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DESIGN OF A MICROCONTROLLER BASED PFC

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Abstract - With the increasing demand for power from the ac line and more stringent limits for power quality, power factor correction has gained great attention in recent years. A variety of circuit topologies and control methods have been developed for the PFC application. International Standards in the area of compliance of a product's AC mains current harmonics have forced that new power supply design must include the power factor correction at the front end. The new trend in Power Supply is towards the digital control. This paper discusses the design of a controller for Power Factor Correction (PFC). A microcontroller based PFC design is proposed and design issues are discussed. PFC is simulated using MATLAB and results are reported. Interface requirement between the power converter and microcontroller are discussed.

Keywords *- PFC, THD, Microcontroller, PI Controller, ac-dc converter, control design.*

I. INTRODUCTION

Most of the power application consists of an AC to DC conversion stage after the AC main source. Rectified DC out put is used for later stages. Usually a filter having a large capacitance is employed for getting proper DC output. This results in discontinuous and short duration current spikes. These discontinuous spikes lead to increase in network losses, total harmonic distortion (THD).

Two factors that provide a quantitative analysis of quality of power in an electrical circuit are Power Factor (PF) and Total Harmonic Distortion (THD). Benefits from improvement of Power Factor include – Lower energy and distribution costs, Reduced Losses in electrical system during distribution, better voltage regulation and capacity enhancement.

With increasing demand in the area of AC to DC Conversion tighter regulation such as IEC61000-3-2 have come into force. Regulations have already been enacted in the EU that constricts how far load current may deviate from a pure sine in phase with the voltage for some types of loads. These regulations will likely get tighter in the future, be applied to smaller loads, and spread to other regions.

II. HARMONIC CURRENT EMISSION GUIDELINES

Increasing use of electronic devices in daily life has greatly increased the stress caused by harmonic currents on low-voltage alternating-current public mains networks. To maintain the quality of these networks, European Standard EN 60555-2 was created to set levels for harmonic currents injected by loads back on to the network.

There has, however, been much discussion about equipment classes and limits to apply to electronic equipment in general and equipment power supplies in particular. EN 60555-2 has been superseded by EN 61000-3-2 which sets some more practical rules and provides a clearer definition of equipment classes.

There are 4 different classes in the EN 61000-3-2 that have different limit values.

III. SYSTEM FOR STUDY

A Traditional PFC Boost Converter is depicted in Figure 3. DC Voltage output Vo is a constant, So the output of the voltage loop V_c is also constant. Outer voltage regulating control loop generates reference to inner current loop.

Fifure 8 depicts the converter transfer function showing both the loops for control. Following equations can be driven from the above figure:

$$i_g(s) = \frac{G_{iv}}{1+T_i} Vg(s) + \frac{G_{id} F_m H_i}{1+T_i} k_x V_c V_g(s) \quad (1)$$

$$Y(s) = \frac{i_g(s)}{v_g(s)} = \frac{G_{iv}}{1+T_i} + \frac{G_{id} F_m H_i}{1+T_i} k_x V_c \quad (2)$$

$$Y(s) = G_{ivcl} + T_{icl} k_x V_c \quad (3)$$

Where $T_i = G_{id} F_m H_i h_s$ is the loop gain transfer and

$T_{icl} = \frac{G_{id} F_m H_i}{1+T_i}$ is the closed loop control to current transfer function.

Y(s) can be considered consisting of two components, $Y_1(s)$ and $Y_2(s)$ in parallel so –

$Y(s) = Y_1(s) + Y_2(s)$

$$Y_1(s) = G_{ivcl} = \frac{s}{V_o F_m h_s \omega_i (1 + \frac{s}{\omega_z})} \quad (4)$$

$$Y_2(s) = T_{icl} k_x V_c = \frac{k_x V_c}{h_s} = Y_{CLO} = \frac{I_g}{V_g} = \frac{P_g}{V_g^2} \quad (5)$$

Y1(s) is the closed loop voltage to current transfer function and Y2(s) is the closed loop current reference to current transfer function.

IV. AVERAGE CURRENT MODE CONTROL

Average current mode control employs a control circuit that regulates the average current (input or output) based on a control signal. For a PFC controller, this control signal is generated by the low frequency dc loop error amplifier. The current amplifier is both an integrator of the current signal and an error amplifier. It controls the waveshape regulation, while the control signal controls the dc output voltage. The output of the current amplifier is a "low frequency" error signal based on the average current in the shunt, and the control signal. This signal is compared to a sawtooth waveform from an oscillator, as is the case with a voltage mode control circuit. The PWM comparator generates a duty cycle based on these two input signals. In microcontroller based system the PWM generator is locked to this error signal.

V. DIGITAL CONTROL OF PFC

The design of a digital control system is the process of choosing the difference equation or equivalent z-domain transfer function for the controller, which will give acceptable performance for the closed loop. The performance specification can be judged from various parameters such as rise time, settling time, overshoot, closed loop frequency, bandwidth, damping ratio etc. Block diagram of a typical Digital controller is shown in Figure 2. Implementation of the controller involves solving the difference equation and interfacing ADC and DAC with the microprocessor.

A. Microcontroller based Control

In a microcontroller based application all the analog parameters and the control loops are required to be digitised. Different blocks required in Microcontroller based PFC Control is depicted in Figure 4.

As indicated in the figure three input signals are needed to implement the control algorithm. The chopper circuit is controlled by the PWM switching pulses generated by Microcontroller based on three measured feedback signals – Input voltage, Input Current and DC Bus Voltage.

B. PIC16F77 based Implementation

In the proposed scheme as shown in Figure 5, the controller is implemented using a 16F877 microcontroller.

C. PFC Software

Output from the controller is triggering pulses to IGBT to control the nominal voltage on the DC Bus. Inner Loop in the control block is current loop, whereas the outer loop in the control block forms the voltage loop.

Software flow chart of the basic PFC Controller is depicted in Figure 4. Three channels of ADC of the microcontroller are used to scan V_{ref}, V_o and I_{in} respectively

D. Proportional integral control using microcontroller

PI Controller is implemented on a micro-controller. Microcontroller is programmed to continuously scan the reference and actual feedback signal and determine the correction using PI algorithm. This correction is than converted in to ON time & OFF time by the micro-controller. Two separate counters are subsequently set in the micro-controller. Generation of pulses is done by Interrupt Driven Subroutines.

Continuous form of PI control algorithm is –

$$m(t) = K_n e(t) + K_i \int e(t) dt \quad (6)$$

Integral portion implementation in a digital controller may be written as –

$$x(t) = \int [v(t) - v_{ref}] dt + x(t_0) \quad (7)$$

Using the trapezoidal rule of integration and substituting t = KT & t_0 = (K-1).T,

$$\int (v(t) - v_{ref}) dt = \frac{T}{2} [V(KT) + V(K-1)T] - T v_{ref} \quad (8)$$

K= 1,2,..

x[(K+1)T] = T/2[V(KT)+V(K-1)T]-T.Vref + x(KT)

m[(K+1)T] = K_p[V(KT) -V_{ref}] + K_ix[(K+1)T]

It is assumed that the control is updated every T second. Control Signal m[(K+1)] is applied at t = (K+1)T, K=0,1,2,3,……

PI Controller thus implemented through above logic is tested and depicted in Figure 7. This output is the oscillogram recorded on Tectronix Digital Storage Oscilloscope. This was a general algorithm but this can be implemented in any application with minor adjustments. By tuning the K_P and K_I we can control different parameters such as overshoot, settling time etc.

E. Analog to Digital Conversion

Selection of suitable ADC for design of controller is also an important decision to be made. Main criterions for choosing an ADC are resolution and speed. Earlier versions of microcontrollers needed external ADC to be connected, but new microcontrollers have inbuilt ADC module. The proposed system uses

F. Pulse Width Modulation

Since most of power electronics application use PWM to convert signal into digital information, implementation of PWM on microcontroller becomes important. PWM requires use of Timers. Microntrollers like PIC have inbuilt PWM module that require only Duty Cycle and frequency information. For implementation of PWM through other microcontrollers we may use two timers one for calculation of T (1/f) and other for ON time (T1).Following logic may be followed.

Frequency of PWM pulse = f

Time period for PWM pulse T = 1/f

Duty Ratio = D

On Time T1 = DxT

Off Time T2 = T-T1

So 2 timers may be used to generate T1 and T2.

VI. SIMULATION OF THE PFC

Power factor correction scheme is simulated on the MATLAB SIMULINK as shown in figure 6. Converter parameters as chosesen are given in Table 4. In order to maintain good EMI performance and reduced switch current rating the PFC boost converter is usually operated in continuous conduction mode (CCM). Power Circuit is a boost converter as depicted, based on IGBT. Capacitor used for bulk energy storage is located on the right side of the circuit. Firing Pulses to IGBT are generated by the proposed controller.

VII. SIMULATION AND TEST RESULTS

Figure 9 to 11 depict the results obtained from the PSIM Simulation. Figure 9 is indicative of the Input voltage and input current. Figure 7 shows the input voltage and output current of the PFC in steady state. Both are fairly stable. Figure 10 shows that output voltage. This figure shows the output voltage when the step input is applied as reference. As we can see the output voltage is regulated within 1% of the desired output voltage. Controller is used to generate the pulses for IGBT. This is done through PWM pulses. PWM duty ratio of the pulses to IGBT is shown in figure 11.

TABLE 1- CLASSES OF EQUIPMENTS

Class	Appliances/ Equipments
Class A	Balanced 3-phase equipment household appliances excluding equipment identified as class D, tools, excluding portable tools, dimmers for incandescent lamps, audio equipment, and all other equipment, except that stated in one of the Class B, Class C or Class D equipment
Class B	Portable tools arc welding equipment which is not professional equipment
Class C	Lighting equipment
Class D	PC, PC monitors, radio, or TV receivers. Input power P <=600 W

TABLE-2 HARMONIC STANDARD

Harmoics (n)	Class of the Equipment			
	Class A (A)	Class B (A)	Class C (% of fund)	Class D (mA/W)
Odd Harmonics				
3	2.30	3.45	30*λ	3.4
5	1.14	1.71	10	1.9
7	0.77	1.1555	7	1.0
9	0.40	0.60	5	0.5
11	0.33	0.495	3	0.35
13	0.21	0.315	3	3.85/13
15-39	0.15*15/n	0.225*15/n	3	3.85/n
Even Harmonics				
2	1.08	1.62	2	-
4	0.43	0.645	-	-
6	0.30	0.45	-	-
8-40	0.23*8/n	0.345*8/n	-	-

TABLE 3 WORLD WIDE POWER SUPPLY MARKET (MILLIONS OF UNITS)

		2006	2007	2008	2009	2010	2011	CAGR
Embedded AC-DC		663.4	724.9	790.1	862.2	942.8	1025.4	9.1%
External AC-DC	Adapters	184.8	211.2	239.3	267.7	297.2	337.5	12.8%
	Off-line Battery Charger	1.5	1.7	1.8	2.0	2.2	2.5	10.8%
Motor Dries		221.7	238.9	257.5	278.0	300.1	324.2	7.9%
Lighting Ballasts		1013.8	1131.3	1257.3	1396.7	1553.8	1731.1	11.3%
Total		2085.2	2308	2546	2806.6	3096.1	3420.7	10.4%

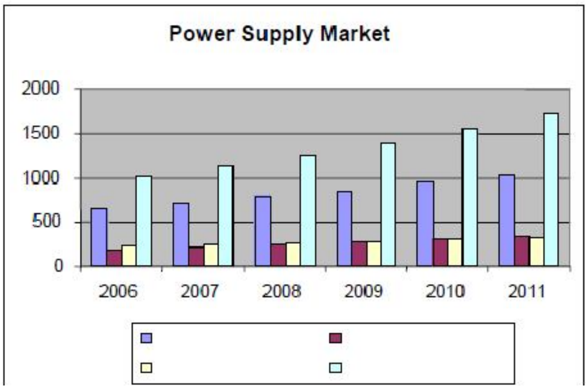

Fig. 1 : Growth of Power Supply market

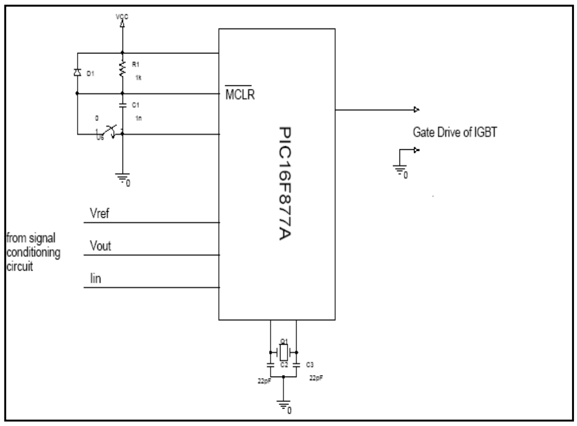

Fig. 5 : Schematic of PIC based controller

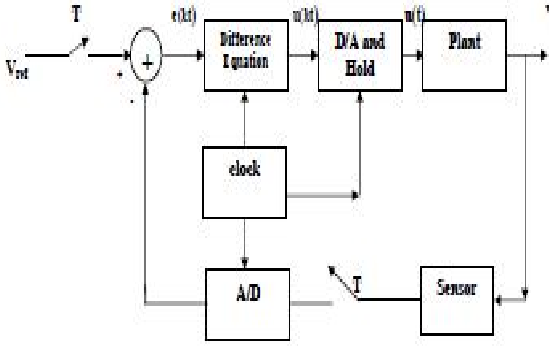

Fig. 2 : Digital Controller

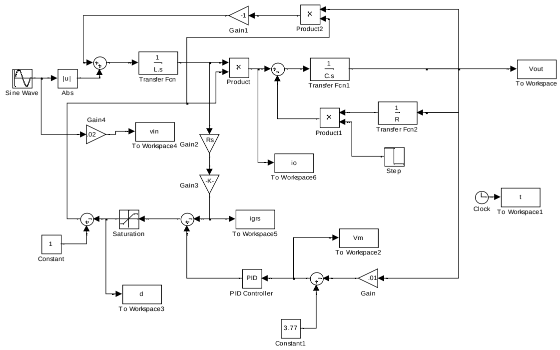

Fig. 6 : MATLAB Simulation Model

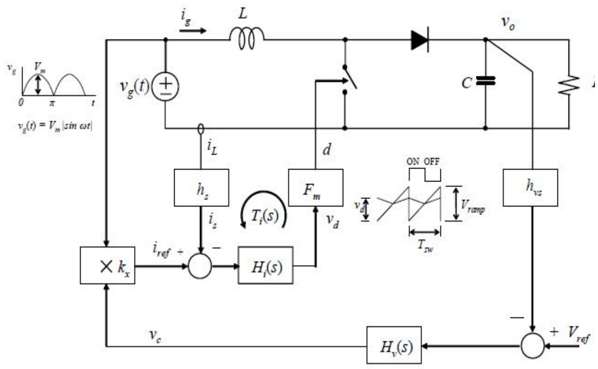

Fig. 3 : General PFC Average current mode controller

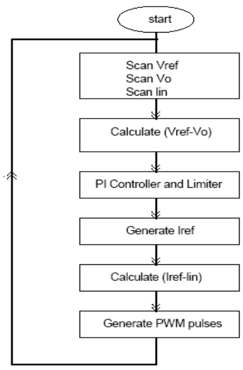

Fig. 7 : Software Flow chart

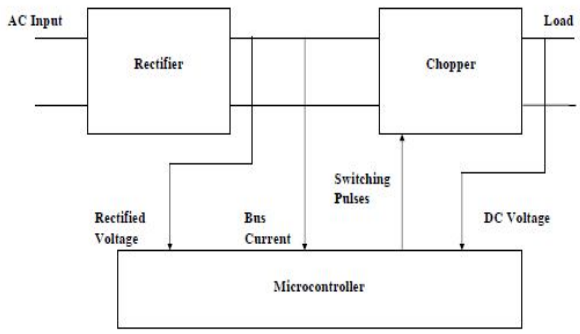

Fig. 4 : Microprocontroller based Control

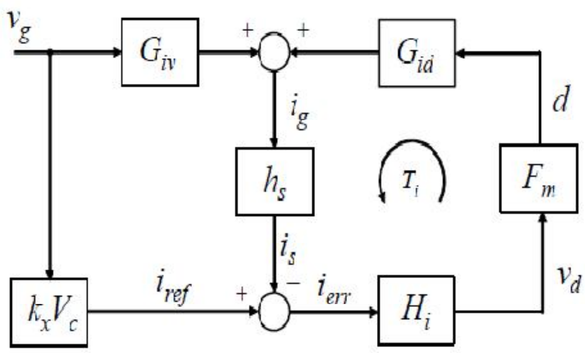

Fig. 8 : PFC Converter Transfer Functions

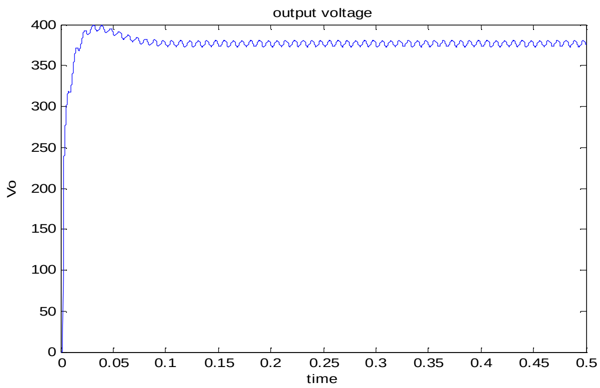

Fig. 9 : Simulated Result -Output Voltage as a result of step input

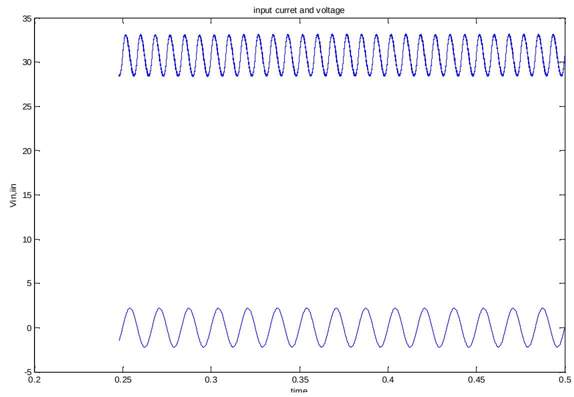

Fig. 10 : Simulated Result - Input Voltage & Current

TABLE – 2 CONVERTER PARAMETERS

Parameter	Value
V_g	200V
R	470 Ω
C	330µF
L	2.5 mH
R_s	0.1 Ω

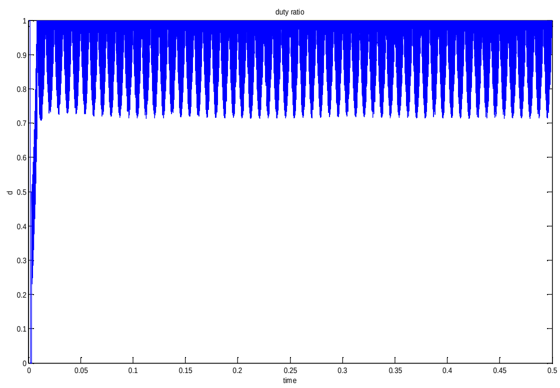

Fig. 11 : Simulated Result – Duty Raio of the Pulses

VIII.CONCLUSIONS

Controller Design for PFC is presented in this paper. Simulation is carried out on MATLAB are reported. Further work on the implementation of PFC for application of BLDC and DC drive is going on and it is expected to be completed soon. Though the microcontroller based controller for PFC in average s mode is presented here it can be applied to other topologies with minor correction in the software.

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