Development of a Single-Phase PWM AC Controller

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ABSTRACT

An AC chopper controller with symmetrical Pulse-Width Modulation (PWM) is proposed to achieve better performance for a single-phase induction motor compared to phase-angle control line-commutated voltage controllers and integral-cycle control of thyristors. Forced commutated device IGBT controlled by a microcontroller was used in the AC chopper which has the advantages of simplicity, ability to control large amounts of power and low waveform distortion. In this paper the simulation and hardware models of a simple single phase IGBT An AC controller has been developed which showed good results.

Keywords: PWM, AC controller, AC choppers

ABBREVIATIONS

PWM	Pulse-Width Modulation
AC	Alternating Current
RMS	Root Mean Square
IGBT	Insulated Gate Bipolar Transistor
DC	Direct Current

INTRODUCTION

The AC voltage regulator is used as one of the power electronic systems to control AC voltage output for power ranges from a few watts up to fractions of megawatts, as in starting systems and speed control for large induction motors. Traditionally, phase-angle control line-commutated voltage controllers and integral-cycle control of thyristors have been used in these types of regulators. These techniques suffer from inherent disadvantages, such as retardation of the firing angle that causes a lagging power factor at the input side, and distorted waveforms in load and supply voltages and currents (Ahmed *et. al.* 1999).

Many researchers have investigated and studied these types of AC controllers. Kwon *et. al.* (1999) have proposed a novel topology of pulse-width modulated AC chopper for single-phase, and three-phase systems are proposed for buck, boost and buck-boost types. The advantages of their proposed topologies for AC choppers include increased power factor, low harmonic input current, fast dynamics, high efficiency and high reliability. They have compared their results with the phase-controlled AC controller using thyristors. Bodur *et. al.* (2000) have carried out research on universal motor speed control with current controlled PWM AC chopper using a microcontroller. The proposed method proved that the universal motor speed control system has stable control in a wide range

of speeds, and also found that the motor shows good response to sudden load changes, which is suitable for many industrial control system applications.

Ryoo *et al.* (2003) has studied the series compensated AC voltage regulator using AC chopper with auxiliary. The proposed AC regulator has many advantages such as fast voltage control, high efficiency and simple control logic. Experimental results proved that it can be used very efficiently as step-down AC voltage regulators for power saving purposes.

Hongxiang *et. al.* (2004) has improved the PWM AC chopper for harmonic elimination. The modulation function is derived from the input voltage signal. Compared with previous constant duty cycle controls, it has the advantage of eliminating 11 low order harmonic voltages contained in AC mains without the need for processing harmonic frequency.

In this work, an AC chopper controller with a symmetrical pulse-width modulation (PMW) was modified to achieve a simple controller for a single-phase induction motor. Only two forced commutated devices IGBTs have been used as switching elements to construct the controller, while in the literature, at least three of these switching devices were reportedly used in the controller (Ahmed, *et al,* 1999).

Simulation of the system was developed using Matlab and the hardware system constructed. The results showed good agreement in the waveforms and harmonics content

Concept of AC Voltage Controller

The concept used in this motor control is to implement the power switching device to chop the input source voltage. This method will cause the pulse-width of the AC voltage waveform to change. So, this method of AC voltage controller is called symmetrical pulse-width modulation (PWM) AC chopper. *Fig. 1* shows the circuit diagram of an AC controller. The current in the inductive load always has a continuous path to flow regardless of its direction. To explain the operation of this circuit, three operating modes are proposed, namely active mode, freewheeling mode and dead time mode. The advantages of the AC chopper are simplicity, ability to control large amounts of power, low waveform distortion, high power factor and high response (Ahmed, 1994).
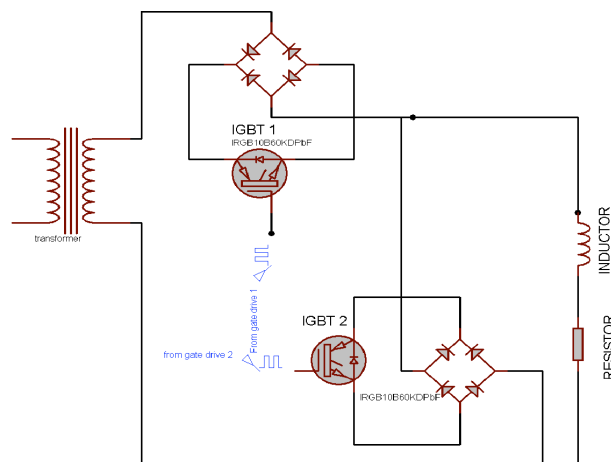

Fig. 1: Circuit diagram of symmetrical PWM AC chopper

A. Active Mode

The active mode occurs when switch 1 is closed and the current is flowing across the load as shown in *Fig. 2(a)*. During this stage switch 2 is opened. Power flows from the supply to the load.

B. Freewheeling Mode

As for the freewheeling mode, switch 1 is opened and the load is disconnected from the supply. Meanwhile switch 2 is closed. The load current freewheels and naturally decays through the freewheeling path according to the direction of the load current as shown in *Fig. 2(b)*. The current can flow until the energy in the inductor is fully depleted. The trapped energy in the inductor is dissipated in the resistances of the freewheeling path.
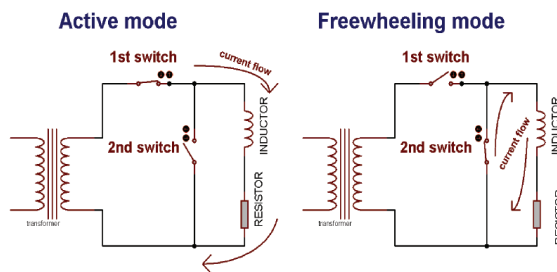

Fig. 2: AC controller operation modes

C. Dead Time Mode

In order to prevent short circuit of switches, a short dead time mode is inserted between the active mode and freewheeling mode. This is due to the characteristic of the switching device that owns rise time, t_r and fall time t_f. A typical time delay of 30 microseconds is introduced to make sure that the switching device 1 is completely opened before the switching device 2 is closed. The value of this delay depends on the specification of the switching devices.

High chopping frequency can be used, thereby reducing the output current harmonics. The root-mean-square (RMS) voltage is proportional to the duty cycle, *D*, which is defined by the ratio of the ON time, T_{on} to the total period, $T_s = T_{on} + T_{off} + 2T_{deadtime}$. Thus chopping frequency, $f = 1/T_s$. Usually $T_{deadtime}$ is very small compared to T_{on} and T_{off}, then $T_s = T_{on} + T_{off}$.

Advantage of the AC Controller

AC chopper regulation has basic advantages over phase and integral cycle techniques which can be summarized as follows (Ahmed, 1994):

i.   Does not require synchronization with the power source. Less switching device used. Only two switching devices are used compared to 4 in a H-bridge inverter.

ii. Faster response of voltage variation across the load. This occurs because a chopper can be turned ON or OFF at any instant in the AC cycle, whereas, in phase controlled circuits, once the power switches have been turned ON, it will go OFF only when the supply voltage polarity is reversed.

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iii. The overall power factor in the chopper regulator is higher than other topologies.
iv. Although the output voltage is PWM modulated sinusoidal, the impact of the harmonics at high frequency is minimal. Output voltage can be smoothed by simple capacitive filter.

MATERIALS AND METHODS

Matlab software has been used to simulate the AC controller circuit, and a hardware model has been designed and constructed. The load and component ratings chosen for power circuit in this work were about 10A and 240V. The main components used are as follows:-

i.   IGBT (insulated gate bipolar transistor)
     The IGBT chosen is IRGB10B60KDPbF with V_{CES} = 600V and Ic = 12A. The rise time (29ns) and fall time (32ns) is also very fast, so it is excellent for fast switching operations.

ii. Rectifier
     The bridge rectifier which consists of a power diode is implemented. The bridge rectifier provides the DC voltage to IGBT because current can only flow through IGBT in one direction.

iii. Microcontroller
     The microcontroller chosen for this project was an 8-bit PIC16F873 microcontroller which has high speed technology, low power consumption, wide operating voltage range and fully static design.

iv. Gate Drive
     To provide voltage isolation and floating points required to operate the IGBTs, single channel gate IR2117 drives have been used. There are a number of ways in which the gate to source, Vgs floating supply can be generated, one of these being the bootstrap method. The duty cycle and on-time are limited by the requirement to refresh the charge in the bootstrap capacitor (long on-times and high duty cycles require a charge pump circuit). This means that the output IR2117 has to be off for a short time enough to charge the bootstrap capacitor.

v.   Freewheeling diode
     A "freewheeling diode" is put into a circuit to protect the switching device from being damaged by the reverse current of an inductive load. Without the "freewheeling diode", the voltage can go high enough to damage the switching devices.

RESULTS AND DISCUSSION

To verify the performance of the proposed symmetrical PWM AC chopper, an experimental model was constructed, and a software simulation of the system developed using Matlab. *Fig. 3* shows the circuit used in Matlab simulation. The circuit consists of a transformer, diodes, IGBTs and pulse generator. Inductive load has been used to represent the induction motor at study state.

A microcontroller program has been written in C language which can provide required signals with variable duty cycles, as shown in *Fig. 4*. Both models have been tested with different types of load (resistive and inductive) and different values of duty cycle. In general close agreement has been found in the simulated and experimental results. Table 1 shows the simulation and practical measurements, and the variation of effective voltage V_{RMS} when the duty cycle changes.
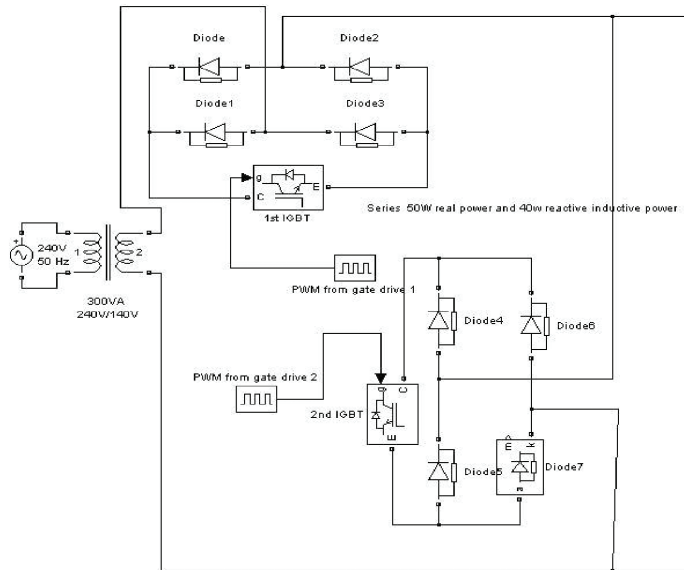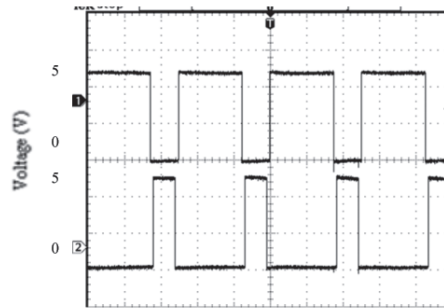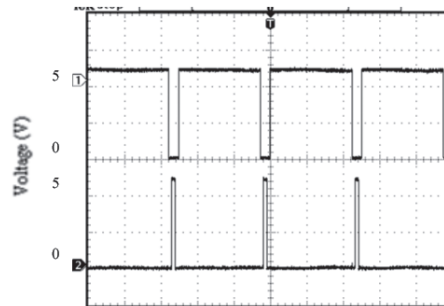
Fig. 3: Circuit arrangement for Matlab simulation for inductive load

(a) 0.7 duty cycle

(a) 0.9 duty cycle

Fig. 4: Triggering signals with variable duty cycles

TABLE 1

Variation of V_{RMS} across the inductive load

Duty cycle	Simulation result (v)		Hardware result (v)	
	Vp	V_{RMS}	Vp	V_{RMS}
0.6	198	106.6	198	107
0.7	198	115	197	115
0.8	198	123	197	123
0.9	198	134.6	196	130
1.0	198	140	198	140

To show the effect of load types on the AC controller waveform and its effect on the harmonics content, simulation and experimental results of current and voltage waveforms of two types of load have been considered, which are resistive and inductive loads. The value of the duty cycle is 0.6 and the chopping frequency is 1 kHz, *Fig. 5* shows waveforms of the resistive load, it is clear that the current waveform has the same shape as voltage waveform, while *Fig. 6* shows the frequency spectrum for simulated and experimental current and voltage waveforms. The dominant harmonics are at the sum/difference of AC supply and the switching frequency.

Fig. 5: Comparison of simulation and experimental voltage and current
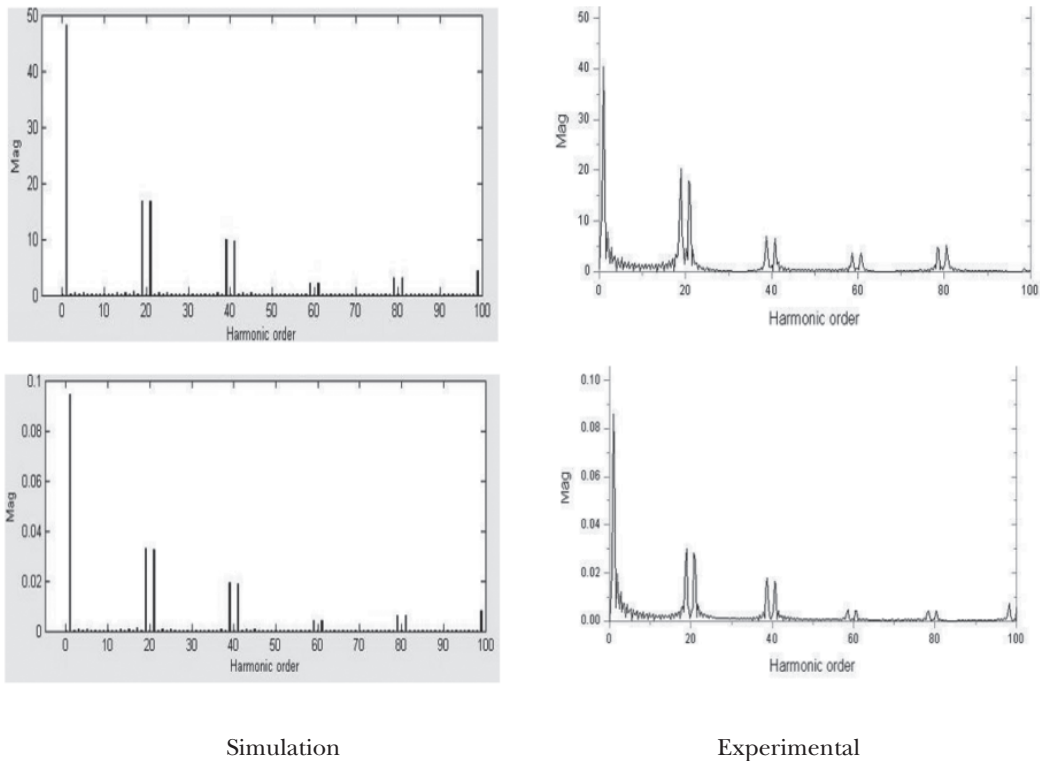*waveforms for 0.6 duty cycle (Resistive load)*

Simulation   Experimental

*Fig. 6: Comparison of simulation and experimental harmonic spectra
for 0.6 duty cycle, voltage and current (Resistive load)*

K= fc / fs , where fc is carrier frequency (1000Hz) and fs is the supply frequency (50 Hz).

The order of the high harmonic content can be found as:

Harmonic order   = nK ±1, where, n=1,2,3,……

So, the high harmonic contents of the voltage and current can be found in order of 19, 21, 39, 40, 59 and 61. Also this can be proven by comparing with harmonic spectra as in *Fig. 7*. The Total Harmonic Distortion, THD of the simulated current waveform was found to be equal to 48% and the experimental was 51%, without any filter.

Similar measurements have been carried out for inductive loads represented by small motors. In *Fig. 8* and due to presence of inductance, the shape of the current and voltage waveforms are not the same. Further, there is a difference in the simulated and experimental current waveforms and this is due to the dynamic parameters of the motor. The harmonics analysis shows that the harmonic order are the same but the amplitude of the current harmonics are smaller due to presence of the inductance. It is clear that the THD of the current waveform has lower values compared with resistive loads which showed 17% for simulation and 21% for the experimental waveform.
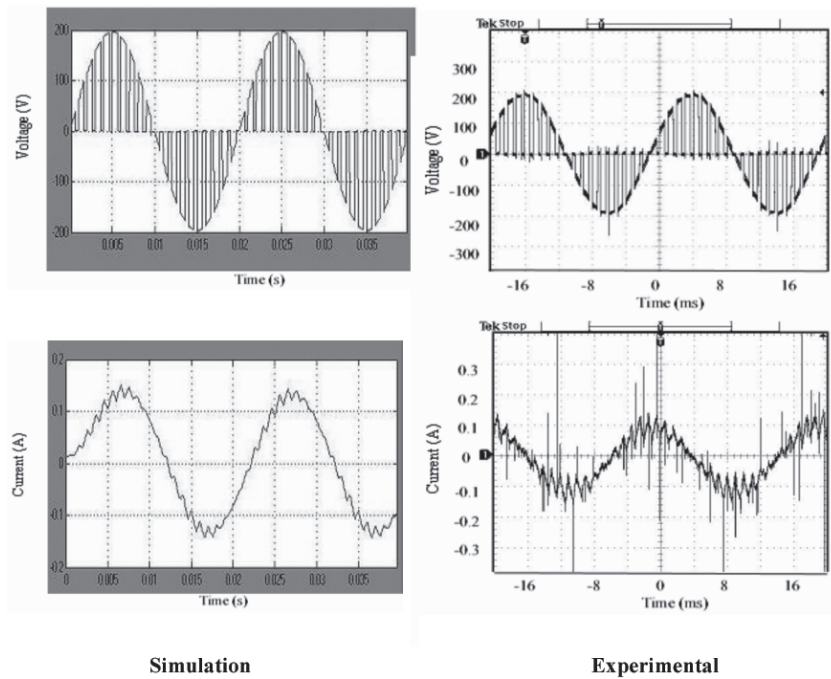
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Simulation   **Experimental**

*Fig. 7: Comparison of simulation and experimental voltage and current waveforms
for 0.6 duty cycle (Induction motor)*
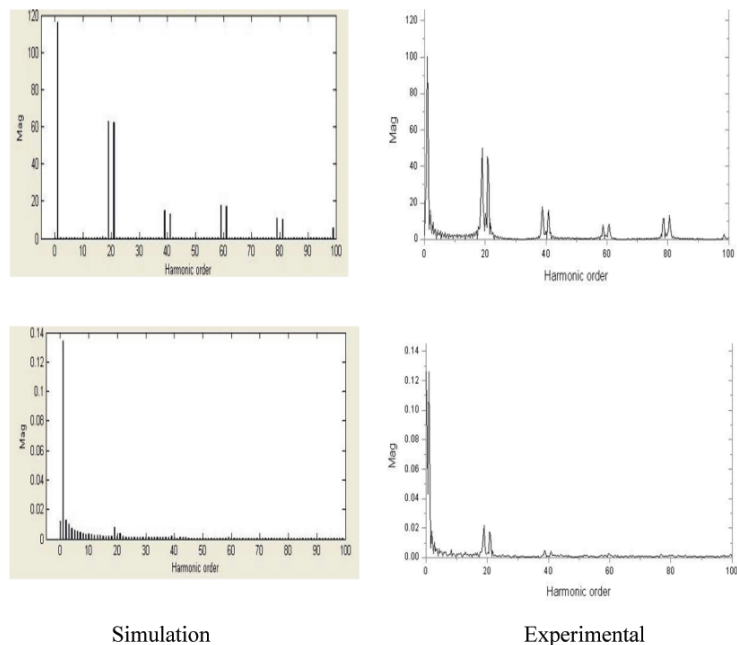

Simulation   Experimental

*Fig. 8: Comparison of simulation and experimental harmonic spectra
for 0.6 duty cycle, voltage and current (Induction motor)*

CONCLUSIONS

A software simulation was developed for a simple AC controller and a hardware system constructed. Good agreement was achieved between the simulation and experimental results. The amount of voltage supply across the motor can be changed by varying the PWM signal of the symmetrical PWM AC chopper. This was done with the aid of a PIC16F873 microcontroller. In general, the performance of the symmetrical PWM AC chopper was good. The high order of harmonic content can be eliminated easily by a small LC passive filter. Therefore, this method can replace the convention phase-angle control line-commutated voltage controllers and integral-cycle control.

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