Analysis and Design of PFC Rectifier System without ADC

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Abstract— The mains current in an ac/dc converter contains periodic current pulses due to the action of rectifier and output filter capacitor. The high current peaks cause harmonic distortion of the supply current and low power factor. This results in a poor power quality, voltage distortion, poor power factor at input ac mains, slowly varying rippled dc output at load end and low efficiency. This project proposes a DC power supply system to give high power factor and low current distortion on the rectifier side and provide stable DC voltage on the isolated DC-DC converter side. The proposed method which uses a MOSFET switch driven by the rectangular pulses of continuously varying duty cycle over a period of supply voltage is analyzed. Method of re-shaping the input current waveform to be similar pattern as the sinusoidal input voltage is done by the Boost converter and the related controls that act as a Power Factor Correction (PFC) circuit. The controller is based on PIC microcontroller, requires no A/D converter type based programmings. Hence cost is low and gives high effectiveness. In this power factor correction is made automatic by using the closed loop circuit and workout by simulink using matlab. A simulation design example of 2600Watts soft-switching single phase DC power supply system is examined to assess the converter performance.

Keywords: Single Phase AC/DC Converter, Bridge Rectifier, Power Factor Correction, DC/DC Boost rectifier

I. INTRODUCTION

When considering the use of power electronics technologies, the main focus is on how to improve their conversion efficiency on the user side. Since the ac source of 110 or 220 Vrms is widely used, the energy saving can be achieved by reducing the complex power transmission between the power company and the user side via the ac–dc conversion interface. The lower the power factor (PF), creates more losses in the transmission line. The traditional ac–dc conversion interface consists of one peak rectifier and one linear regulator. Such a peak rectifier has a pulse-type input current, which contains many harmonics and whose fundamental phase deviates from the phase of the input voltage. Hence, the line voltage is polluted to a certain extent. Aside from this, such a system has low efficiency since the switch operates in the linear region, and hence is not suitable for high-power applications. Consequently, the rectifier with power factor correction (PFC) is presented to overcome the aforementioned disadvantages. In the literature, describes how to design a PFC rectifier based on one analog pulse width modulated (PWM) control IC. And also simple circuit is added to the boost converter to increase the value of PF under high switching frequency.

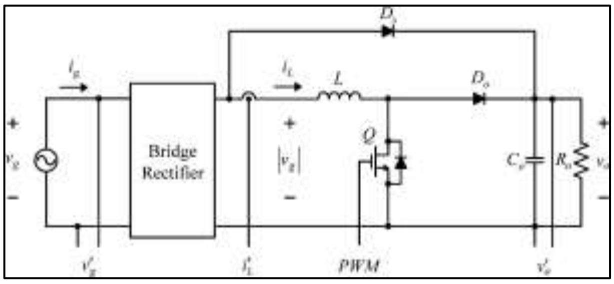

Fig. 1: Main power stage of the PFC rectifier

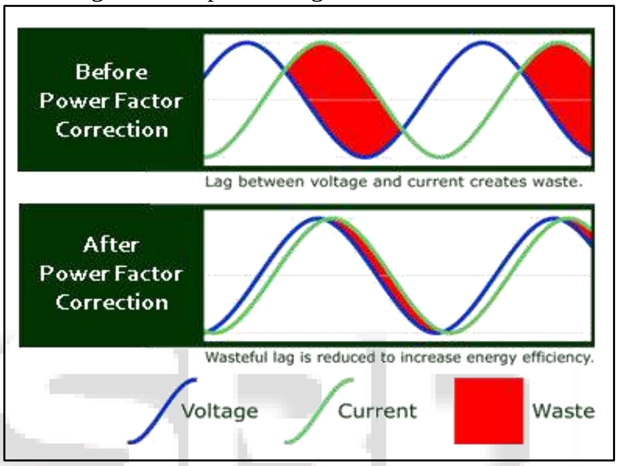

Fig. 2: Power factor correction waveform

The operations of the PFC control are divided into two types: analog control and digital control. Analog control has some demerits, such as low immunity from the switching noise, low resistance to environmental variations. In order to solve the aforementioned problems, digital control techniques are proposed. Under digital control, DSP and FPGA controllers play major roles. However, as is generally acknowledged, the above controllers program is executed sequentially. Therefore they required too many complicated mathematical equations. The proposed topology we use PIC controllers in order to solve the above drawbacks.

Generally acknowledged, the main drawback of a fully digitalized power factor correction (PFC) rectifier is that too many analog-to-digital converters (ADCs) are used, and hence, the corresponding cost is high. In this paper, the information on the desired signal is obtained from two paired saw-toothed waves compared with the sensed signal, without the use of any ADCs.

II. RELATED WORKS

The Automatic Boost Power Factor Correction (PFC) is a method to improve the power factor very closed to unity, reduces harmonics distortion noticeably and automatically corrects the distorted line current of a DC power supply. This research aims to implement the Unity Power Factor (UPF) for single-phase rectifier which is used in designing the ZVS-PWM strategy. For this purpose, a power electronic circuit is inserted between the bridge rectifier, the output filter capacitor and the load.

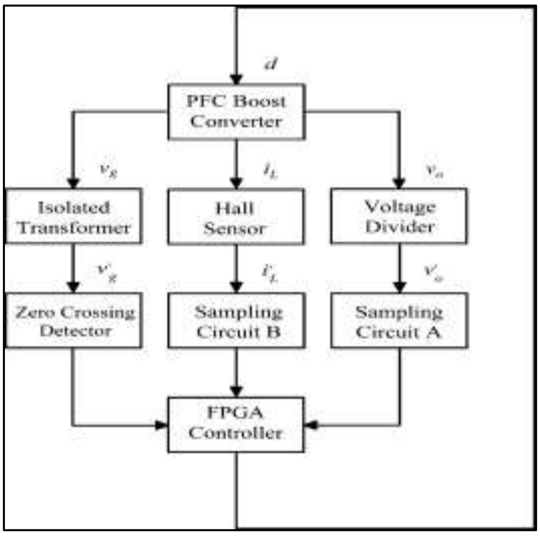

Fig. 3: Conventional FPGA based PFC method

A. Average Current Control Mode:

The average current mode control works with the smallest peak-to-peak inductor current and makes the PFC rectifier operate under constant switching frequency.

The converter consists of the AC voltage as the input with bridge rectifier to convert the AC voltage to DC. Now the DC voltage is boosted to a higher DC voltage by the boost converter. The PFC of the system is obtained from the feedback system of the boost converter. Feedbacks of the V_g from the AC voltage supply, than the i_L inductor current and V_o the output voltage of the converter is taken as the feedback from the converter. These feedback signals from the converter are given to the isolated transformer, Hall sensor and the voltage divider respectively. The output of the corresponding blocks is sent to the Zero crossing detector, Sampling Circuit B and Sampling Circuit A respectively. And the output of these blocks is given to the controller which performs the corresponding operation and produces a duty cycle which is given to the converter as the switching pulse signal. Fig.1 shows the main power stage used in this paper.Fig.3 shows the proposed overall system function block diagram. The main power stage is constructed by one PFC rectifier. This system consists of AC voltage as the source. The converter systems will converter the AC voltage into DC voltage. There are some sample signals taken from the converter system for control process. The samples are from the source, from the inductor current and the from the output load voltage. The sample from the input section is given to the isolated transformer and then to the zero crossing detector. The sample of the inductor current if taken to the Hall sensor then through which it is given to the sampling circuit. Then the sample from the converter output section which is the output voltage is given to the voltage divider and then to another sampling circuit. All the sampling are given to an PIC controller which performs the desired operation and gives the feedback to the converter to obtain the desired operation. In order to make the input current in phase with the input voltage, the PIC controller needs information on the inductor current and on the phase angle of the input voltage, and the former is achieved by the Hall sensor and the sampling circuit B, whereas the latter is achieved by the isolated transformer and the zero-crossing detector. Aside from these, the output voltage information needed by the PIC controller is achieved by the voltage divider and the sampling circuit A. Above all, the sampling circuits A and B are realized by the proposed sampling method. Therefore, the suitable duty cycle figured out from the PIC controller is sent to the main switch Q, to not only stabilize the output voltage of this converter but also to perform the required PFC. Furthermore, the diode D, shown in Fig.1, is utilized to establish the voltage across the output capacitor Co so that the inrush current at start-up can be suppressed. It is noted that in Fig.3, the input voltage, the inductor current, and the output voltage are signified by v_g, i_l, and v_o respectively. whereas the input voltage after the isolated transformer, the inductor current after the Hall sensor, and the output voltage after the voltage divider are represented by $v_{g'}$, $i_{l'}$, and $v_{o'}$ respectively.

III. SAMPLING TECHNIQUE CONCEPT

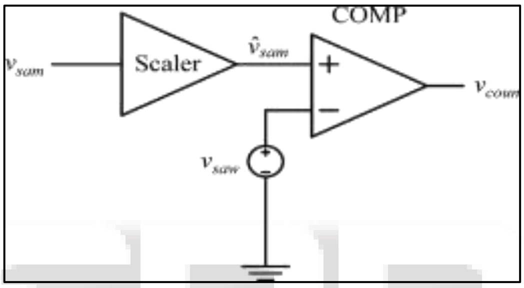

Fig. 4: Main sampling circuit

The main sampling circuit of a proposed converter is shown in fig.4. where v_{sam}, $\hat{v}_{sam}$, v_{saw}, and v_{coun} are the signal to be sampled, v_{sam} after the scaler, the sawtoothed wave, and the signal outputted from the comparator COMP, respectively. After this, there are some symbols to be defined prior to the following analysis: 1) one counter, named cycle_count with the period of Ts , is used as a function block enabling counter so as to make function blocks work; 2) the width of vsaw is expressed to be Tsaw; and 3) the other counter, named sam_count, is used as a sampling counter. These all shown in fig.5 respectively.

Therefore

$$T_s = T_{saw} + t_1 + t_2 – t_b = t_2$$

A. Pulse Generator

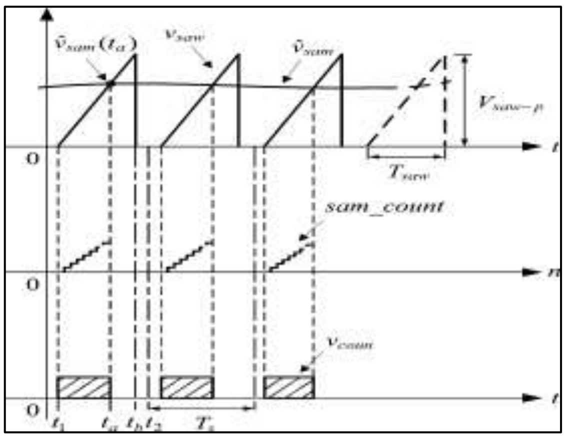

Fig. 5: Key waveforms in sampling

B. Sampling Interval and Resolution

If the sampling frequency is synchronous with the switching frequency, then the sampling process will occur during the turn-on period t_{on} or the turn-off period t_{off}. The saw-toothed wave used to sample the signal during the turn-on period, where PWM is represented as the gate driving signal used to drive the main switch Q. In order to obtain accurate digital information on the signal during the turn-on period, the following inequality must be satisfied,

$$T_{on} \geq a + b + T_{saw}$$

Where a, b, and T_{saw} are t_1, $t_2 - t_b$, and $t_b - t_1$, respectively.

C. Pulse Width Modulation

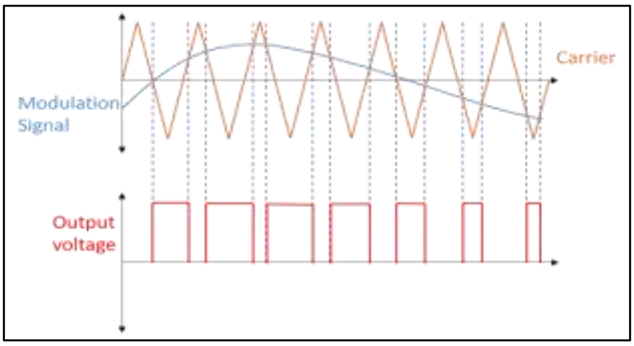

Fig. 6: PWM waveform

PWM is the technique used to generate analogue signals from a digital device like a MCU (Microcontroller Unit). MCUs have dedicated hardware for PWM signal generation. A digital device like a microcontroller can easily work with inputs and outputs that has only two state, on and off. So you can easily use it to control a LED's state i.e. on or off. In the same way you can use it to control any electrical device on/off by using proper drivers (transistor, triac, relays etc).But sometimes you need more than just "on" & "off " control over the device. Like if you want to control the brightness of a LED (or any lamp) or the speed of DC motor then digital (on/off) signals simply can't do it. This situation is very smartly handled by a technique called PWM or Pulse Width Modulation.

IV. Experimental Results

Simulink, developed by Math Works, is a commercial tool for modelling, simulating and analyzing multi-domain dynamic systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries. It offers tight integration with the rest of the MATLAB environment and can either drive MATLAB or be scripted from it. Simulink is widely used in control theory and digital signal processing for multi-domain simulation and Model-Based Design.

Variables	Values
Input Voltage($V_{rms)}$	110V(AC)
Input Current($I_{rms)}$	3.5A
Input Power Factor	0.9890
Output Voltage	516V(DC)
Output Current	5A
Output Power	2600W
Efficiency	98.76%

Table 1: Input and Output Data Specification

The total harmonic distortion increases and the power factor decreases. The power factor at lower output power is lower than at higher output power. The subsystem used to give the closed loop function for enabling the pulse signal to soft switching. These subsystems contain various blocks. That is AC voltage source, linear transformer, rectifier unit using diode, measuring blocks are voltage and current, slider gain, low pass filter, product, relational operator, constant, not gate, signal generator and scope.

Methods	THD in %	PF	Efficiency in %
Conventional method	150	0.4077	66.33
Novel method	50	0.6223	72.45
Series resonant filter method	10	0.9570	84.34
Proposed method	2	0.9890	98.76

Table 2: Comparison of THD, PF and efficiency of various methods with proposed method

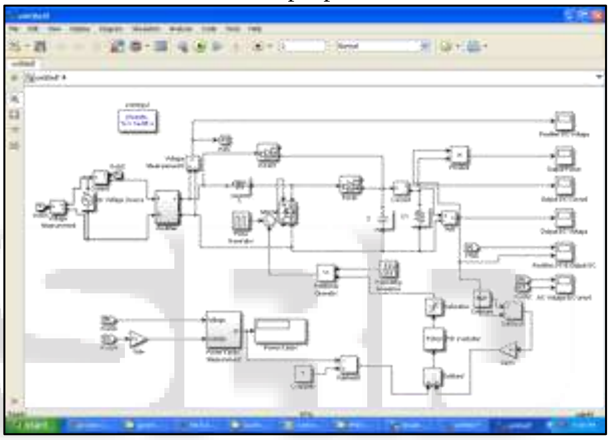

Fig. 7: Proposed Simulation Design

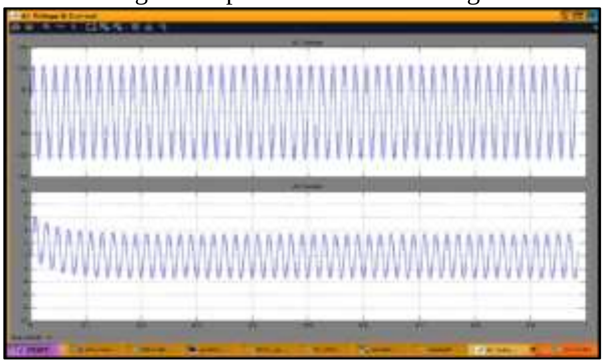

Fig. 8: Input AC Voltage and Current

Fig. 9: Rectifier DC Voltage VS Output DC Voltage

Fig. 10: Output DC Current

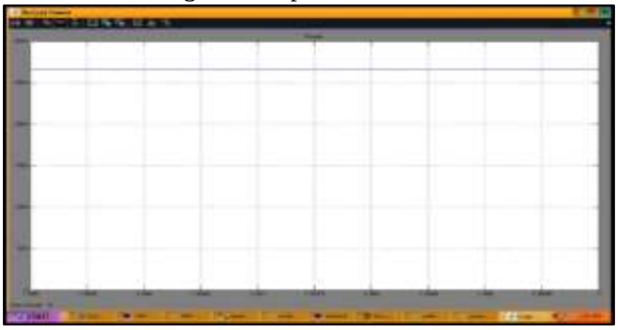

Fig. 11: Output DC Power

Fig. 12: Experimental setup

V. CONCLUSION

Method of re-shaping the input current waveform to be similar pattern as the sinusoidal input voltage is done by the Boost converter and the related controls that act as a Power Factor Correction (PFC) circuit. During the conversion of AC-DC power supply, high current peaks cause harmonic distortion of the supply current and low power factor. This results in a poor power quality, voltage distortion, poor power factor at input ac mains, slowly varying rippled dc output at load end and low efficiency. The proposed method which uses a MOSFET switch driven by the rectangular pulses of continuously varying duty cycle over a period of supply voltage is analyzed. This project proposes a DC power supply system to give high power factor and low current distortion on the rectifier side and provide stable DC voltage on the isolated DC-DC converter side. In future work: Introducing a MOSFET switch on the DC end of the improved method with a freewheeling diode may result in better efficiency. Because among passive methods, the power factor is high and the total harmonic distortion is less for improved method. But the efficiency is very less which needs to be improved a lot. This method involves both active power switch and the passive elements. This method comes under the category of active passive wave shaping methods. Also the use of IGBTs instead of MOSFET may have significant effect in reducing the THD and the efficiency may still go up. The input and the output filter circuits should be designed accordingly.

REFERENCES

[1] M. Chen and J. Sun, "Feedforward current control of boost single-phase PFC converters," IEEE Trans. Power Electron., vol. 2, no. 2, pp. 338–345, Mar. 2006.
[2] D. N. Samaraweera and D. D.-C. Lu, "Novel implementation of average current mode controlled power-factor-correction converters," in Proc. 2nd IEEE Conf. Ind. Electron. Appl., 2007, pp. 1468–1472.
[3] D. Maksimovic, R. Zane, and R. Erickson, "Impact of digital control in power electronics," in Proc. IEEE Int. Symp. Power Semicond. Devices ICs, 2004, pp. 13–22.
[4] J. David Irwin, Basic Engineering Circuit Analysis, 7th ed. New York: Wiley, 2002, pp. 362–363.
[5] M. Barai, S. Sengupta, and J. Biswas, "Dual-mode multiple-band digital controller for high-frequency DC–DC converter," IEEE Trans. Power Electron., vol. 24, no. 3, pp. 752–766, Mar. 2009.
[6] L. Corradini, A. Costabeber, P. Mattavelli, and S. Saggini, "Parameterindependent time-optimal digital control for point-of-load converters," IEEE Trans. Power Electron., vol. 24, no. 10, pp. 2235–2248, Oct. 2009.
[7] F. Krismer and J. W. Kolar, "Accurate small-signal model for the digital control of an automotive bidirectional dual active bridge," IEEE Trans. Power Electron., vol. 24, no. 12, pp. 2756–2768, Dec. 2009.
[8] C. Kranz, "Complete digital control method for PWM DC–DC boost converter," in Proc. IEEE Power Electron. Spec. Conf., 2003, pp. 951–956.
[9] W. Zhang, G. Feng, Y.-F. Liu, and B. Wu, "New digital control method for power factor correction," IEEE Trans. Ind. Electron., vol. 53, no. 3, pp. 987–990, Jun. 2006.
[10] M. Chen and J. Sun, "Feedforward current control of boost single-phase PFC converters," IEEE Trans. Power Electron., vol. 21, no. 2, pp. 338– 345, Mar. 2006.
[11] W. Zhang, G. Feng,Y.-F.Liu, and B.Wu, "Adigital power factor correction (PFC) control strategy optimized for DSP," IEEE Trans. Power Electron., vol. 19, no. 6, pp. 1474–1485, Nov. 2004.
[12] X. Guo, X. Wen, and E. Qiao, "A DSP based controller for high power dual-phase DC–DC converters," in Proc. IEEE 5th Int. Power Electron. Motion Control Conf., 2006, vol. 1, pp. 1–5.
[13] H. M. Kojabadi, B. Yu, I. A. Gadoura, L. Chang, and M. Ghribi, "A novel DSP-based current-controlled PWM strategy for single phase grid connected inverters," IEEE Trans. Power Electron., vol. 21, no. 4, pp. 985–993, Jul. 2006.
[14] K. I. Hwu and Y. T. Yau, "Improvement of one-comparator counterbased PWM control by applying a saw-toothed wave injection method," in Proc. 22nd Annu. IEEE Appl. Power Electron. Conf., 2007, pp. 478–481.