iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 6 Issue: I Month of publication: January 2018

DOI: http://doi.org/10.22214/ijraset.2018.1406

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor :6.887
Volume 6 Issue I, January 2018- Available at www.ijraset.com

Digital control of Active Power Factor Correction using SPWM Technique

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Abstract: This paper proposes a simple Digital control of PFC using sine pulse width modulation (SPWM) technique. This technique requires DSPIC30F3011, an Inverter circuit & Power factor measurement circuit which detects voltage and current lead/lag. Results of using SPWM give very pure sine wave output with very less harmonics and distortions. The proposed Digital control of PFC is a different approach than boost converter control used in PFC and overcomes the problem of limited switching frequency. The efficiency of the inverter is high and offers very less harmonic distortion. Simulation results indicate that power factor very near to unity can be achieved using the proposed method.
Keywords: PFC, DSP, SPWM.

I. INTRODUCTION

The day by day increase in electronics consumers and the rigid occurrence of mains rectification circuits inside the electronic devices dominants the cause of mains harmonic distortion. Some form of ac to dc power supply are used within the construction of most modern electrical and electronic apparatus and for each half cycle of the supply these supplies take pulses of current. Considering for single apparatus (a domestic television, for example) the amount of reactive power drawn may be small, but for bulk, may be 100 or more TVs the reactive power utilization from the same supply phase causing a flow of substantial amount of reactive current and hence harmonics generation.

It is not always the case that the amount of electricity you receive is equivalent to the amount of electricity you use –in fact many on sumers are billed on "wasted" electricity. Customers are liable to pay for the amount supplied even if you aren't able to utilize all of it. Power Factor is a measure of this inefficiency and Power Factor Correction is the solution used to minimize these inefficiencies.

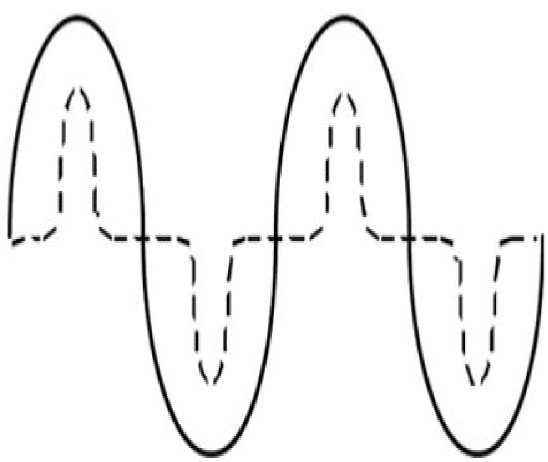

Figure 1: Input of switch mode power supplies without PFC. The voltage waveform is a sine wave and the current waveform is a pulse or spike. PF<1

Power Factor Correction is a technique of shaping the input current so that it will in-phase with the input voltage in an AC circuit. The purpose of it is to minimize the unwanted effects (harmonic distortion) introduced by electronic equipments in the power system and utilizing the usable power in the mains. The Power Factor can be improved by using PFC circuits. These circuits "smooth out" the pulsating AC current, improving the PF, and reducing the chances of a circuit breaker tripping prematurely.

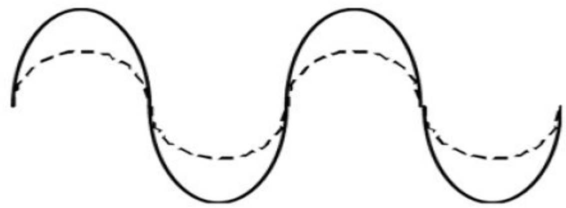

Figure 2. Voltage and Current waveform s are sinusoidal and in-phase. PF=1

The PF, much like the supply's efficiency rating, determines the amount of useful power a switch mode power supply can draw from the AC line and then deliver to its output load.

Specifically, the formula that determines this is:

VLrms x ILrms x PF x Eff = Pout

As an example, if a power supply is operating off of 120VAC line, which is protected by 15A circuit breaker, UL guidelines say you should not draw more than 12A. So, using the formula above, we can compare two power supply examples with different Power Factors as follows:

Example A : No PFC, PF = 0.65, 85% Efficiency, 120VAC input, 12A max. current:

Therefore: 120VAC x 12A x 0.65 x 0.85 = 796 Watts Output Power

Example B : PFC used, PF=0.98, 85% Efficiency, 120VAC input, 12A max. current:

Therefore: 120VAC x 12A x 0.98 x 0.85 = 1200 Watts Output Power

As can be seen above, the power supply in Example B (with PFC) can deliver 404 Watts or 51% more power to its output load than the non-PFC supply, a significant increase.

II. HARDWARE ARCHITECTURE

Figure 3 shows the basic block diagram of Active Power Factor Correction Unit. The components of this APFC unit are Battery for supplying DC voltage to Inverter Circuit, a Transformer which is of Push-Pull type and gives 230V AC output, Switches for switching 5V DC into 12V AC, DSP for SPWM generation and switch control, Potential and Current Transformers along with PIC controller determines Current and Voltage Lead or Lag. Here at the beginning we can use Bridge rectifier to get the 12V DC voltage instead of Battery as a DC source. But, we need to embed a big step down transformer after 230V AC supply which is costlier approach.

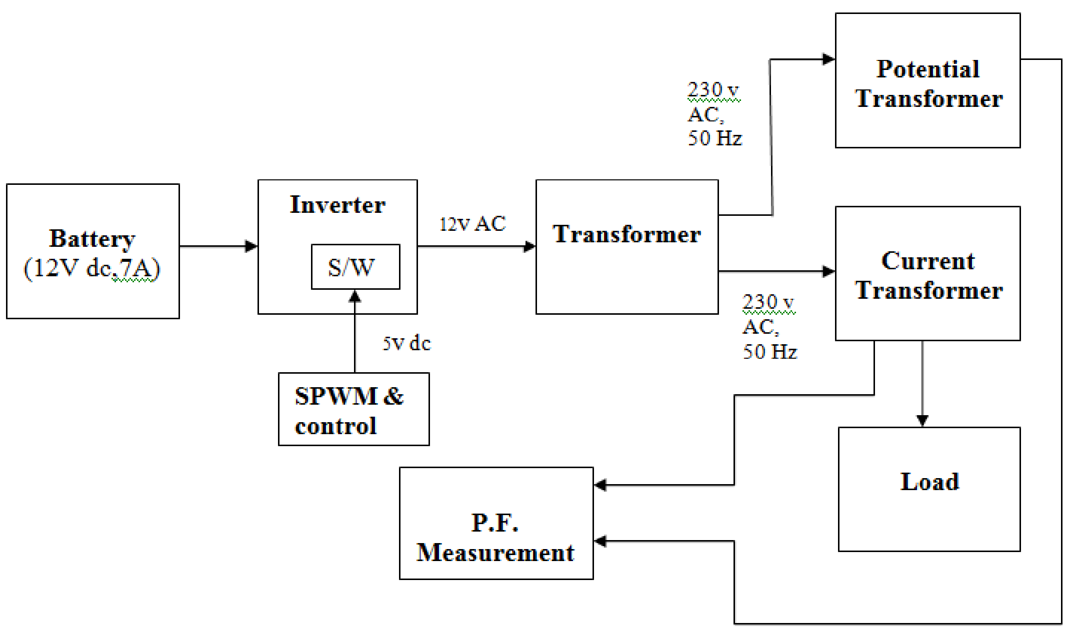

Figure 3. Basic Block diagram

III.METHODOLOGY

A. Sinusoidal Pulse Width Modulation

To turn the DC voltage on and off, most of the inverters use this PWM technique. This technique generates a DC voltage in a form of pulses of different widths. The width of each pulse is varied as required and hence in a region where you need higher Amplitudes, it will generate pulses of larger widths.

It is one of the PWM method used in Inverters and widely used in Industries. SPWM can be obtained by comparing High frequency Carrier triangular waveform with a Low frequency Sinusoidal waveform, which is nothing but reference or modulating signal. So, by comparing a sine wave with a high frequency triangular wave the On and Off instances of a PWM signal can be determined. In Sinusoidal pulse width modulation, the frequency of Output Voltage is determined by the Frequency of Sine wave or Modulating wave. Also, Modulating waves peak Amplitude determines the modulation index and in terms controls the out voltage rms value. In figure below, we can see "p" pulses. Throughout the cycle widths of these pulses vary to give fundamental component of Frequency.

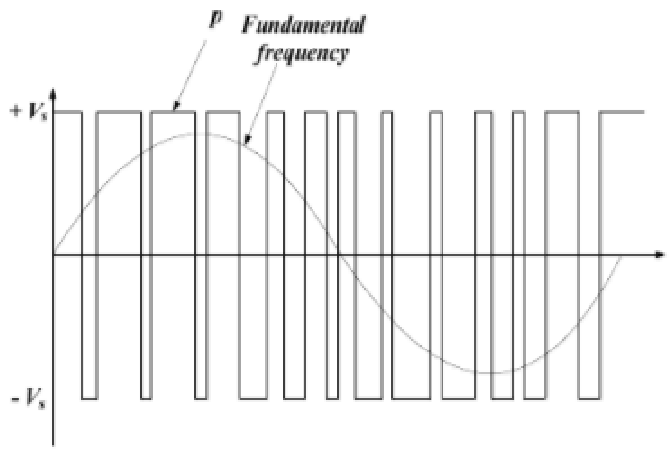

Figure 4. Sinusoidal PWM signal

B. SPWM Implementation using DSPIC30F3011

DSP has it's in-built Oscillator which can produce high frequency signals.

In SPWM method, by comparing Sinusoidal reference signal with Triangular Carrier wave frequency, the gating signal is generated. By varying the width of each pulse in proportion to the amplitude of the reference wave we can achieve following major advantages

The distortion factor and lower order harmonics can be reduced significantly.

The width of all the pulses are maintained the same. This type of modulation is known as Sinusoidal Pulse Width Modulation. By comparing sinusoidal reference signal with a triangular carrier wave of frequency, the gating signal is generated.

IV.HARDWARE DEVELOPMENT & RESULTS

A. Inverter Circuit & DSP Output

It consists of one PWM modulator SG3524 and 2 MOSFET switches. For SG3524, we are giving 9V DC regulated output and we get a 5V DC, 50Hz little distorted square wave as its output. DSPIC30F3011 compares carrier triangular wave with sinusoidal reference signal generates two SPWM signals which are opposite to each other using NOT logic gate inside it. These two SPWM Signals are of very high frequency in Khz but with pure square wave of 5V DC signal.

Now these two signals i.e. one from PWM modulator and other from DSP are ANDed together to generate a pure 5V DC Square wave of 50Hz frequency. So, we get 2 signals in inverted manner. These two signals are given as an input to two MOSFET's which are connected to Primary of the Push-Pull transformer. These Switches are controlled by DSP and are switched in such a way that when first MOSFET is On, we get one half of the AC cycle and when it switches of, other turns On, giving another half of the AC cycle. Output of these Switches would be 12VAC signal fed to Primary of the Transformer. Now by its turns ratio, transformer converts this 12V AC into 230V AC output. Also, across these 3 terminals from secondary of the Transformer we can get different voltages w.r.to ground and in turn different wattages to drive the Load.

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B. Push-Pull Transformer

The Basic theory is as follows: The top transistor switch closes and causes current to flow from the battery negative through the transformer primary to the battery positive. This induces a voltage in the secondary side of the transformer that is equal to the battery voltage times the turns ratio of the transformer. Note: Only one switch at a time is closed. (See state Figure 5 below). After, certain desired period the switches flip-flop. The top switch opens and then the bottom switch closes allowing current to flow in the opposite direction (See state Figure 6 below). This cycle continues and higher voltage AC power is the result.

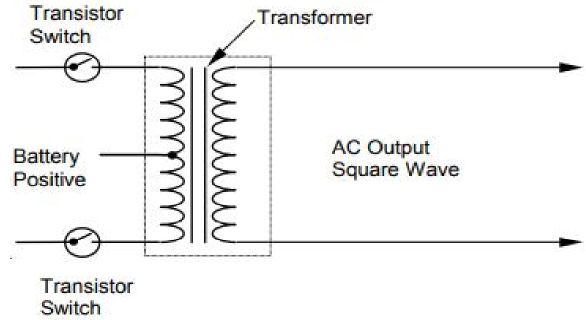

Figure 5. Push-Pull Topology – Square wave output

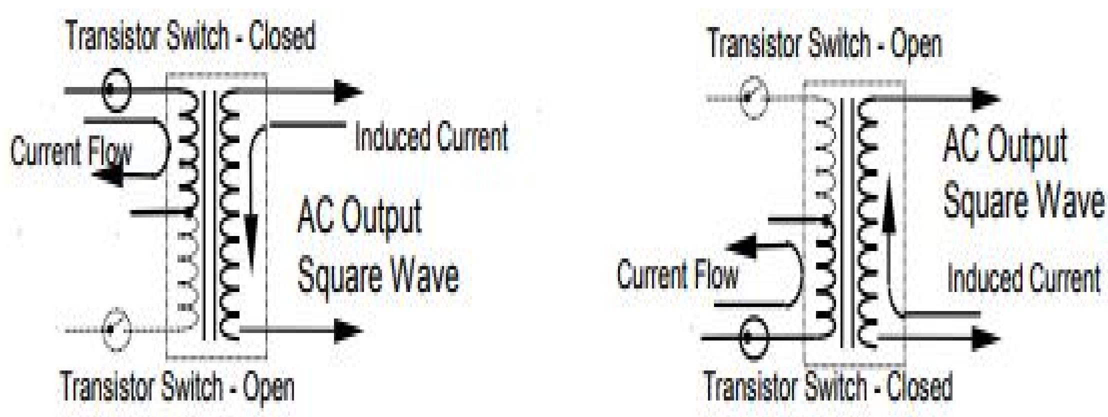

Figure 6. Push-Pull Working with Switches open and closed

C. Power Factor Measurement Circuit

We are using Current transformer and Potential Transformer across transformer output and then their output would be connected to Power Factor Measurement Circuit. This measurement circuit consists of PIC microcontroller and LM358 used as ZCD to detect voltage and current lead and lag. This way Power factor is measured and shown on LCD display.

V. SIMULATION & RESULTS

A. Push-Pull Inverter system using SPWM is simulated using MATLAB/SIMULINK

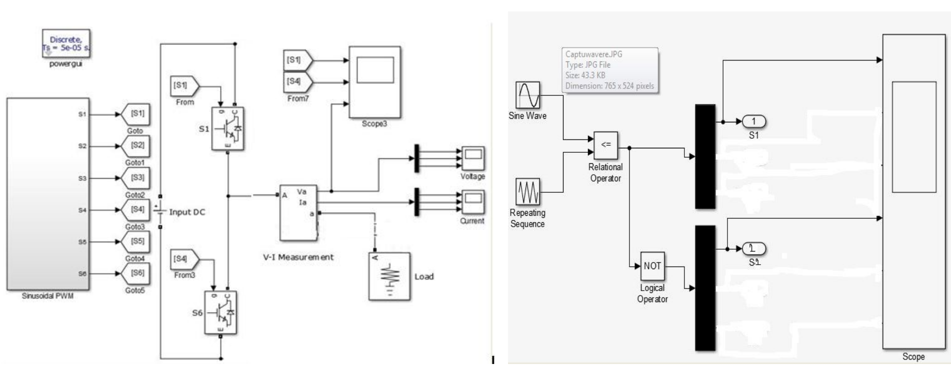

Figure 7: Simulink model of Push Pull Inverter system with SPWM

VI. SIMULATION RESULTS

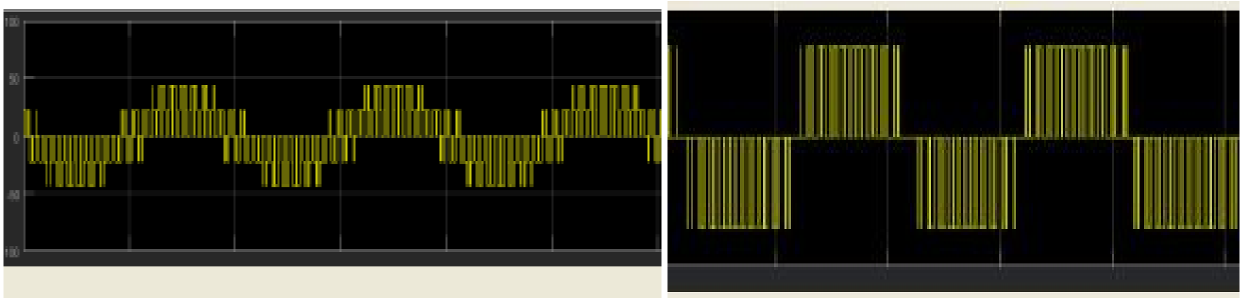

Figure 8. Simulation Results- Current and Voltage

VII. PROTEUS SIMULATION

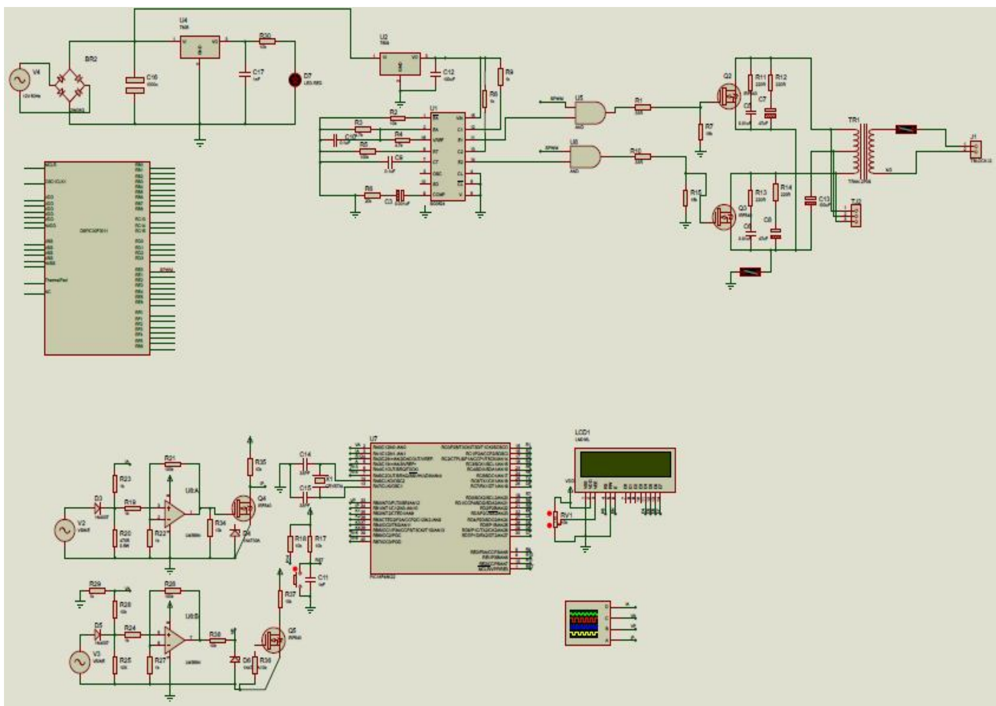

Figure 9. Proteus Simulation of overall circuit.

The simulation results are matching with actual behavior of system. Same will be used in actual Hardware implementation.

VIII. CONCLUSIONS

With a higher power factor at light load, meeting higher power factor requirement at light load will be possible for power supplies of desktop computers and servers. Moreover, bringing the power factor at light load to be close to unity helps in reducing the rms current drawn from the ac mains. This helps in reducing the power consumption under light load conditions and in meeting the ENERGY STAR light load efficiency requirement.

The prototype has been tested with two different loads (electronic choke coil and 100W tungsten bulb), and the experimental results show, in both cases, high power factor with reliable performance under different load and voltage conditions.

Some of the features of the proposed method for the PFC unit presented in this paper are as follows.

Information on the required signal is obtained via two paired sawtooth waves compared with the sensed signal, without any ADC used.

This scheme doesn't use traditional boost approach hence reducing complex designing of inductor and also cost effective.

There is no ADC required to realize the fully digitalized control of the PFC.

SPWM technique gives pure Sine wave output with very less distortion and harmonics.

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