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Implementation and Waveform Analysis of Single Phase Single Switch Power Factor Corrector Using DSP (TMS320F2811)

Komal A. Sonagra,
(Department of Electrical Engineering, Assi. Prof., Government Engg. College, Bhuj, Gujarat)

ABSTRACT
AC-DC converters are used in various applications like SMPS, UPS. In electronics equipment, mostly an input stage is rectifier. Due to this non-linear load power factor at supply sides become poor. Boost converters with continuous conduction mode is commonly used in power factor correction. High speed and low cost digital signal processor is evaluated to control this PFC scheme. Converter topology and simulation results are shown to demonstrate PFC control.
Keywords – Continuous conduction mode, Digital signal processor, Boost converter, PFC, PI – controller,

I. INTRODUCTION

A typical switched-mode power supply first converts AC to DC, using a bridge rectifier. The problem with this is that the rectifier is a non-linear device, so the input current is highly non-linear. That means the harmonics content are present at the source side. This presents a particular problem for the power companies, because they cannot compensate for the harmonic current by adding simple capacitors or inductors, as they could for the reactive power drawn by a linear load. Many jurisdictions are using power factor correction for all power supplies above a certain power level. The simplest way to control the harmonic current is to use a filter: it is possible to design a filter that passes current only at line frequency (e.g. 50 or 60 Hz). This filter reduces the harmonic current, which means that the non-linear device now looks like a linear load. At this point the power factor can be brought to near unity, using capacitors or inductors as required. This filter requires large-value high-current inductors, however, which are bulky and expensive. It is also possible to perform active PFC. In this case, a boost converter is inserted between the bridge rectifier and the main input capacitors. The boost converter attempts to maintain a constant DC bus voltage on its output while drawing a current that is always in phase with and at the same frequency as the line voltage. Another switch mode converter inside the power supply produces the desired output voltage from the DC bus. This approach requires additional semiconductor switches and control electronics, but permits cheaper and smaller passive components. It is frequently used in practice. Due to their very wide input voltage range, many power supplies with active PFC can automatically adjust to operate on AC power from about 100 V (Japan) to 240 V (UK).

II. PROPOSED SCHEME AND OPERATION

1. Block Diagram

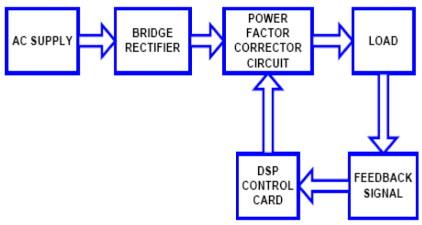

Fig. 1 – Block diagram of active PFC

"Fig.1" shows the block diagram of active PFC. AC supply is given to the bridge rectifiers. Output voltage of the bridge rectifiers is given to the APFC circuit which will take the correcting action of power factor and also control the output voltage. Output of the APFC is supplied to the load. Feedback is taken from the output and input for controlling action. This feedback signal is given to the DSP which will take the correcting and controlling action.

2. Converter Topology

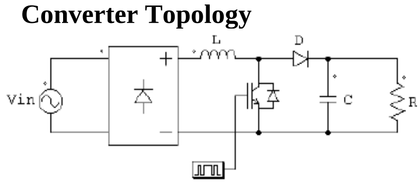

Fig. 2 – Power circuit diagram of active PFC

This converter produces an output voltage greater than the source voltage. The ideal boost converter has the five basic components, namely a power semiconductor switch, a diode, an inductor, a capacitor and a PWM controller. The operation of the circuit is explained. The control mechanism of the circuit shown in "Fig. 2" is turning the power semiconductor switch on and off. When the switch is ON, the current through the inductor increases and the energy is stored in the inductor. When the switch is OFF, current through the inductor continues to flow via the diode D, the RC network and back to the source. The inductor is discharging its energy and the polarity of inductor voltage is such that its terminal connected to the diode is positive with respect to its other terminal connected to the source. It can be seen then the capacitor voltage has to be higher than the source voltage and hence this converter is known as the boost converter. It can be seen that the inductor acts like a pump, receiving energy when the switch is closed and transferring it to the RC network when the switch is open. When the switch is closed, the diode does not conduct and the capacitor sustains the output voltage. Waveform of inductor voltage, inductor current, capacitor voltage and capacitor current is shown in “Fig.3” and “Fig.4”.

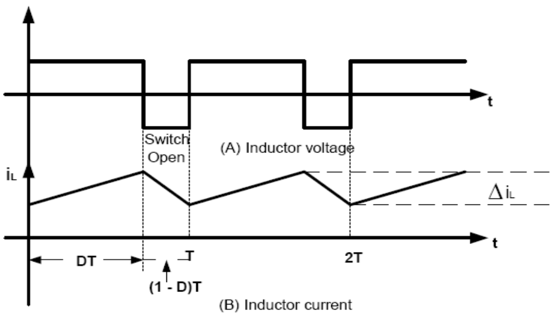

Fig.3 - Inductor voltage and current waveform

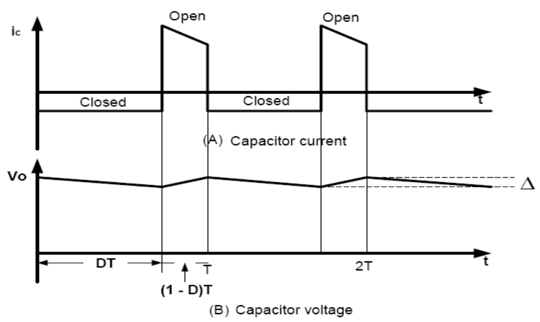

Fig. 4 - capacitor current and voltage waveform

3. Control Topology

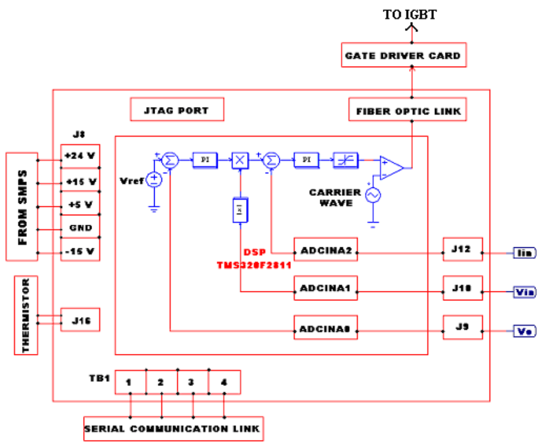

Fig. 5 – Control topology with control card
Where, I_{in} – sensed input inductor current
V_{in} – sensed input voltage
V_{out} – sensed converter output voltage

The sensed input voltage Vin will be in the form of a rectified sine wave, which accurately reflects the instantaneous value of the input AC voltage. This signal is used as an input to a multiplier, along with the output error voltage, to formulate a voltage that is proportional to the desired current. This signal is then compared with the sensed actual converter current to form the error signal that drives the converter switch. The result is the input current waveform which tracks the AC input voltage waveform. The active boost circuit will correct for deficiencies in both the power factor and harmonic distortion. The converter is controlled by two feedback loops based on linear PI controllers as shown in “Fig. 5”. The output DC voltage is regulated by an ‘outer loop’, whereas the ‘inner loop’ shapes the inductor current. The relationship between the input voltage Vin and the output DC voltage Vo is given by,

$$\frac{V_o}{V_i} = \frac{1}{1-d} \quad (1)$$

Where d is the duty ratio. Hence, for a fixed output voltage Vo, the input voltage will actually affect the duty ratio required. If the controller is tuned at a low input voltage level, it may produce an oscillatory response when the input voltage rises to a higher value. From (1), the duty ratio required at low input voltage level will be much higher than the duty ratio required at high input voltage level for the same output voltage. Hence, the controller gain required at low input voltage level will be larger than the controller gain required at high input voltage level. However, if the controller is tuned at a high input voltage level, it may produce a sluggish response when the input voltage drops to a lower value.

III. SIMULATION OF APFC CONVERTER

For the simulation the power rating has been choose to be 2.1 kW. The corresponding inductor value is taken for the steady state condition and the simulation is done. “Fig. 6” shows the simulation diagram.

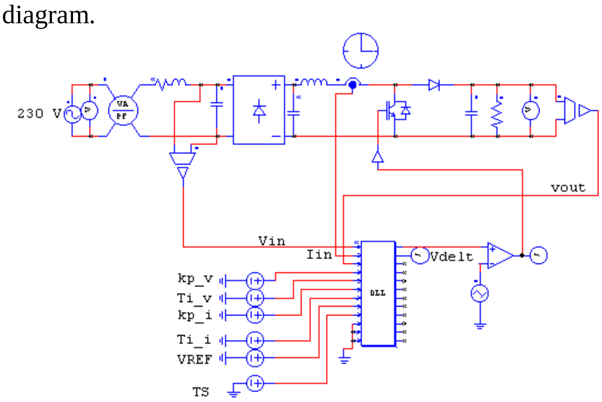

Fig. 6. Simulation of APFC in steady state condition

“Fig. 6” shows the simulation of 2.1kW active power factor corrector and the waveforms are shown in below. “Fig. 7” shows the power factor waveform. Average of that is 0.998. “Fig. 8” shows the output voltage waveform, which can be steady state at 0.35 s. “Fig. 9” shows the condition only after steady state. “Fig. 10” shows source voltage and source current, which shows that source current, is in phase with source voltage. “Fig. 11” shows the chopper inductor current waveform. “Fig. 12” shows the PWM pulses.

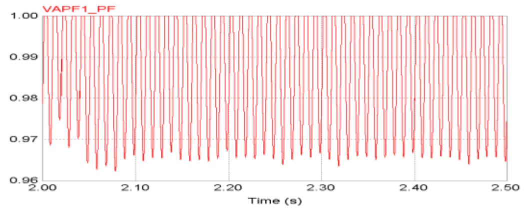

Fig. 7 Power factor waveform

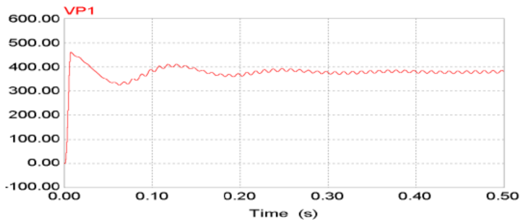

Fig. 8 Initial condition of output voltage waveform

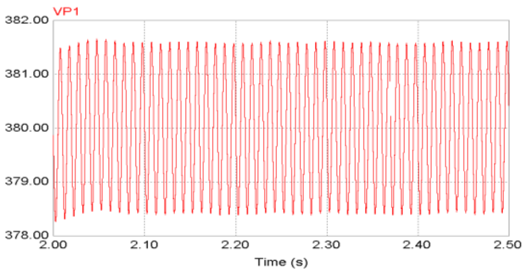

Fig. 9 Steady state Output voltage waveform

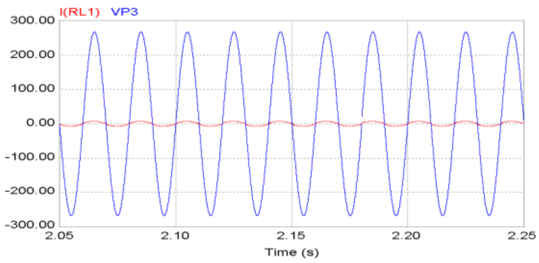

Fig. 10 Source current and source voltage waveform

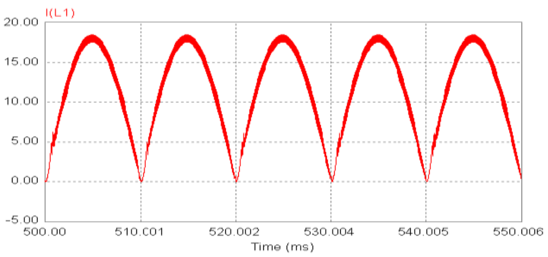

Fig. 11 Chopper inductor current waveform

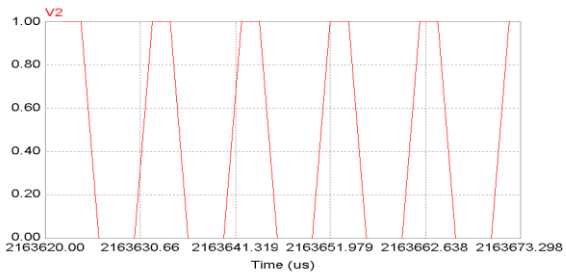

Fig. 12 PWM pulses

IV. HARDWARE DESCRIPTION

The boost converter has been first implemented on the prototype module. The basic hardware setup is implemented and it’s shown in “Fig. 13”. This shows the DSP (TMS320F2811) based implementation of APFC. PCA- 2004A is the DSP control card, which houses the TMS320F2811 DSP processor along with appropriate interfacing circuitry. The current sensor sense the input current and these current signals are applied to the ADC input pin (ADCINA1,2,3) of the DSP through proper interfacing circuitry, which reduces the current signal to a maximum of 3.3 V. AC voltage sensor sense the input voltage and this input voltage is applied to the ADC channel. In addition to this, voltage divider circuit senses the DC bus voltage and through the proper interfacing circuitry the DC bus voltage is fed to the ADC channel of the DSP processor. As per control algorithm generated the pulses to trigger the IGBT. The task of generating the PWM pulse is accomplished by the DSP with the help of PWM circuit, counters, compare and period resisters. A SMPS provides the DC supply for the gate driver card and DSP control card. The control card has also a facility of serial interfacing. The DSP interrupts are employed for the implementation of over current, over voltage, over temperature.

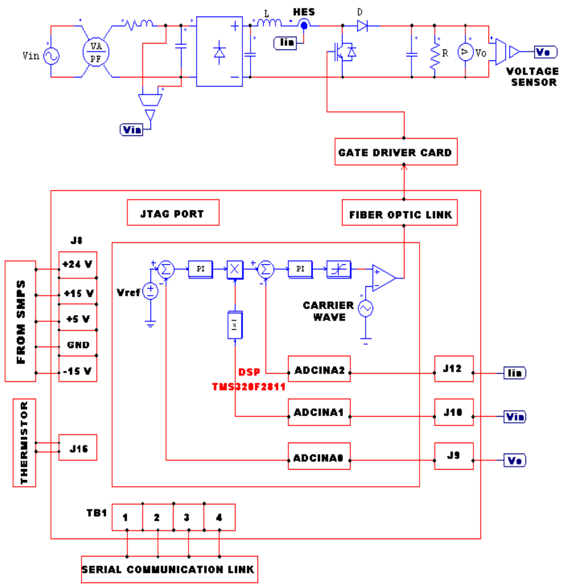

Fig. 13 Implementation of APFC with control card

V. EXPERIMENTAL RESULTS

"Fig. 14" shows the gate pulse for the IGBT. As per the control algorithm the gate pulse of 166.66 µsec is generated and measured at the output of the gate driver circuit. The gate pulse is taken before the loading of the converter.

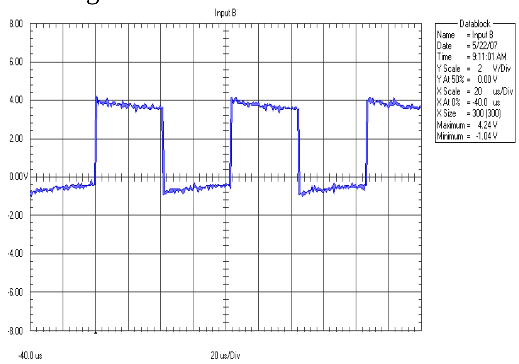

Fig. 14 Gate pulse for IGBT

The prototype modal is first tested on the 30 V ac input and the boosting the voltage of 50 V to for the duty cycle of 0.75. The reference voltage is first slowly incremented as it was set in control algorithm. "Fig. 15" shows the output voltage waveform across the load.

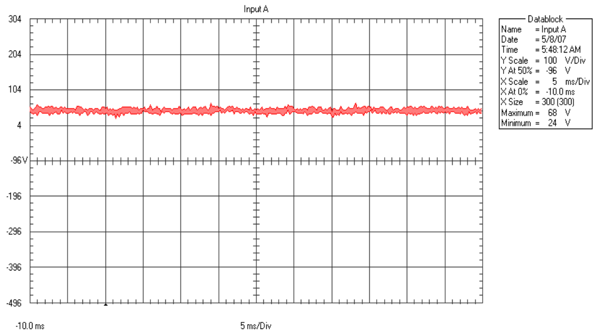

Fig. 15 Output voltage waveform

"Fig. 16" shows that the source current is in phase with the source voltage. Source current is not purely sinusoidal due to the harmonic content but zero crossing point of the source voltage and source current is near to zero and power factor is 0.95.

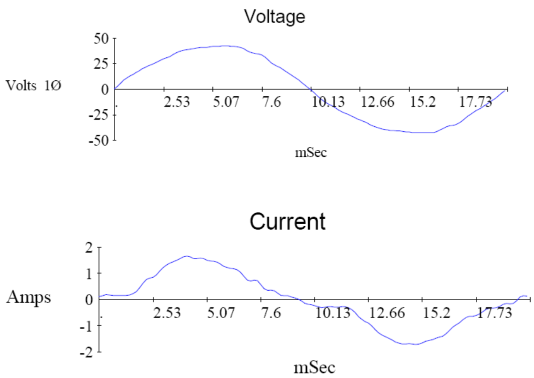

Fig.16 Source voltage and source current waveform

VI. CONCLUSION

A low cost digital design solution for APFC is presented for implementation for industry involved in manufacturing of SMPS/UPS. For voltage mode controller testing, input voltage given is 30 VAC. Output voltage is regulated at 50V DC for load of 1.2Amp. Current mode controller using DSP TMS320F2811 can be implemented as per algorithm. By implementing PFC at low cost in non-PFC based SMPS/UPS, it complies with International agency regulation and become energy efficient.

For improvement, the saved resources of DSP can be utilized to control DC/DC converter (for SMPS) and DC/AC converter (for UPS) plus front-end man machine interface (for SMPS/UPS) and to integrate the converter with Computer as system for monitoring its status in a limited cost.

Therefore APFC in a reduced hardware to minimum, increases the reliability, hence the cost by achieving high Input power factor and reduced Input current harmonics.

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