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A Simple Sector Independent Space Vector Modulation using DSP Processor

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ABSTRACT

This paper presents the software implementation of a simple sector independent Space Vector Modulation (SVPWM) technique for simple motor drive applications using DSP processor. Conventional Space Vector modulation techniques are quite complex and computation intensive. In both software as well as hardware based implementation it is required to determine first, the magnitude of the voltage vector from the set speed and Volts/Hz profile. Then the corresponding phase angle, quadrant, sector, and the decomposition matrices are calculated in order to determine the switching time segments. In contrast to the conventional method, the algorithm developed here eliminates all such computational burden. The closed loop control scheme with Volts/Hz principle, suitably regulates the switching period and operates with a fixed set of compare register values. The Space Vector Pulse Width Modulation hardware module on the TI TMS320LF2407A is used to produce the Pulse Width Modulated (PWM) pulses with four switching states in one PWM period. A 1 hp, 3 phase induction motor fed from an IGBT based inverter module is tested with the control pulses generated from the DSP processor and the performance is found to be satisfactory.

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1. INTRODUCTION

Pulse Width Modulated (PWM) Inverter fed adjustable speed AC motor drives are now widely used as they offer better efficiencies and performance compared to fixed frequency motor drives. The PWM inverter controls both the frequency and magnitude of the voltage/current applied to a motor for constant flux. Different PWM techniques exist like Sinusoidal PWM, Hysteresis PWM, Trapezoidal PWM and Space Vector PWM. These techniques are applied for the control of different motors e.g., AC Induction, BLDC or Switched Reluctance Motor. Space Vector PWM technique has become more popular as it yields higher value of fundamental voltage from a given DC bus voltage level and lesser harmonics in the output [1]. The implementation of the complex control algorithm is feasible due to advent of high speed DSP. For the proposed work, Texas Instruments TMS320LF2407A DSP controller with useful peripherals has been used.

There are two different techniques of SVPWM waveform generation [2]. One is fully software based that utilizes the regular compare functions of the digital processor. Here, the compare registers are loaded with the calculated time periods for the switches. All the PWM channels are switched twice within one period thus producing six switching states. In hardware implemented topology, the PWM pulses are produced by using the built-in hardware module on the DSP LF2407A. Here, one of the PWM channel is not switched, thereby producing four switching states in one PWM period. Hence, compared to the software topology, the switching losses in this scheme is less.

However, for both the above cases, it is required in the conventional method, to determine first the magnitude of the voltage vector [3, 5] from the set speed and Volts/Hz profile. In next step, phase of the voltage is calculated by integrating speed and subsequently the quadrant, sector and switching time components are determined. SVPWM methods implemented for DSP based Multilevel inverter interface for grid connection of wind turbines [7] eliminates look-up table and calculate time periods independent of the voltage magnitude. However the scheme involves computation of the sector number and the modulation index in each cycle of the program execution. A generalised model is presented [6] both for continuous and discontinuous SVPWM which is realized using the PWM hardware in the Event Manager module on the TMS320F2812 DSP board. In this case, detail flowchart of the algorithm is not available. However, the software needs to determine the reference voltage in the two dimensional d-q plane and the switching time segments are computed from the corresponding sector and the decomposition matrices. In contrast to the existing schemes, the algorithm presented in this paper fully eliminates the burden of computing the reference voltage magnitude, phase angle and the corresponding quadrant, sector and the decomposition matrices. Thus the proposed technique is very simple and easy to implement.

In the proposed control scheme described here, the set frequency range is first selected (Figure 1) based on the motor rating and the corresponding DC bus voltage level.

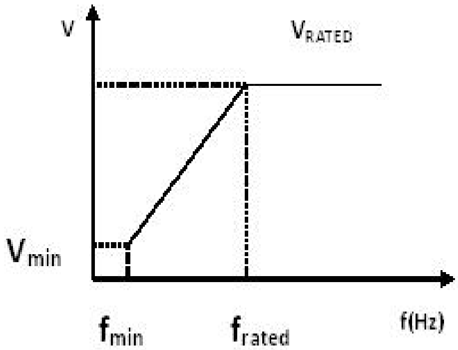

Figure 1. Volts/Hz profile

Operation below base speed has been considered here since above rated speed constant V/Hz cannot be maintained. The lower and upper limits of the PWM period are fixed automatically as these are functions of output frequency. In one cycle of the AC output, six sectors are selected in the desired order based on the direction of rotation of the motor. For each sector, the Space Vector rotates by a fixed angle in one sampling period. The compare register values for that angular position are same for each sector and can be easily referenced from a look-up table. Sector selection is done based on the SVPWM bit selection in the ACTRA register. Any increase in set frequency reduces the PWM period which in turn increases proportionately the magnitude of the output voltage vector. The automatic adjustment of the voltage vector is achieved because of fixed periods of the switching states at different angular positions.

2. CONTROL METHODOLOGY

The objective of the SVPWM method is to approximate the motor voltage vector by suitable combination of switching states corresponding to the basic space vectors [4]. This requires that, for any small time period (normally the sampling period set by the program), the average inverter output voltage must be equal to the average reference voltage U_{out}. The basic Space Vector orientations are shown in Figure 2. In this diagram, the reference voltage U_{out} is in sector 1 between U_0 and U_{60}. The required switching durations T_1 and T_2 corresponding to U_0 and U_{60} are given below.

$$T_1/2 = m*\cos(\alpha+30)/(2*f_{pwm}) \quad (1)$$
$$T_2/2 = m*\sin(\alpha)/ (2*f_{pwm}) \quad (2)$$

$U_0, U_{60}, \ldots U_{300}$ = Basic space voltage vectors
α = Phase angle of output vector (deg)

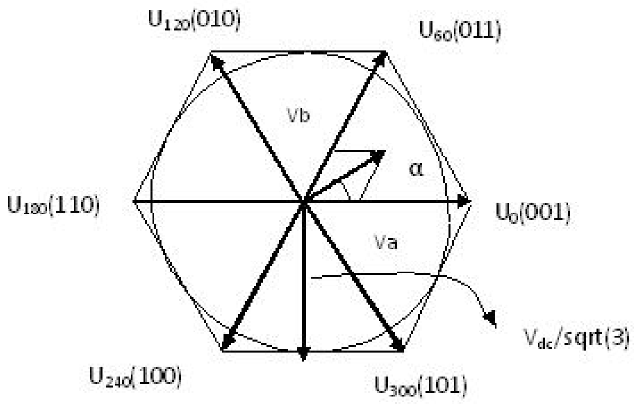

Figure 2. Space Vector Diagram

Modulation index is given by

$$m = U_{out}/(V_{dc}/(sqrt(3))) \quad (3)$$

T_1, T_2 = Switching durations for U_0 and U_{60} vectors
Switching frequency is given by

$$f_{pwm} = 1/T_{pwm} \quad (4)$$

For one sampling period,

$$T_{pwm}*U_{out} = T_1.U_x + T_2.U_{x+/-60} + T_0 \quad (5)$$
$$T_1 + T_2 + T_0 = T_{pwm} \quad (6)$$

where
T_0 = Zero vector
U_{out} = Output reference voltage vector
V_{dc} = DC Link voltage

The step angle increment of the voltage vector in one sampling period (Figure 3) is considered as $\Delta\theta$. Hence, the number of intermediate positions of the rotating Space Vector will be $(60°/\Delta\theta - 1)$. The compare register values T_1, T_2 for each angular position, can be easily calculated from equations (1) and (2) before program execution and then obtained via a look-up table during execution. Only register values for one sector is required to be calculated, as the other sectors are treated exactly in the same way.

The order of execution of the different sectors, however, depends on the direction of rotation of the motor and is accordingly set by the program. One complete cycle time of the AC output thus generated, is therefore $(360°/\Delta\theta)*T_{pwm}$.

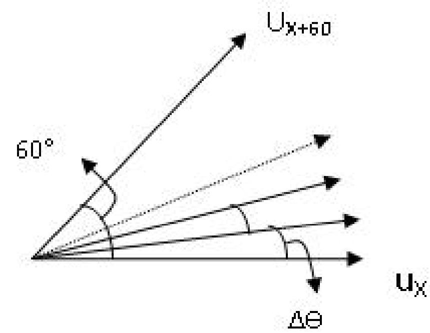

Figure 3. Step angle increment

From equations (1) and (2), it is clear that as the program operates with a fixed set of values for T_1 and T_2, hence, the output voltage changes in the same proportion automatically in response to a speed variation, thereby maintaining fixed Volts/Hz ratio. A block diagram of the closed loop control scheme is shown in Figure 4.

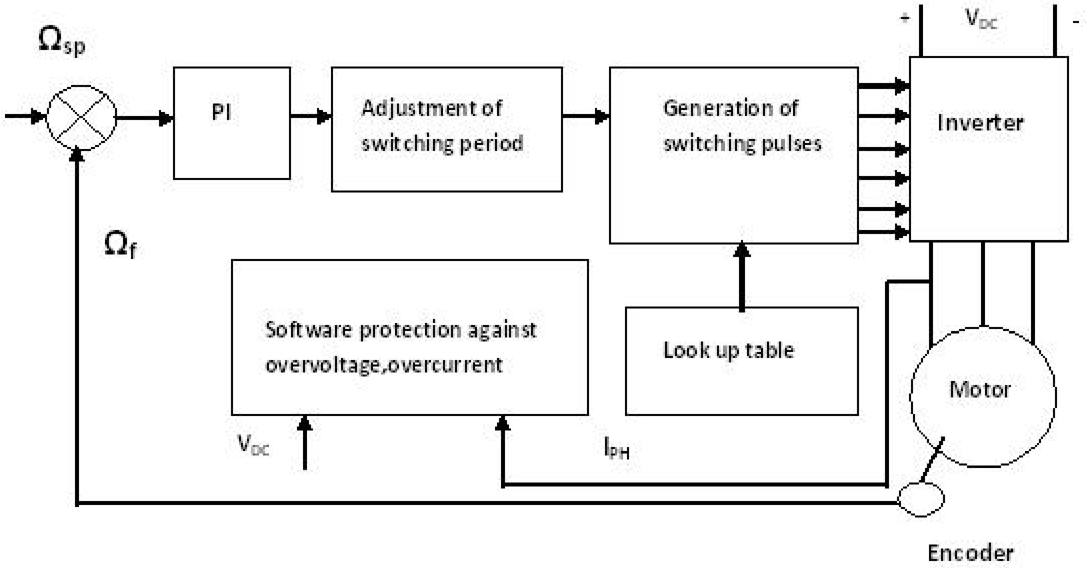

Figure 4. Block diagram of control scheme

3. DSP IMPLEMENTATION

The basic features of the algorithm includes:

a. Configuration of the GP timers in continuous up/down mode for generation of symmetric PWM output.
b. Configuration of the ACTRA register bits for selection of sector and direction of rotation.
c. Timer 1 underflow interrupt and PDPINTA functions are enabled for proper synchronization of the program and to block the pulses in case of power device fault.
d. COMCONA is configured to enable compare operation and Space Vector PWM mode.
e. Software protection is implemented against over-current and over-voltage.
f. In the program, incremental step angle ($\Delta\theta$) is considered as 4°.
g. The switching scheme (Figure 5) produces symmetric waveforms. The hardware topology utilizes only two PWM channels which toggles twice in a PWM period. At the beginning, the outputs are set as per the bit pattern in ACTRA register. On the first compare match, the PWM output toggles from U_x to U_{x+60} or U_{x-60} depending on the direction of rotation. After second compare match, the output toggles to (000) or (111), whichever differs from the second pattern by one. During down counting, the same output states are produced but in the reverse order. Software flowchart of the algorithm implemented is shown in Figure 6.

4. EXPERIMENTAL RESULTS

The schematic of the hardware setup utilized, is shown in Figure 7. The motor was operated upto its rated speed with and without load and the performance was found satisfactory. The upper limit of switching frequency was taken as 5.88kHz and the DC link voltage was set at 300V. Motor terminal voltage under no-load operation at 500rpm is shown scaled down in Figure 8. The same output voltage waveform, after filtering through a low pass filter (cutoff at 50Hz), is shown in Figure 9. Phase current waveform (scaled down) under above operating condition is also shown in Figure 10.

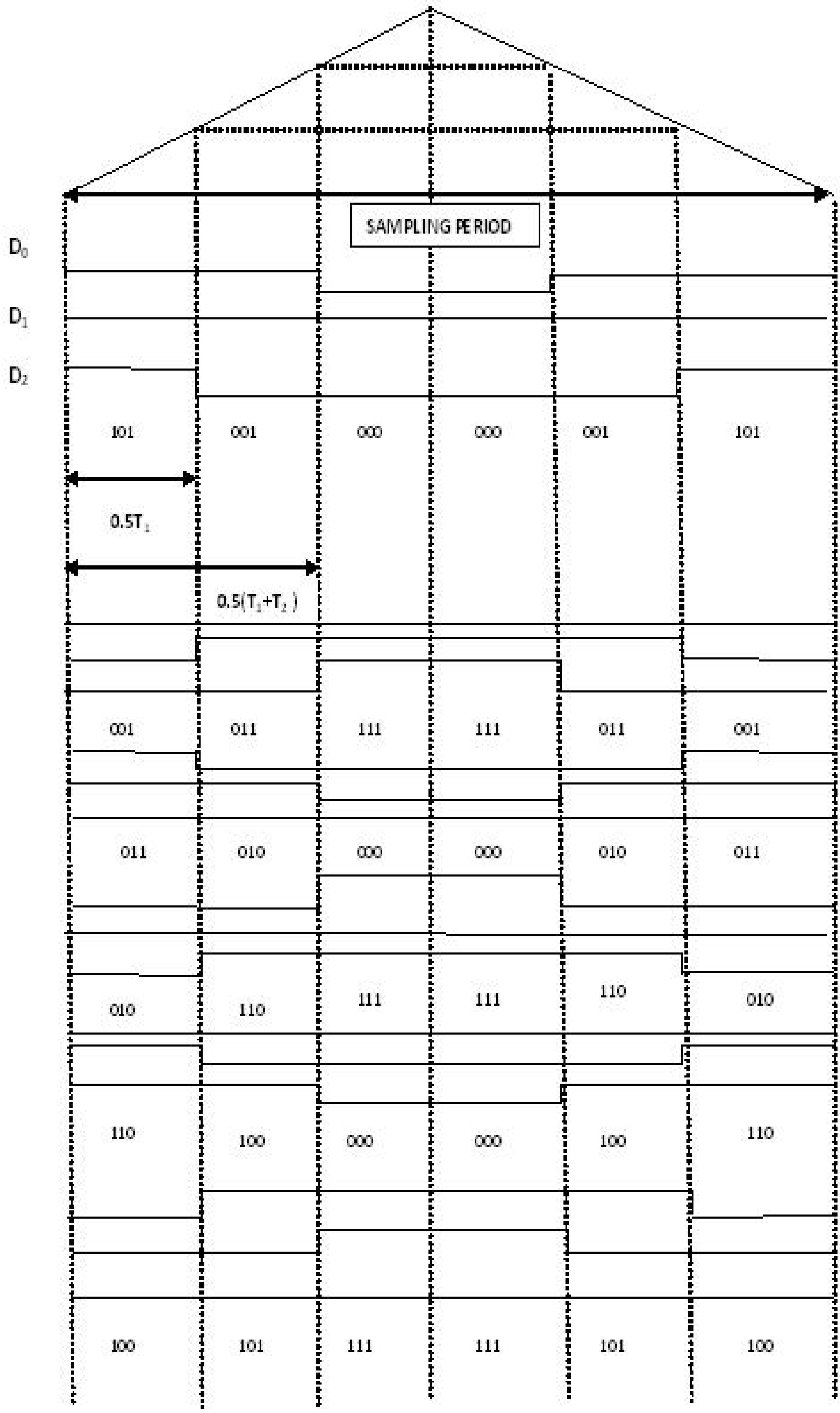

Figure 5. Switching pattern

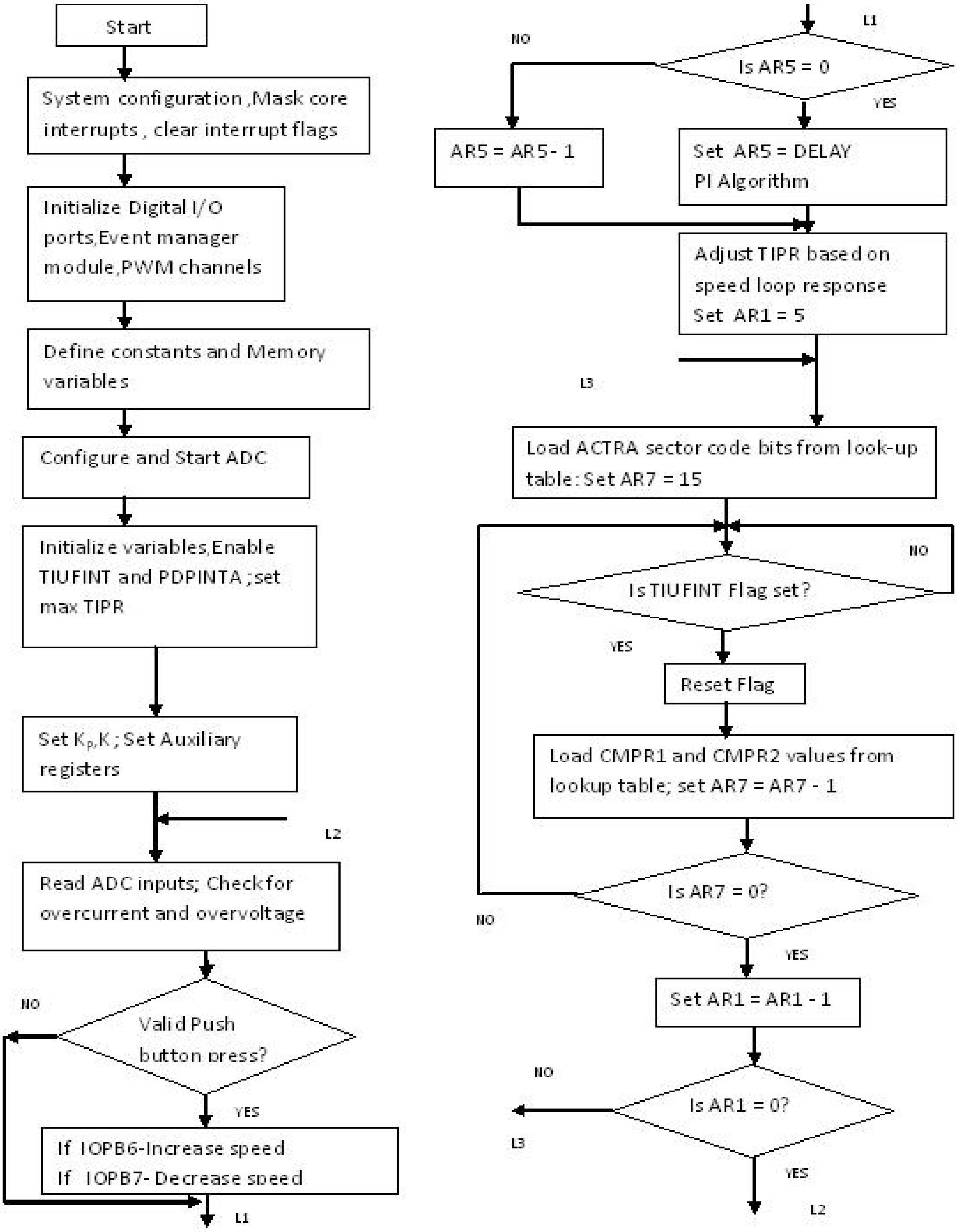

Figure 6. Software Flow Chart

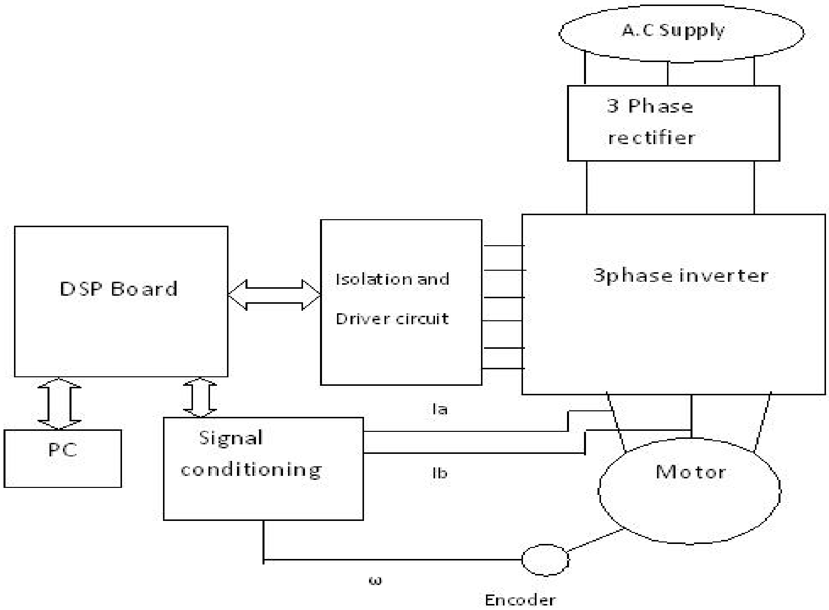

Figure 7. Experimental Setup

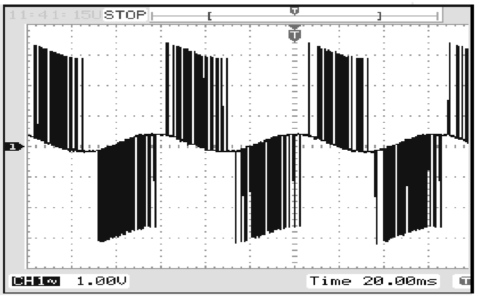

Figure 8. Unfiltered output voltage

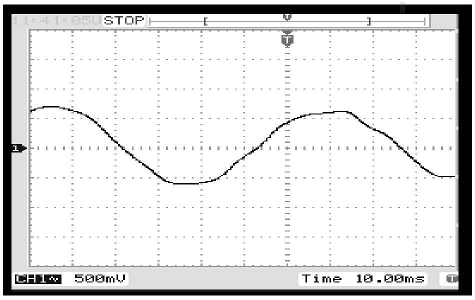

Figure 9. Filtered output voltage

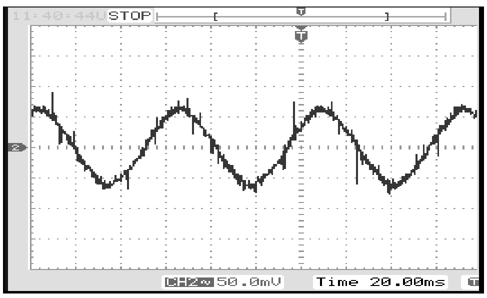

Figure 10. Phase current

5. CONCLUSION

A simple technique for implementing space vector modulation for simple motor control applications, without the conventional computational burden is presented in this paper. This technique can be utilized for open as well as closed loop operation of an induction motor, with variable speed and loading conditions. Due to high speed computational ability of the DSP processor, automatic adjustment of the step angle is also feasible, to improve drive performance under variable operating conditions. Finally, this idea can be extended in other areas, where space vector modulation is applied.

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Susovan Mukhopadhyay received his BE degree (with honours) in Electrical Engineering from Jadavpur University, Kolkata, India in 1985. He worked in the Industry for more than 16 years and has experience in various process control plants and Engineering Workshops. Presently, he is teaching at the Electrical Engineering Department of Future Institute of Engineering and Management, Kolkata and is also pursuing his integrated PhD at the Dept of Electrical Engineering, Jadavpur University. His field of interest includes Power Electronics and Drives. He is a life member of The Institution of Engineers(India).

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