Low Cost Microcontroller Based Implementation of Modulation Techniques for Three-Phase Inverter Applications

T. Erfidan, S. Urgun, *Student Member, IEEE,* and B. Hekimoglu, *Student Member, IEEE*

Abstract: **Sinusoidal and Space Vector Pulse Width Modulation (SPWM-SVPWM) techniques have been extensively used to build inverters, which generate AC voltage from DC voltage. The main application of this type of inverters is for variable speed induction motor drives. With the popularity of microprocessors, the implementations of these techniques are being used widely in inverters. This paper describes the procedures for the implementation of these two modulation techniques on a low-cost high speed microcontroller.**

Index Terms: **PWM, SVPWM, SPWM, driver, three-phase inverter and microcontroller.**

I. INTRODUCTION

The alternating power supply is usually obtained from electric rotating machines called generators, alternators, or synchronous generators and these machines operate at a fixed speed to generate three-phase power at a desired frequency. By using threephase transmission lines great amount of power that is produced at a generating station, transmitted over long distances. In places where three-phase or single-phase power supply can power a machine, there may not be any need to obtain it from a dc source, however there are situations where the conversion of dc supply to a time-varying supply becomes a necessity such as when there is a power outage and no remote power-generating system is available. The conversion to time-varying (ac) voltage may also be necessary where the single or three-phase power is beyond reach such as vehicles and houses in rural areas. Most of the power is generated at 50-Hz or 60-Hz depending on national standards in different countries. However, we may also need a power source at some other frequency, such as 400 Hz as in aircrafts or 20 kHz as in industrial heaters. To obtain the power at a frequency other than the standard frequency is to first convert ac power to dc and then reconvert to ac at the desired frequency.

The power conversion from dc to ac makes use of power electronics switches such as transistors, SCRs, MOSFETs and IGBTs. However SCRs are usually being avoided for inverter application because it requires circuits not only for gating but also for its commutation, which simply means switching the SCR off after it has been conducting for a predetermined time. On the other hand, MOSFETs and IGBTs are good candidates for the switches in dc-to-ac conversion applications. The main drawback of dc-to-ac conversion is that the output voltage is not a sinusoid. Beside the fundamental component, it may include harmonic components. These harmonic components can be filtered out by using high-frequency filters on the output side. To avoid the harmonic content there are many different techniques have been proposed and put into practice. These techniques require sophisticated gating circuits or controls. Sinusoidal pulse-width modulation (SPWM) and space vector modulation (SVPWM) are two of these techniques.

During the past decades, PWM has been studied extensively [1]-[2]. In literature, many different PWM techniques have been developed and with these techniques; wide linear modulation range, less switching loss, less total harmonic distortion (THD) in the spectrum of switching waveform, easy implementation and less computation time have been achieved.

In the past, in most applications carrier-based PWM methods were widely used. The earliest modulation signals for carrier-based PWM are sinusoidal. However, with sinusoidal three-phase PWM, the linear modulation range can not be extended for line-to-line voltages. To overcome this limitation, the non-sinusoidal carrier-based PWM methods, which use zero-sequence signals, has emerged.

SVM, as a non-sinusoidal carrier-based PWM method, uses the space-vector concept to compute the duty cycle of the switches and is one of the most important PWM method for three-phase converters [3]-[4]. With the development of microprocessors, easy digital implementation and wide linear modulation range for output line-to-line voltages are the notable features of space vector modulation.

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Microcontrollers and Digital Signal Processors (DSPs) are increasingly being used in applications previously assigned to the analogue domain. As their functionality continues to increase by integrating more peripherals into a single package, they are becoming a viable option to replace analogue designs. Applications previously controlled using analogue techniques were single-phase inverters, but today there is a shift towards the digital due to the benefits microcontrollers or DSPs can offer [5-6], as shown in Table 1.

TABLE 1
Comparison of analogue and digital control [6].

	Advantages	Disadvantage
Analogue Control	• High bandwidth • High resolution • Ease of design	• Component aging • Temperature drift • Hardwired design
Digital Control	• Programmable solution • Insensitive to environment • Shows precise behavior • Advanced algorithm • Capable of additional functions	• Creates numerical problem • difficult to design

II. THE POWER CIRCUIT

The three-phase power converter shown in Figure 1 is commonly used in industrial applications. The operations of the power converters are based mainly on the switching of power semiconductor devices and as a result, the converters introduce current and voltage harmonics into supply system and on the output of the converters. At the inverter side, there are six power switches, which are connected in anti-parallel with six diodes. At DC side, the capacitor is used to create a voltage at the converter end of the inductors to oppose the voltage at the utility end [3]. The AC voltage produced by the modulation has peaks restricted to less than the DC voltage.

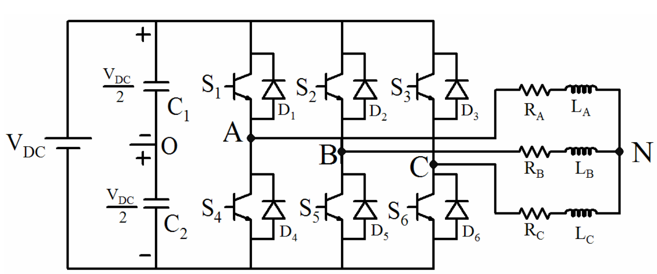

Fig. 1. Three-phase inverter circuit.

Both modulation techniques, SPWM and SVPWM, will be used in this circuit.

A. SPWM Signal Generation

PWM has been studied extensively during the past decades. Many different PWM methods have been developed to achieve the following aims: wide linear modulation range; less switching loss; less total harmonic distortion (THD) in the spectrum of switching waveform; and easy implementation and less computation time.

SPWM modulator is comprised of modulation signals and carrier signal. The operation of PWM can be divided into two modes [7],

1) *Linear Mode*: In the linear mode, the peak of a modulation signal is less than or equal to the peak of the carrier signal. When the carrier frequency is greater than 20 modulation signal frequency, the gain of SPWM G=1.

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2) *Nonlinear Mode*: When the peak of a modulation signal is greater than the peak of the carrier signal, over modulation occurs with G<1. The six-step mode marks the end of the nonlinear mode. The THD of output switched waveforms increases.

Figure 1 shows the circuit of a three-phase PWM inverter. It is usually controlled in a bipolar manner. The PWM of phase A, B, and C is usually jointly controlled by a triangular wave carrier V_c , and the phase differences between modulation signals V_{s1}, V_{s2}, and V_{s3} of the three phases are always 120. The power switch components of phase A, B, and C are controlled in the same way. Suppose the switch is an ideal component, and take phase A as an example. If $V_{s1} > V_c$, a cut-off signal is sent to upper bridge arm power switch *S*1, and a cut-on signal is sent to lower bridge arm power switch *S*4, then the output voltage for phase A, V_{A0}, is equal to *Vd*/2 with respect to the DC current hypothetical neutral point *O*.

If $V_{s1} < V_c$, a cut-on signal is sent to *S*1, and a connection signal is sent to *S*4, then the output voltage for phase A, V_{A0}, is equal to -*Vd*/2. *S*1 and *D*1, as well as *S*4 and *D*4, motion signals or states are always complementary. If a connection signal is sent to *S*1(*S*4), either *S*1(*S*4) or the diode *D*1(*D*4) continuous flow will be connected; this will be determined by the direction and magnitude of the current initially found in electric inductive load, and it is similar to the condition wherein the single-phase, two-level PWM bipolar circuit is controlled. The control methods of phase B and C are the same as that of phase A. Reference, carrier and produced inverter signals are shown in Figure 2.

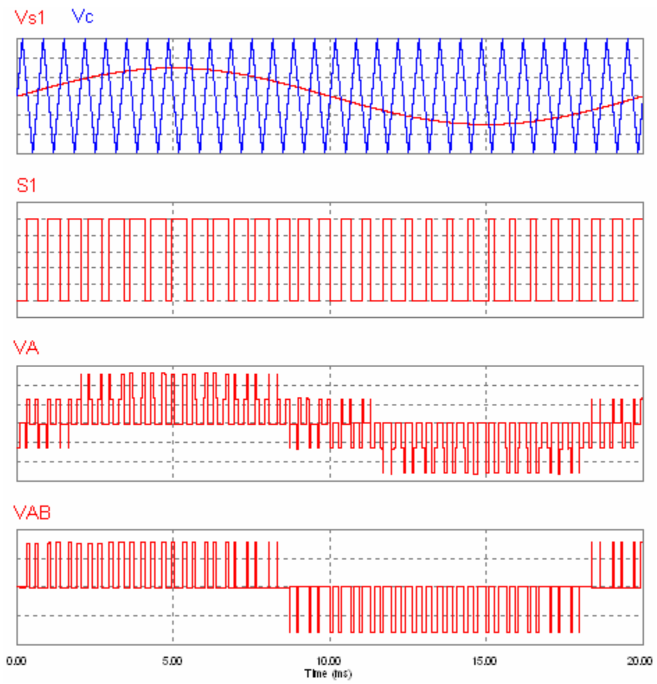

Fig. 2. Inverter reference and carrier voltage, switching signal, inverter outputs.

B. SVPWM Signal Generation

With the development of microprocessors, space-vector modulation has become one of the most important PWM methods for three-phase converters. It uses the space-vector concept to compute the duty cycle of the switches. It is simply the digital implementation of PWM modulators. An aptitude for easy digital implementation and wide linear modulation range for output line-to-line voltages are the notable features of space vector modulation.

The operation of space vector modulated voltage source inverter is revisited. The three phase two level inverter is shown in Fig. 1. Its switching operation is characterized by eiglht switch states i = (SWa, SWb, SWC), i= 0, 1..7. The output voltages of the inverter are controlled by these eight switching states.

Let the inverter voltage vectors, $\overline{v}_0(000),..,\overline{v}_7(111)$ correspond to the eight switching states. These vectors form the voltage vector space as shown in the Fig. 3. The three phase reference voltages can be represented by a space vector $\overline{V}$ with the magnitude v^* and phase angle θ^* [8]. In a sampling interval, the output voltage vector is expressed as

$$\overline{V} = \frac{t_0}{T_s}\overline{v}_0 + \frac{t_1}{T_s}\overline{v}_1 + .. + \frac{t_7}{T_s}\overline{v}_7 \qquad (1)$$

where $t_0, t_1, ..t_7$ are the turn on time of the vectors $v_0, v_1, ..v_7$ respectively and T_s is the sampling time. From the above equation, the vector $\overline{V}$ can be decomposed into $v_0, v_1, ..v_7$ in infinite number of ways. However, in order to reduce the number of switching actions and make full use of active turn on time, the vector is commonly split into two nearest adjacent vectors and zero vectors in an arbitrary sector.

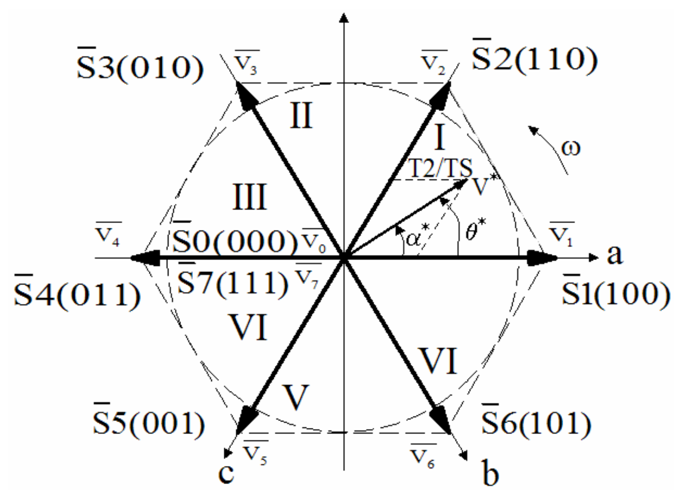

Fig. 3. Voltage vector space

The equations of the effective time of the inverter switching states can be given as [8],

$$\begin{aligned} t_a &= 2KV^* \sin(\pi/3 - \alpha^*) \\ t_b &= 2KV^* \sin(\alpha^*) \\ t_0 &= (T_s/2) - (t_a + t_b) \\ K &= \sqrt{3}T_s / 4V_{DC} \end{aligned} \qquad (2)$$

Where

V^* Magnitude of command or reference voltage vector

t_a Time period of switching vector that lags V*

t_b Time period of switching vector that leads V*

t_0 Time period of zero switching vector

T_s Sampling time $= (1/f_s)$

α^* Angle of V* in a 60° sector

f_s Switching frequency

V_{DC} DC link voltage

The time periods need to be distributed such that symmetrical PWM pulses are produced. To produce such pulses, the instant of switching on for each phase and each sector is calculated. The generalized equation for turn on instant calculation for phase A is given below [8].

$$T_{A\_ON} = (T_s/4) - v^* T_s g_a(\alpha^*) \qquad (3)$$

Where

$$g_a(\alpha)^* = \begin{cases} \dfrac{\sqrt{3}}{4V_{DC}}\left[-\sin(\pi/3-\alpha^{'})-\sin(\alpha^{'})\right], S=1,6 \\ \dfrac{\sqrt{3}}{4V_{DC}}\left[-\sin(\pi/3-\alpha^{'})+\sin(\alpha^{'})\right], S=2 \\ \dfrac{\sqrt{3}}{4V_{DC}}\left[\sin(\pi/3-\alpha^{'})+\sin(\alpha^{'})\right], S=3,4 \\ \dfrac{\sqrt{3}}{4V_{DC}}\left[\sin(\pi/3-\alpha^{'})-\sin(\alpha^{'})\right], S=5 \end{cases} \quad (4)$$

$g_a(\alpha)^*$ is defined as the turn on pulse width function. To maintain the symmetry of switching, the turn off instant T_{A_OFF} is calculated and given below.

$$T_{A\_OFF} = T_s - T_{A\_ON} \quad (5)$$

For phases B and C, the switching instants are same but phase shifted by 120°.

III. IMPLEMENTATION

For the implementation of fore-mentioned techniques Microchip's dsPIC30f4011 microcontroller is used, which has six motor control PWM channels and can run up to 120MHz [9]. The block diagram and picture of the implemented system are shown in Figures 4 and 5, respectively.

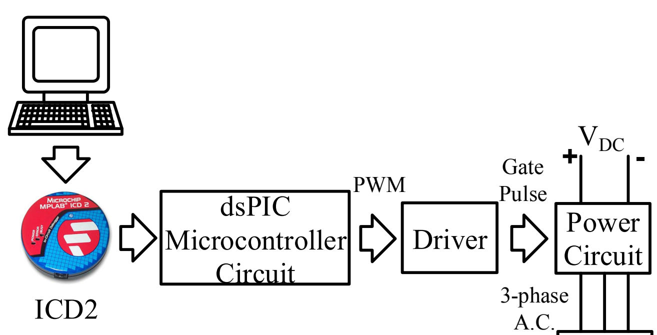

Fig. 4. The block diagram of the implemented system.

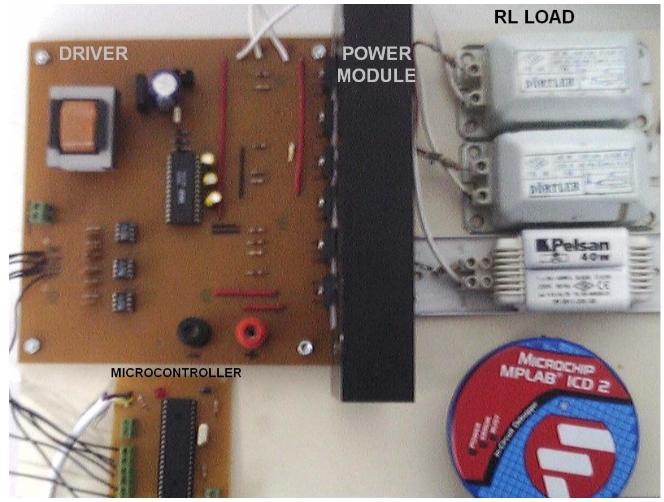

Fig. 5. The picture of the implemented system.

dsPIC microcontroller is programmed by ICD2 for SPWM and SVPWM techniques. For sine and cosine values a look-up table with 64 word size is placed in program memory of microcontroller. For a specified angle, linear interpolation will be used on this table [9].

IV. RESULTS

The results of implemented system for the case of 25VDC supply voltage, 20kHz PWM and SVPWM switching frequency with star connected RL load (R=47ohm, L=1.2mH) are given in Figures 6 and 7.

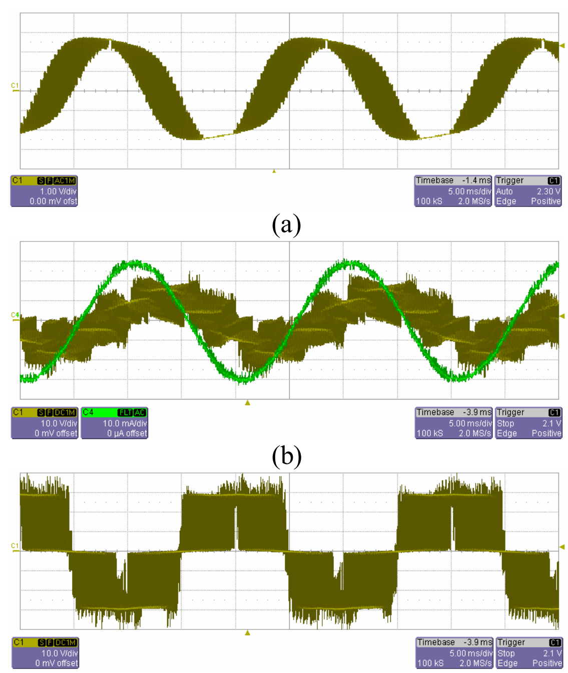

Fig. 6. SPWM signals at 20kHz (a) switching signals of S1, (b) phase voltage and phase current, (c) phase-phase voltage.

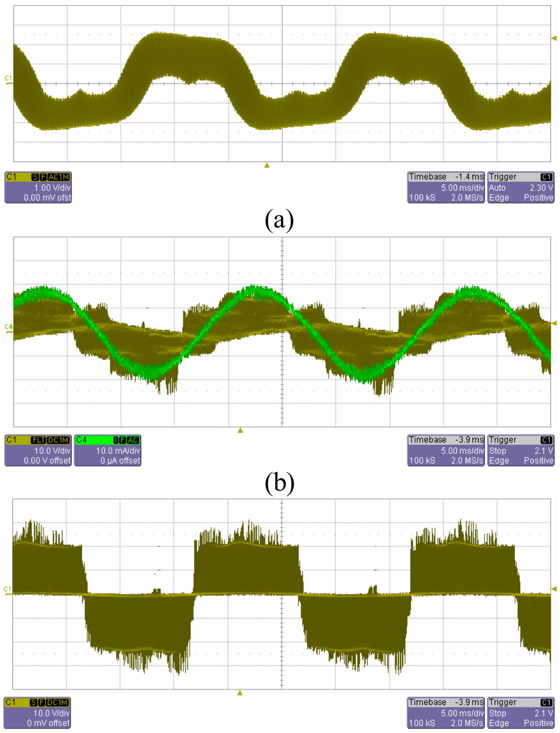

Figure 7. SVPWM signals at 20kHz (a) switching signals of S1, (b) phase voltage and phase current, (c) phase-phase voltage.

V. CONCLUSION

Inverters, which generate AC voltage from DC voltage, are being widely used in motor control driver, UPS and solar system applications. The success of output AC voltage generation highly depends on the switching techniques used in inverters such as SPWM and SVPWM. This paper presented a low-cost high speed microcontroller based system for implementation of these two modulation techniques and the results are taken successfully.

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