UPF Harmonic Current Detection Based Shunt Active Filter for Harmonic Reduction

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Abstract- **In modern distribution systems the proliferation of large power electronic systems results in increased harmonic distortion. Harmonic distortion results in reduction of power quality and affects the system stability. The harmonics extraction is based on the unity power factor (UPF) theorem in time domain to calculate the reactive power compensation in the power system. The switching control algorithms of the proposed UPF based shunt active filter manages to generate appropriate switching gates to the active power filter. The intention of this method is to compensate reactive power and reduce the unwanted harmonics. The simulation of the system is done using MATLAB-SIMULINK and finally, the proposed detection method is applied to shunt active power filter and to be implemented in PIC16F8777A microcontroller.**

Keywords- **Power Quality, SAPF, THD, Harmonics, VSI, Unity Power Factor Theory (UPF), PIC 16F877A**

1. INTRODUCTION

In recent years, the electrical power quality (PQ) is a more and more discussed issue. The main problems are stationary and transient distortions in the line voltage such as harmonics, flicker, swells, sags and voltage asymmetries. With the significant development of power electronics technology, especially static power converters, voltage harmonics resulting from current harmonics produced by the non-linear load have become a serious problem. However the power electronics based equipments which include adjustable-speed motor drives, electronic power supplies, DC motor drives, battery chargers, electronic ballasts are responsible for the rise in PQ related problems [1].

A number of control concepts such as instantaneous reactive power theory [5], synchronous reference frame and synchronous detection are reported in the literature on APF [6] [7]. The proposed UPF theory based extraction algorithm to estimate the harmonics and adaptive to various changes in system operating conditions [3] [8].

Harmonic distortion in power distribution systems can be suppressed using two approaches namely, passive and active filtering. The passive filtering is the simplest conventional solution to mitigate the harmonic distortion [2]. However, the use of passive filter has many disadvantages, such as large size, tuning and risk of resonance problems. Recently, because of the rapid progress in modern power electronic technology, the presented work was oriented mostly on the shunt active power filter (SAPF) instead of passive filters.

In this paper, we present the developing of harmonics reduction system by using active filter based on PIC16F877A microcontroller. Harmonic reduction system based on the FFT technique in order to evaluate the occurring harmonics in the system and control active harmonic filter to compensate the harmonics by PWM signal from microcontroller.

2. UNITY POWER FACTOR THEORY

The intention of this method is to make nonlinear loads and APF in parallel to be an equivalent resistance. Suppose source voltage is sinusoidal, it can be expressed as

$$u_s = U_m \sin \varpi t \tag{1}$$

If the impedance of load-link is resistive, so after compensation, source current can be expressed as

$$i_s = k u_s = k U_m \sin \varpi t \tag{2}$$

Where k is multiple load conductance.
Fourier Transform of source current before compensation can be expressed as,

$$i_s = \sum_{n=1}^{\infty} I_n \sin(n \varpi t + \varphi_n) = k u_s + i_q(t) \tag{3}$$

$$\frac{1}{T}\int_0^T u_s i_q(t) dt = 0 \tag{4}$$

Substituting equation (3) into equation (4), so

$$k=\frac{\frac{1}{T}\int_0^T u_s i_q(t)dt}{\frac{1}{T}\int_0^T u_s^2(t)dt}=\frac{\overline{u_s i_s}}{\overline{u_s^2}} \qquad (5)$$

Where, the integrals of $u_s i_s$ and u_s^2 in single period are equal respectively to the products of their dc components and integral period.

Active power component of current is computed as

$$i_p(t)=k u_s(t) \qquad (6)$$

Generalized reactive power current (sum of fundamental reactive power current and harmonic current) can be expressed as

$$i_q(t)=i_s(t)-i_p(t)=i_s(t)-k u_s(t) \qquad (7)$$

The schematic diagram of detection of harmonic and reactive power currents is shown in figure 2, here into the low pass filters can be used to obtain the dc components required in this detection technique [10].

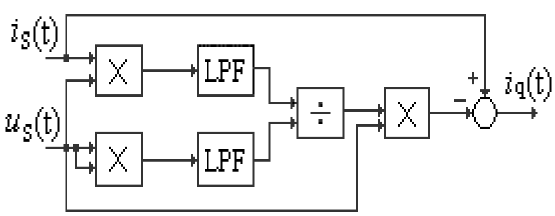

Fig.1 The Schematic Diagram of Detection of Harmonics and Reactive Power Current

3. SIMULATION RESULTS

A single-phase uncontrolled rectifier with RL load is considered as the non-linear load are shown in fig 5.The parameters selected for simulation studies are: Vs = 120 V, frequency 50Hz, Rs = 0.1mΩ, Ls = 2mH, L_{dc} = 3 mH, C_{dc} = 1000μF,R_{load},=20Ω, and second-order butter worth LPF with the cut-off frequency at 20Hz is proposed in simulation. Fig. 6 shows the simulation model of the proposed method.

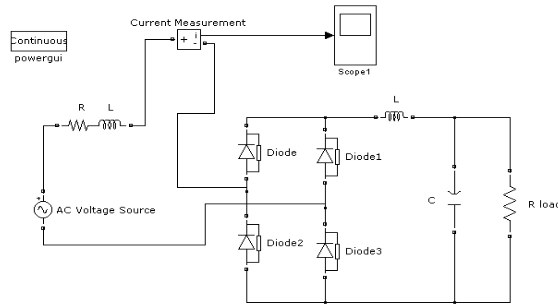

Fig. 3 Simulation Model of the Single Phase Diode Rectifier

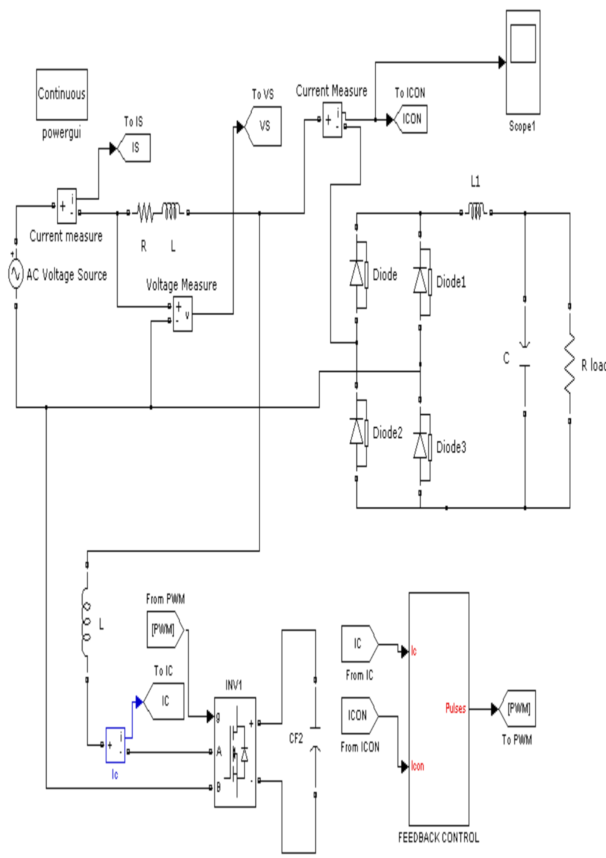

Fig. 2 Simulation Model of Proposed System

Various simulations are carried out to study the performance of the active filter during both steady state and transient conditions. Table 1 show the simulated current THD for different L_s and L_d. The above parameters shows a very high harmonic content when both ac inductance and dc-link inductance have small values and also show a continuously decreasing harmonic content as these inductances will have bigger values.

Table 1 Simulated THD with Different L_s and L_d

L_d \ L_s(mH)	2	4	6	8	10
2	52.83	46.16	41.14	36.62	32.89
4	46.39	40.93	36.48	33.02	29.99
6	40.71	36.39	32.94	29.93	27.53
8	36.42	32.88	30.03	27.49	25.15
10	32.90	29.33	27.46	25.18	23.17

Figures 3-8 show the Simulation results of the proposed method. Source voltage, distorted load current, Frequency Spectrum of System without Filter, Compensating current, source current and frequency spectrum of system with filter are shown. Figure 7 show the harmonics of source current are detected and active power components of source current is nearly to sinusoidal. The distorted line current has been compensated where by %THD is reduced from 46.60% to 4.95%.

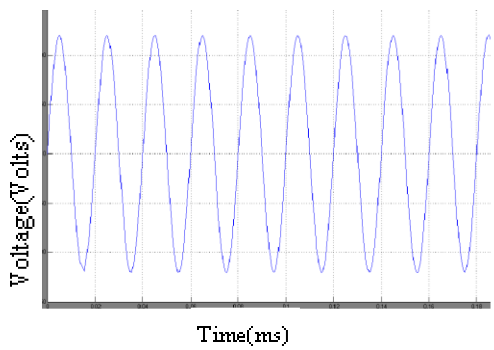

Fig. 3 Source Voltage

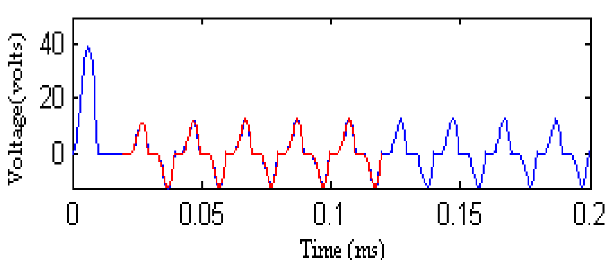

Fig. 4 Distorted Load Current

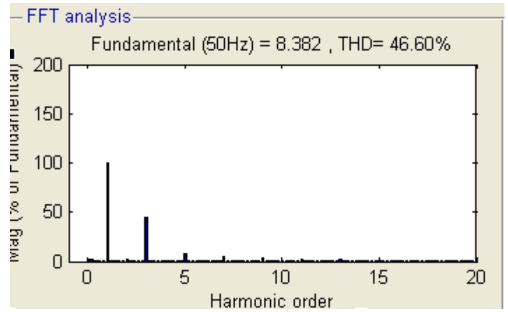

Fig.5 Frequency Spectrum without Filter

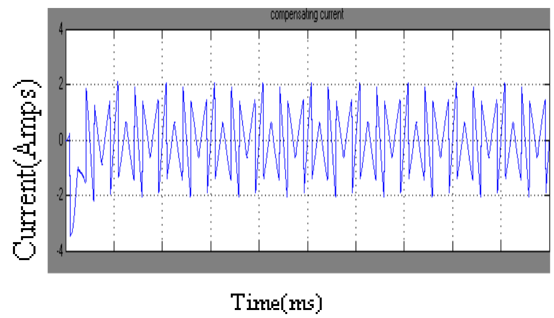

Fig. 6 Compensating Current

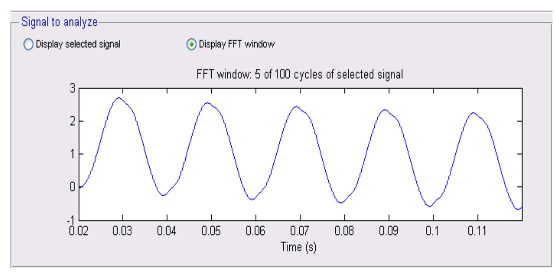

Fig.7 Source Current with Filter

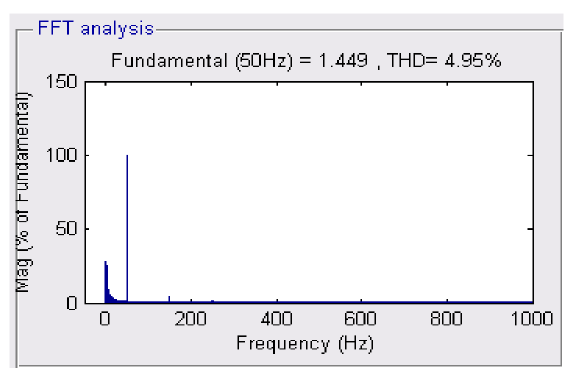

Fig. 8 Frequency Spectrum with Filter

4. HARDWARE IMPLEMENTATION

4.1 Hardware Configuration

Fig. 9 shows the hardware implementation diagram of the proposed shunt active power filter. The APF consists of four main parts, AC sampling circuit PIC 16F877A, isolation and driver circuit, and main circuit based on IGBT.

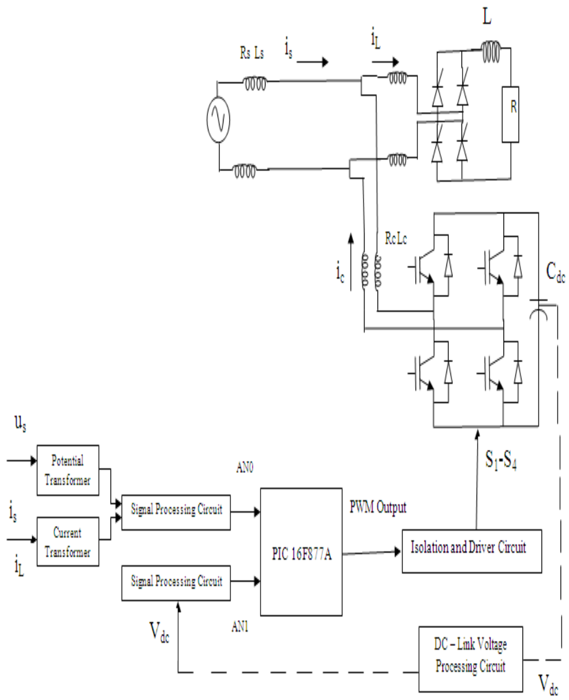

Fig. 9 Hardware Implementation of SAPF Using PIC16F877A Microcontroller

As shown in figure 9, transformer and signal processing circuit sample the voltage and current. The harmonic detection method is implemented on PIC to obtain the reference current i_c* and then PIC gives PWM output which can control the switching of IGBT to generate the actual compensation current i_c*.

4.2 Software Configuration

The software is developed by MPLAB CCS complier program and the function of software is electric signal monitor, Program PWM and Harmonic filter control. Program in microcontroller consist of program for sampling signal and generate PWM signal from data. Fig. 10 shows control system flowchart of harmonics reduction system. The first, we sampling data from signal of system and then monitoring signal on computer. We analyze the harmonics. The next, we calculate PWM data from program PWM.Finally, we sent PWM signal to control filter.

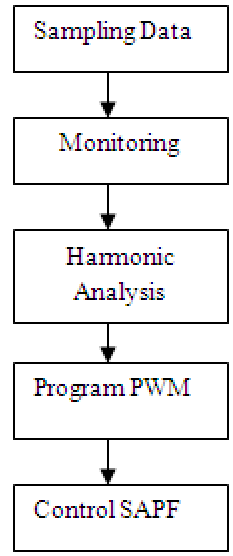

Fig. 10 The Control System Flow chart

4. 3 Signal Conditioning

The signal conditioning circuit consists of following units.

- Current Sensor
- Voltage Sensor
- Zero Crossing Detector
- OP-AMP
- Level Shifter

Input load current is sensed using current sensor CS60-010 and the line voltage is sensed using voltage transformer. The output of the current transformer is in terms of mill volts so it is amplified using operational amplifier in non-inverting configuration. A zero crossing detector literally detects the transition of a signal waveform from positive and negative, ideally providing a narrow pulse that coincides exactly with zero voltage condition. The level shifter circuit provides match the voltage signal to the input voltage range of the ADC.

4.4 Harmonics Analysis

Harmonic analysis program in this paper use FFT method. This method can sharply convert the measured signals from A/D converter in microcontroller on the time domain to the frequency domain. We can calculate total harmonic distortion (THD) from (8) and (9).

$$THD_I = \sqrt{\frac{\sum_{n\neq 1} I_{n,rms}^2}{I_{1,rms}^2}} \qquad (8)$$

$$THD_V = \sqrt{\frac{\sum_{n\neq 1} V_{n,rms}^2}{V_{1,rms}^2}} \qquad (9)$$

Where
THD is Total Harmonic Distortion
In is n^{th} harmonic current
Vn is n^{th} harmonic voltage

This program analyzes the harmonics and sent data of harmonics to program PWM in order to calculate PWM data (switching angle).The microcontroller generate PWM signal for active filter to compensating harmonics in electrical system.

4.5 PIC16F877A

All single cycle instructions except for program branches which are two cycle, the operating speed is 20 MHz and clock input is 200 ns instruction cycle It is having up to 8K x 14 words of FLASH Program Memory, up to 368 x 8 bytes of Data Memory (RAM) and up to 256 x 8 bytes of EEPROM Data Memory.

4.6 Digital PWM Implementation

The standard method for generating a PWM using a Micro-controller is by using one of the built-in PWM modules. Depending on the type of micro-controller used the PWM can be left, centre or right aligned. Many low-cost micro-controllers only produce a left aligned PWM [13].The PIC 18F877A has two options available for generating a PWM using the Capture, Compare, PWM (CCP) module. The most common and easily implemented is PWM mode, which only allows a left aligned PWM to be generated as shown in Fig 11.

The CCP module on the PIC18F877A operating in PWM mode is shown in Figure 4. There are two identical CCP modules available (CCP1, CCP2) and they both share the same Timer 2 module. Timer 2 provides the time base for the PWM switching and duty periods, which are programmed by writing to the PR2 and CCPRIL/CCPR2L, registers respectively.

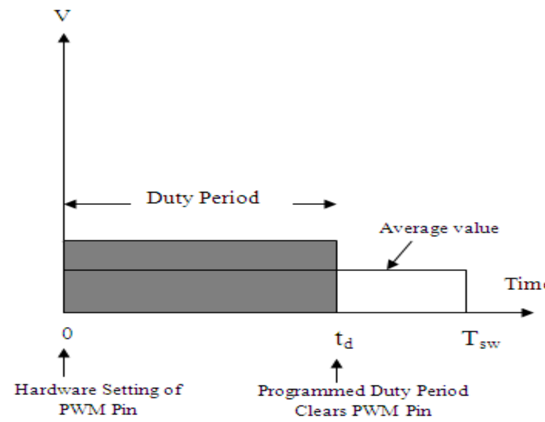

Fig. 11 Left aligned PWM

The programmed PWM is then output continuously until it is updated, allowing for an increase in switching frequency without any additional load on the microcontroller. As the PWM duty period is double buffered(CCPRxL, CCPRxH) it can be updated in the previous switching period, which allows a 0- 100% duty period to be achieved.

4.7 Obtaining the SPWM and Gating Pulses for Shunt Active Filter

The control system is constructed by microcontroller as being standard with a clock pulse generator. Sinusoidal PWM that is used to drive IGBTs in the inverter is generated by PIC16F877A via software. Conventionally, to generate this signal, triangle wave as a carrier signal is compared with the sinusoidal wave, whose frequency is the desired frequency. Figure 12 below clearly illustrated the comparison signal between carrier signal and reference sinusoidal signal and the gating pulses signal (Vg).The gating pulses (Vg) drive the IGBTs of shunt active filter. Timing interval is increased by using 20 MHz oscillator in the microcontroller. A look-up table is occurred by sampling 50 Hz sinusoidal signal with 11.250 degree intervals with PIC microcontroller. 16 pulses sinusoidal PWM signal is obtained by sampling 16 times in the one alternance of 50 Hz sinusoidal signal. Obtained SPWM signal is 1.6 KHz. So, IGBTs are switched at 1.6 KHz frequency. PWM signal is taken from RC1 and RC2 Pin of PIC16F877A. It is assured that distorted current is compensated by adjusting the conduction durations of SPWM.

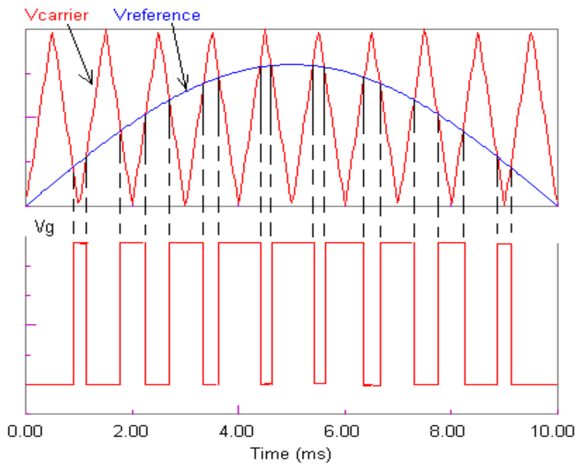

Fig. 12 Comparison signal and gating pulses signal

5. CONCULUSION

In this paper, UPF harmonic current detection theory has been applied to a shunt active power filter to compensate for reactive and harmonic currents under balanced and unbalanced source voltage conditions. The simulation has been carried out in MATLAB/SIMULINK environment and the hardware implementation is in progress. Based on simulation results, the proposed method provides real-time detection of harmonics and reactive power current quickly.

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