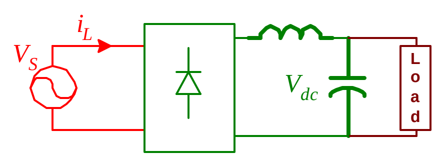
intelligent control, it can be employed for power supply applications as shown in. Fig. 2. In order to obtain high speed bandwidth of the fixed point DSP, TMS320LF2407, numerous off-line computations are first performed and the outputs of the controller based on fuzzy logic rules are stored in a memory block. Further low cost implementation on an 8-bits micro-controller, ST52x420, along with ST-Fuzzy Studio is explored and achieved.

III. Operation Concept and Analysis

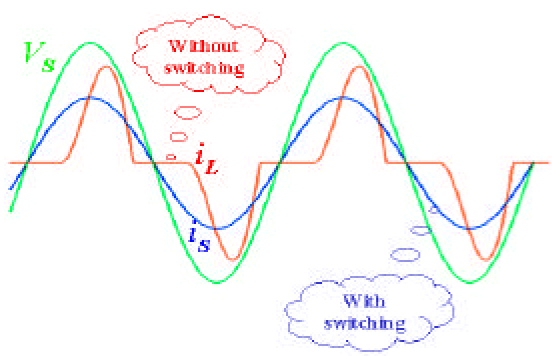
Normally, diode rectifier system contains a lot of harmonic contents such as 3rd, 5th, 7th, etc. as shown in Fig. 3. To improve the input THD, the additional PFC boost converter in the system is employed. Due to the rectified voltage V_{dr} and the characteristic of diode rectifier current, a disturbance is considered as,

$$\underline{D} = \frac{V_{dc}^{*} - V_{dr}}{V_{dc}^{*}}, \tag{2}$$

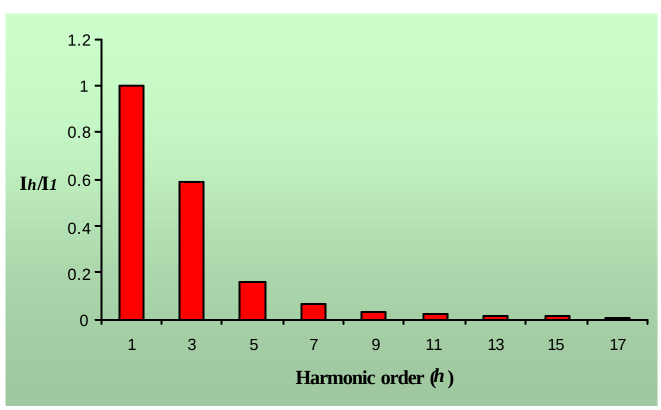
where, $\underline{D}$ is the duty ratio of the boost converter controlled by open-loop control. The duty ratio D_{PI} by closed loop PI control is obtained from the control block diagram which consists of dc voltage and current controllers and the disturbance as shown in Fig. 4. Since the duty ratio D has a reverse waveform of the rectified voltage V_{dr} to make input current sinusoidal as shown in Fig. 5, lower and higher harmonic components are obtained from $\underline{D}$ and D_{PI}, respectively. Therefore, higher bandwidth of the whole control system can be achieved with lower bandwidth of current PI controller.



(a) Diode rectifier system



(b) Utility current and voltage



(c) Harmonics of diode rectifier current

Fig. 3 The concept of power factor correction.

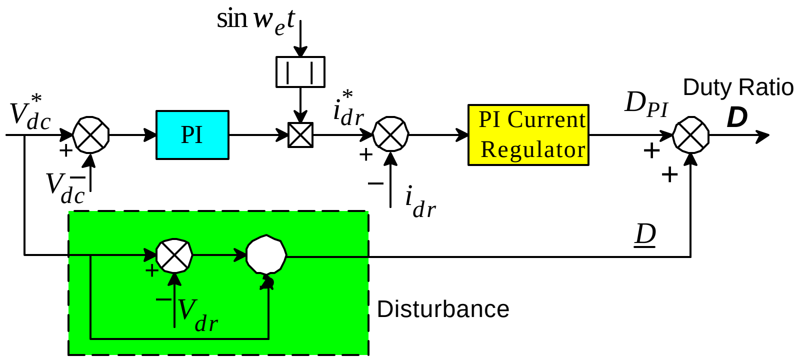
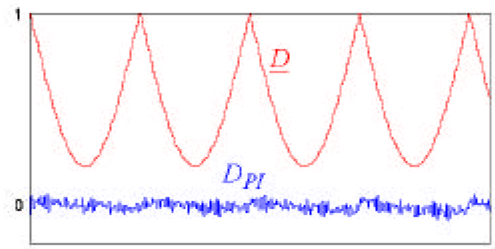
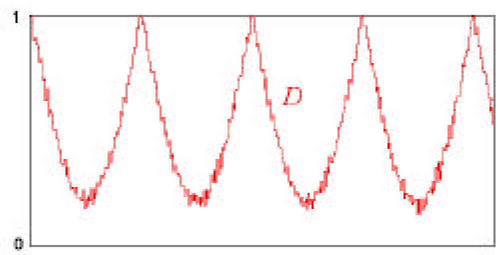


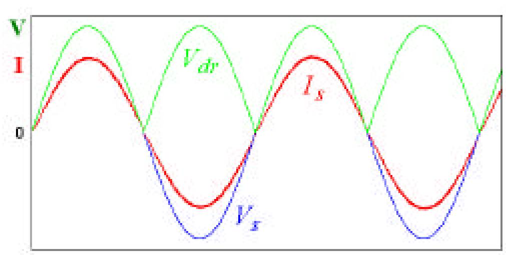
Fig. 4 Control block diagram for the proposed PFC boost converter.



(a) $\underline{D}$ and D_{PI}



(b) Duty ratio D



(c) Utility voltage and current

Fig. 5 The waveforms of control system parameters.

IV. Controller Implementation

The proposed control system is implemented by using either ST-Fuzzy Studio (ST52x420) or TI DSP, TMS320LF2407. The features of two digital controllers are shown in Table I. The utility voltage V_s, output dc voltage V_{dc}, and inductor current i_{dr} are sensed through A/D converters. A gate signal is obtained from PWM channel. The switching frequency for the boost converter is 40[kHz].

A. 16-bit Fixed-point DSP implementation [4]

The proposed PFC approach is implemented on TMS320LF2407 DSP which has a function of 16 bit fixed-point arithmetic and is designed to meet a wide range of digital motor control and other control applications. This DSP chip comes from the 24x family, which is optimized for control applications. It has a 30Mhz CPU clock and several peripherals such as Event Manager, CAN Interface, SPI, SCI, and ADC modules. Fig. 6 illustrates the simplified hardware diagram for the DSP. The TMS320LF2407 DSP also comes with a flash ROM, allowing it to be reprogrammed for software updates. The '240x series of TI DSP controllers combines this real-time processing capability with controller peripherals to create an ideal solution for control system applications. To achieve fast real time processing of the fuzzy logic control algorithm, 16k (128×128) byte flash ROM blocks are used with off-line computations based on Fig. 7 [5, 6]. The control loop sampling frequency for the proposed PFC scheme can be up to 100 [kHz].

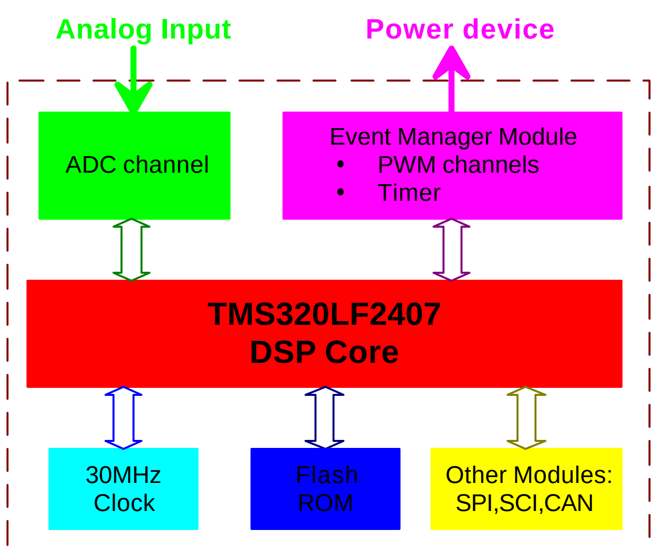


Fig. 6 TMS320LF2407 DSP simplified hardware diagram.

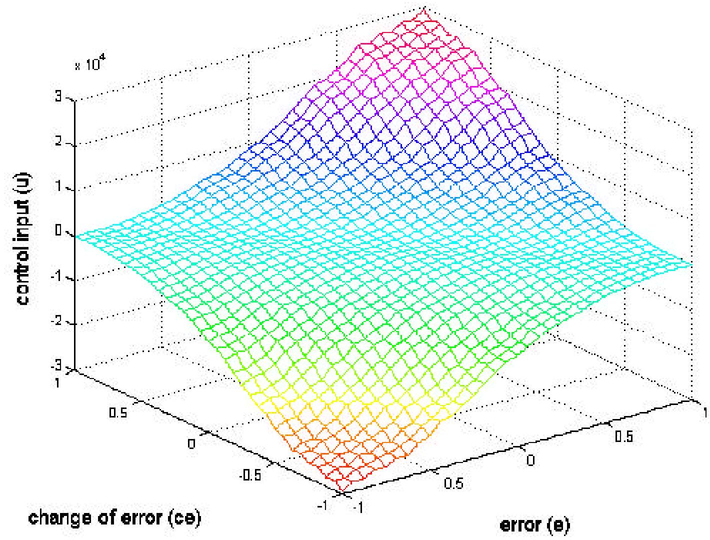


Fig. 7 The output of fuzzy logic controller obtained from off-line computation.

B. 8-bit micro-controller implementation [7]

To achieve further low cost implementation, in this article, ST micro-controller, ST52x420, is explored. The controller is designed for fuzzy logic implementation for control applications such as home appliances and industrial controls. ST-Fuzzy Studio block diagram is shown in Fig. 8. The flexible I/O configuration of ST52x420 allows to interface with a wide range of external devices, like D/A converters or power control devices. The A/D Converter of ST52x420 is an 8-bit analog to digital converter with up to 8 analog inputs offering 8-bit resolution and a typical conversion time of 4.1 us with a 20 MHz clock. ST52x420 is supported by FuzzyStudio allowing to grapically design a project and obtain an optimized microcode. The control loop sampling frequency for the proposed PFC scheme can be up to 7.5 [kHz].

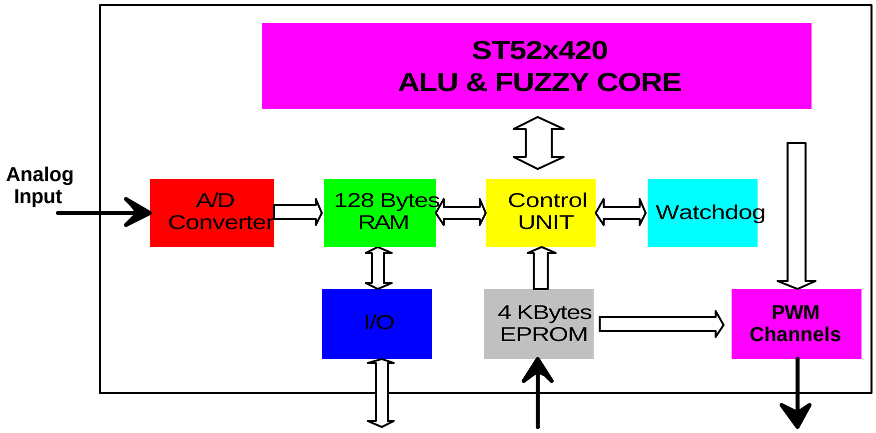


Fig. 8 ST-Fuzzy Studio (ST52x420) architectural block diagram.

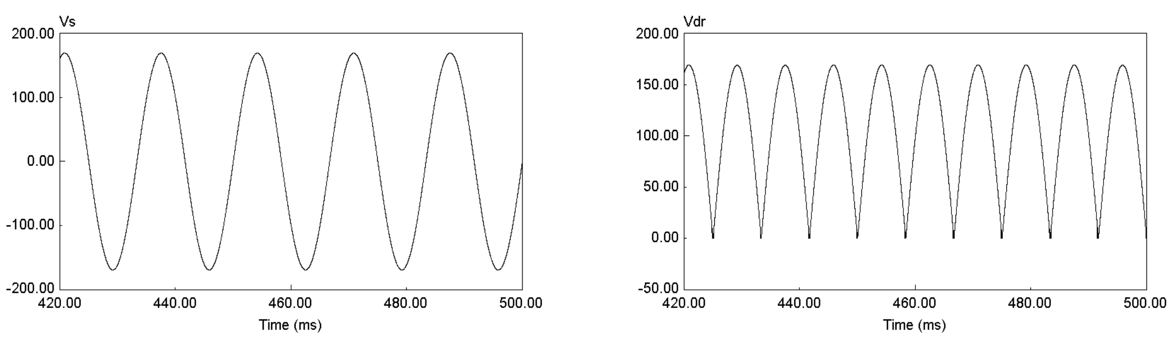
Table I. Comparison of two digital controllers

Feature	***TMS320LF2407***	***ST52x420***	***Unit***
Computational quantity	16	8	Bits
CPU frequency	30	20	Mhz
Memory(ROM)	32k flash	4k EPROM	Bytes
Memory(RAM)	128	2.5k	Bytes
ADC channels/bits	16/10	8/8	Channels/bits
AD conversion time	0.5	4.1	μsec
PWM	16	3	Pins
Timer	4	3	Pins
Digital I/O pins	41	19	Pins
Software tool	Code Composer	FuzzyStudio	
Price*	5	1	

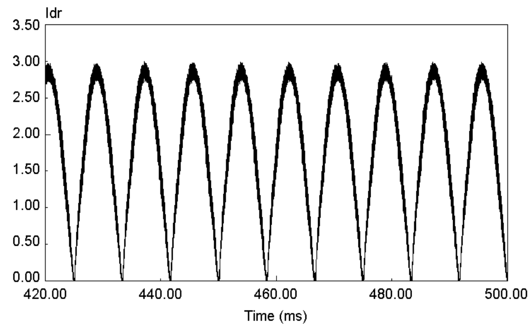
***** The item is approximated price.

V. Simulation and Experimental Results

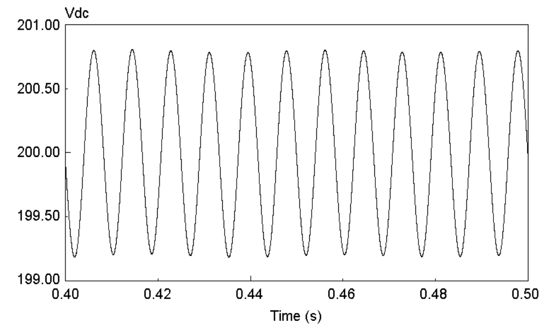
Simulation results are shown in Fig. 9 and Fig. 10, with and without input voltage distortion respectively. Fig. 11 shows the experimental results.



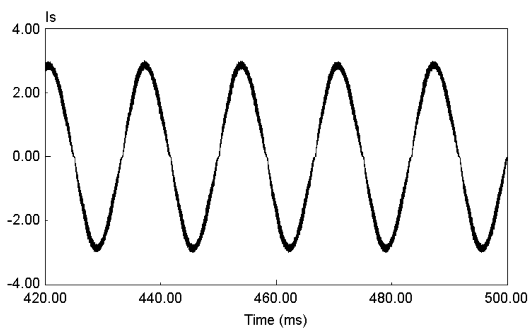
(a) Utility voltage (b) Rectified input voltage



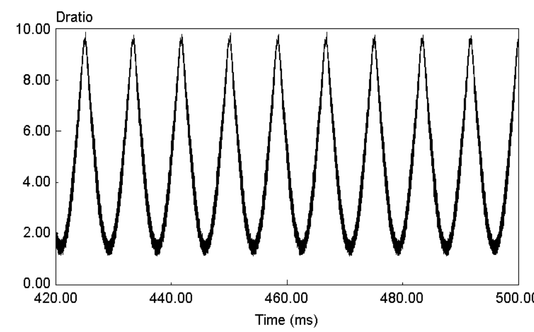
(c) Boost inductor current



(e) Dc voltage

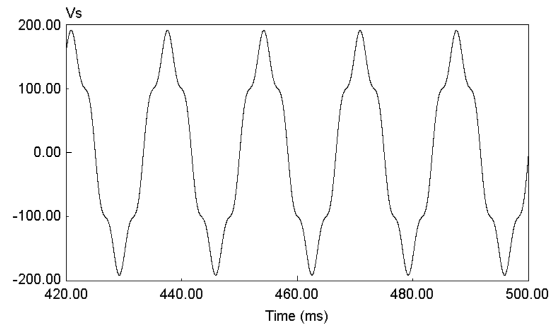


(d) Utility current

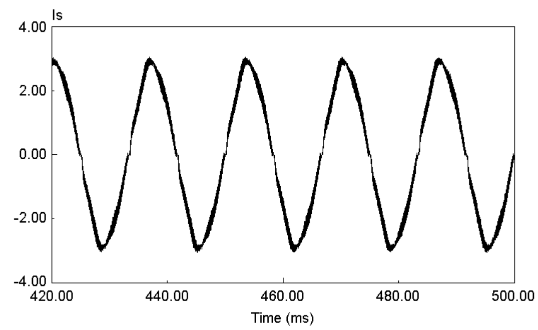


(f) Fuzzy logic output (PFC input; D×10)

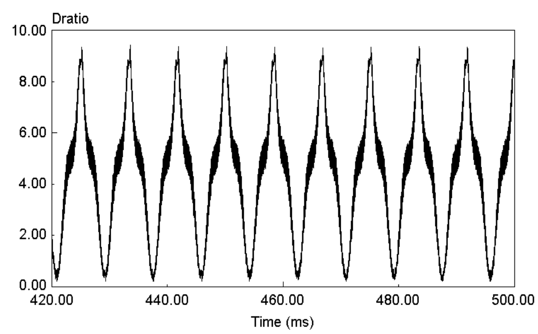
Fig. 9 Simulation results.



(a) Utility voltage



(b) Utility current



(c) Fuzzy logic output (PFC input; D×10)

Fig. 10 Simulation results with utility voltage distortion.

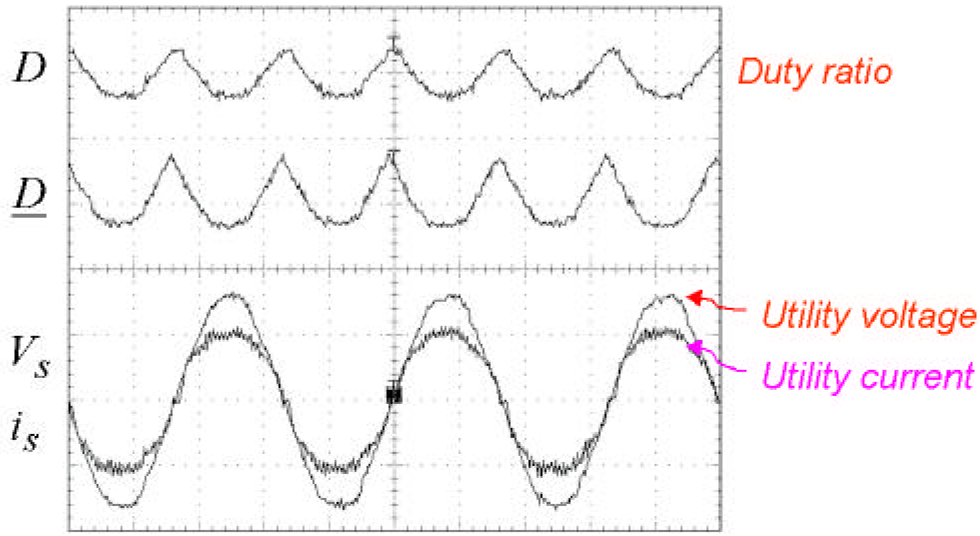


Fig. 11 Experimental results.

V. Conclusions

Several implementation aspects of digital control of power factor correction (PFC) stage of SMPS have been explored with low cost digital controllers: TMS320C2407 and ST52x420. Strict harmonic limit such as IEC 1000-3 are here to stay. To meet the limits and come up with growing ac/dc power supply markets, the PFC stage is currently required. Analog PFC control is the current industry choice but this type of control is not flexible. Therefore, digital based control has many advantages with higher performance since the cost of digital controller (due to its usage in many applications) has the potential to become lower. Higher speed digital controller can guarantee higher bandwidth and higher switching frequency for ac/dc power supply.

References

[1] Jigna Patel, "The Hottest Markets for External Power Supplies Now ans a Look at Potential Future Markets", *APEC'01*, pp. , 2001.
[2] Mark T. Gaboriault, "U.S. Merchant Markets and Applications for Internal AC/DC Switching Power Supplies and DC/DC Converters", *APEC'00*, pp. 59-63, 2000.
[3] P. C. Todd, "UC3854 Controlled Power Factor Correction Circuit Design," Application Note U-134, Unitrode Corporation/ Texas Instruments.
[4] Texas Instruments, *TMS320LF/LC240x DSP Controllers Reference Guide: System and Peripherals*, 2000.
[5] Bimal K. Bose, "Expert System, Fuzzy Logic, and Neural Network Applications in Power Electronics and Motion Control," *Proceedings of IEEE*, vol. 82, No. 8, pp. 1303-1323, August, 1994.
[6] Yu Qin and Shanshan Du, "Comparison of Fuzzy Logic and Digital PI Control of Single Phase Power Factor Pre-Regulator for an On-Line UPS," *IECON '96*, pp. 1796 –1801, 1996.
[7] STmicroelectronics, *ST52T420/E420*, 2000.