

Implementation of Different Methods of Space Vector Pulse Width Modulation (PWM) - A Survey

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Abstract

The inverter efficiency can be computed with its switching frequency. This switching frequency can be increased by using the method space vector PWM which is an optimum pulse width modulation technique. In this paper a survey of implementing space vector pulse width modulation with different processors is made. The SVPWM is implemented using DSP, Microcontroller ATmega16 and Artificial neural network. Further the comparison between the three processors is made and is concluded that the response time of DSP is very fast, high switching frequency, reduced harmonics and modulation index can be varied from 0.3 to 0.9.

Keywords: SPWM, Space Vector PWM, DSP 320F2812, Microcontroller ATmega 16, Artificial Neural Network

I. INTRODUCTION

In the power system the major issue is the power quality. Due to complexity of the power system the power quality gets affected due to switching circuits. Thus it is required to optimize control technique to achieve quality output voltage of an inverter with required frequency and amplitude. The switching of power transistor in the control technique will decide the efficiency of the inverter. To reduce the switching losses Space Vector Pulse Width Modulation (SVPWM) technique is used, which increases the use of DC bus voltage. The Switching pulses are generated with the help of Digital Signal Processors (DSP) which is independent of magnitude of voltages. DSP processor consists of compare units and event manager which helps in implementing SVPWM algorithm. This methodology extends the frequency and voltage to a wide range. Microcontroller ATmega 16 which is the local content. The power converter can be designed to supply DC power to its own load and also it acts as an active filter to supply it to AC line compensating current which is equal to harmonic current produced by non-linear load. In power electronics system application of Artificial Neural Network (ANN) is booming. A feed forward ANN implements non-linear input output mapping. SVPWM is a feed forward carrier based PWM technique is a non-linear mapping phenomenon where at the input command phase voltages are sampled and at the output pulse width patterns are established. Therefore a back propagation type ANN has high computational capability to implement SVPWM algorithm. Even in the offline the ANN is trained with the data generated by the calculation of SVPWM algorithm. ANN has improved precision by interpolation compared to the other standard look-up table methods. In this paper DSP, Microcontroller and ANN are the three different methods which is used for implementing SVPWM technique. Among the three methods DSP is an excellent choice for implementing SVPWM in the real time applications of power systems.

II. SPACE VECTOR PWM METHOD

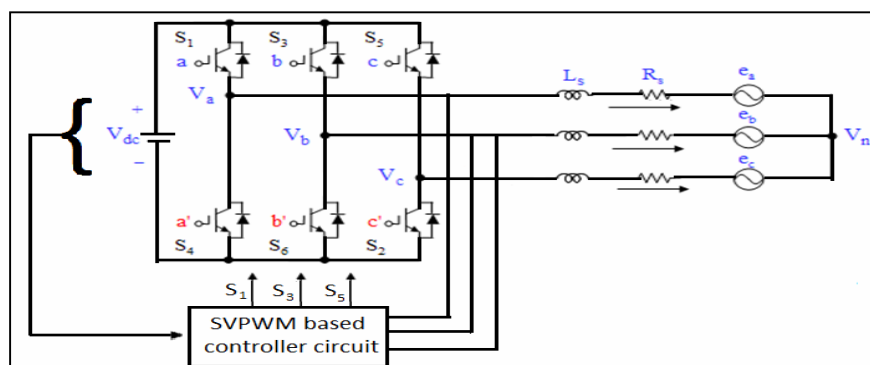


Fig. 1: Structure of three phase voltage source inverter

SVPWM consists of six power switches which is of three phase Voltage Source Inverter (VSI). Compared to sinusoidal modulation method SVPWM is more efficient to utilize the DC supply voltage with minimum harmonic distortion as shown in Fig. 1 [1].

Modeling of two level voltage source inverter in terms of switching functions is given by equation (1) [1]

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{V_{dc}}{3} \begin{bmatrix} 2 & -1 & 2 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} S_1 \\ S_3 \\ S_5 \end{bmatrix} \quad (1)$$

The two voltages V_α and V_β can be given as

$$V_\alpha = 3/2 \times V_{an} \quad (2)$$

$$V_\beta = \sqrt{3}/2 \times [V_{bn} - V_{cn}] \quad (3)$$

The reference voltage is given by,

$$V_s = V_\alpha + j \times V_\beta \quad (4)$$

$$\alpha = \tan^{-1} \left(\frac{V_\beta}{V_\alpha} \right) \quad (5)$$

At any instant of time there are eight possible position of the voltage space phasor as shown in Fig .2 [1]

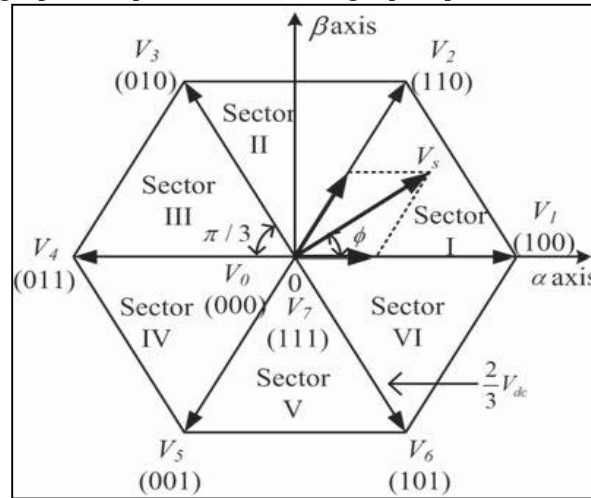


Fig. 2: Voltage Space Vectors

The inverter which is considered as a single unit in SVPWM can be driven to eight unique states. By switching the state of an inverter modulation is accomplished. SVPWM makes the sinusoidal voltage a constant amplitude vector which rotates at a constant frequency. The eight switching patterns V_0 to V_7 helps PWM technique to approximate the reference voltage V_{ref} . The switching patterns V_1 to V_6 divide the plane into six sectors. V_{ref} is obtained by two zero vectors and adjacent non-zero vectors.

A. SVPWM using DSP

Three phase voltages are connected as input to the three ADC pins. The three digital voltages are stored in the ADC result register with the help of voltages V_{an} , V_{bn} , and V_{cn} , V_α and V_β are obtained which is a two phase voltage as shown in equation (1) and (2) and angle α is calculated using the equation (5). Sector number is determined in which reference vector located, by calculating the variables P_0 , P_1 and P_2 which is shown in the following equations [1]

$$P_0 = V_\beta \quad (6)$$

$$P_1 = \sin 60 \times V_\alpha - \sin 30 \times V_\beta \quad (7)$$

$$P_2 = -\sin 60 \times V_\alpha - \sin 30 \times V_\beta \quad (8)$$

Variable B is defined and computed using the variables P_0 , P_1 and P_2 for sector identification. Fig. 3 depicts the flow chart for sector identification and table 1 represents the corresponding values of B of sector number.

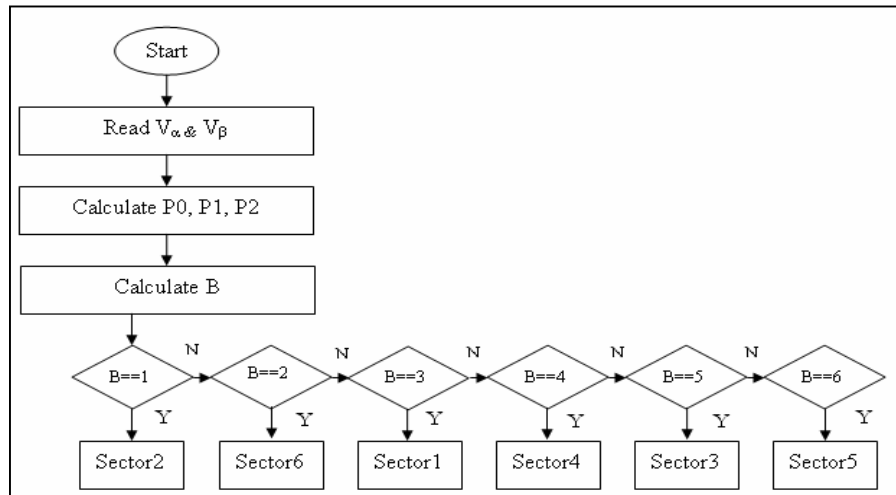


Fig. 3: Flow chart for sector identification

Table – 1

Identification of sector number						
B	1	2	3	4	5	6
SECTOR	2	6	1	4	3	5

$$B = 4 \text{ sign}(P_2) + 2 \text{ sign}(P_1) + \text{sign}(P_0) \quad (9)$$

Where Sign (p) is a function given by,

Sign (p) = 0, if $p < 0$;

Sign (p) = 1, if $p > 0$;

By calculating three sub intervals T_0 , T_1 and T_2 from the sampling period T_s , the switching pattern is obtained.

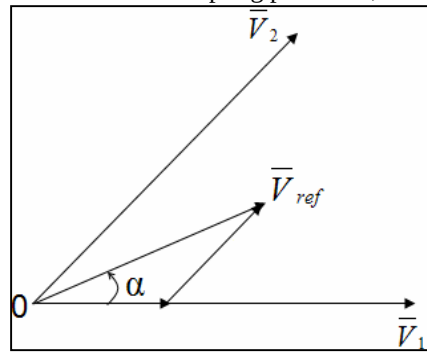


Fig. 4: Voltage space phasors combination

Figure 4 shows the combination of voltage space phasors. In the first sector reference voltage is in between V_1 and V_2 . By switching the vectors V_1 and V_2 for T_1 and T_2 time seconds, the space phasor voltage is obtained. The vectors V_0 and V_8 are switched for $T_0/2$ seconds. The time period of three sub intervals are calculated by [1]

$$T_1 = T_s \times a \times \sin(60 - \alpha) / \sin 60 \quad (10)$$

$$T_2 = T_s \times a \times \sin \alpha / \sin 60 \quad (11)$$

$$T_0 = T_s - T_1 - T_2 \quad (12)$$

The above equations that are equation (10), (11) and (12) do not have term that relates the magnitude of the voltage. Hence with the above three equations we conclude that time periods are independent of voltage. The modulation index represented by “a” which represents the variations in the voltage magnitudes is in the range of 0.3 to 0.9. The duty cycles T_a , T_b and T_c will help in generating SVPWM pulses. The equations for these duty cycles are given below [1].

$$T_a = T_0/4 \quad (13)$$

$$T_b = T_a + T_1/2 \quad (14)$$

$$T_c = T_b + T_2/2 \quad (15)$$

As soon as the sector is determined, the duty cycle for the pulses compares the registers that are CMPR1, CMPR2 and CMPR3. When these CMPR registers are compared to the general purpose timer then the corresponding PWM signal is generated at six PWM pins of the event manager. When it comes to conventional approaches T_1 , T_2 , and T_0 are generated with the negative values. Therefore the duty cycles will also be negative, which definitely cause distortion in the PWM waveforms. Figure 5 shows the block diagram of experimental setup. [1]

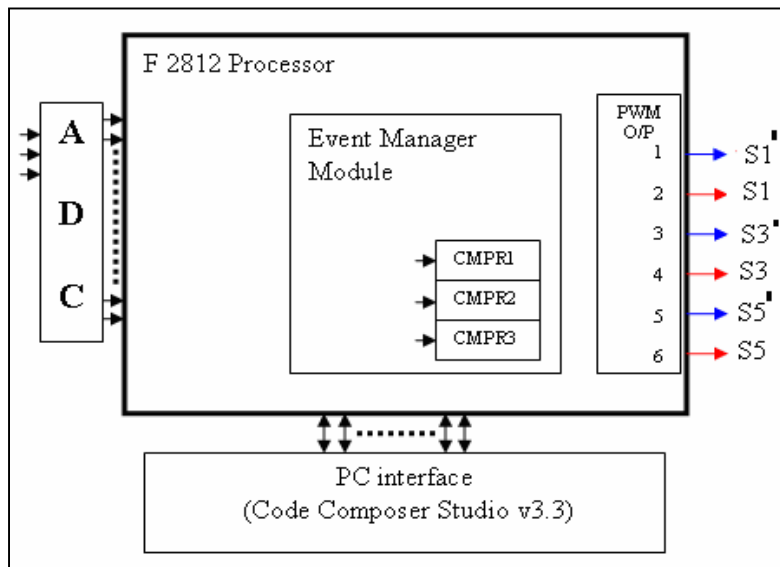


Fig. 5: Block diagram of experimental setup

The module TMS32F2812 has two event manager modules. Both modules contain 6 PWM output pins. The module A has pin numbers from 9 to 14 whereas B module has pin numbers from 30 to 35. In the given experimental setup module A is used for generating S_1 , S_3 and S_5 switching pulses at the respective pins 10, 12 and 14. The remaining three pins which are not connected will show the inverted output of the previous pins. Hence S_2 , S_4 and S_6 is obtained. Figure 6 shows the flow chart for SVPWM implementation using TMS320F2812.

The three phase voltages are obtained from ADC pins. The space phasor voltage is obtained from the equations (2), (3) and (4). The sector number and duty cycle values are determined. The values of duty cycles are loaded into the compare registers. The general purpose timer will continuously compare it with compare registers to produce PWM pulses.

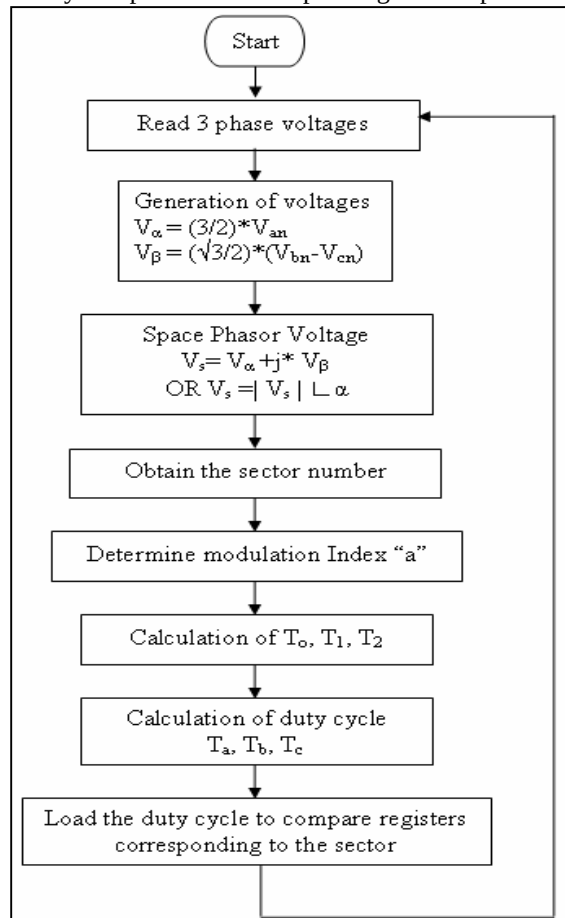


Fig. 6: Flow chart for SVPWM implementation

B. Space vector PWM using mc ATmega16 Hardware Implementation

There are several steps involved in implementing the hardware which is shown in the block diagram. In figure (7) the 5 volt DC supply is given to the microcontroller and the timer circuit. The output obtained at the microcontroller is fed to the interfacing circuit. This interfacing unit connects the microcontroller with opto isolator circuit. This opto isolator circuit isolates the high voltage of the inverter circuit from the components which work on the low voltage. For example TTL. The output of the opto isolator and the next interfacing unit is given to the gate of each switching devices. Here the opto isolator is excited by the independent power supply for isolation. The microcontroller supply the signals to a controller which controls an inductive load such as motor but the inductive load produces back emf spikes which can easily destroy a microcontroller. These back spikes are of very short duration which may or may not have the enough energy to destroy a microcontroller. Therefore the opto coupler will help in preventing from such high voltage spikes [5].

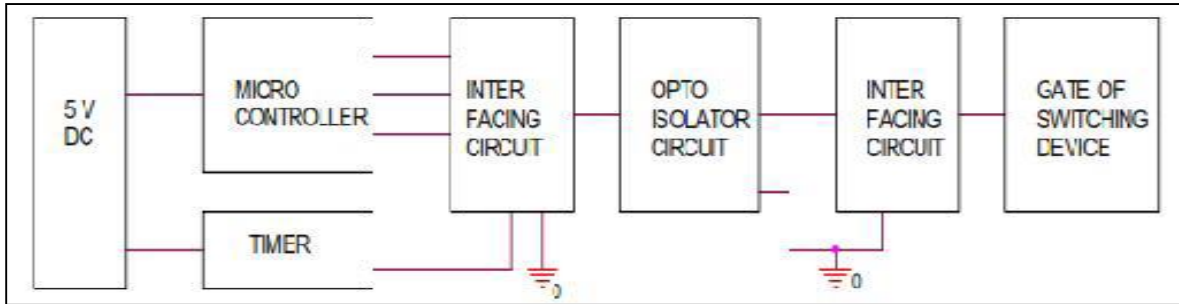


Fig. 7: Block diagram representation of gating signal generation

C. SVPWM Technique using Artificial Neural Network (ANN)

The first step involved for generating SVPWM using ANN is to generate the training data. These training data is obtained by using the below equations that is equation (16), (17) and (18). The angle subnet is trained with an angle of 2° interval that is from 0 to 360° [3]

$$v_s^* = \frac{2}{3} (v_a + a v_b + a^2 v_c) \quad (16)$$

Where $a = \exp(j2\pi/3)$

$$v_A = v_a + v_{nN}$$

$$v_B = v_b + v_{nN} \quad (17)$$

$$v_C = v_c + v_{nN}$$

$$v_{nN} = (1/3) (v_A + v_B + v_C) \quad (18)$$

The phase-A turn ON time can be expressed as

$$T_{A-ON} = T_s / 4 + f(V^*) g_a(\alpha^*)$$

$$g_a(\alpha^*) = \begin{cases} K \left[-\sin\left(\frac{\pi}{3} - \alpha^*\right) - \sin(\alpha^*) \right], s = 1, 6 \\ K \left[-\sin\left(\frac{\pi}{3} - \alpha^*\right) + \sin(\alpha^*) \right], s = 2 \\ K \left[-\sin\left(\frac{\pi}{3} - \alpha^*\right) + \sin(\alpha^*) \right], s = 3, 4 \\ K \left[-\sin\left(\frac{\pi}{3} - \alpha^*\right) - \sin(\alpha^*) \right], s = 5 \end{cases}$$

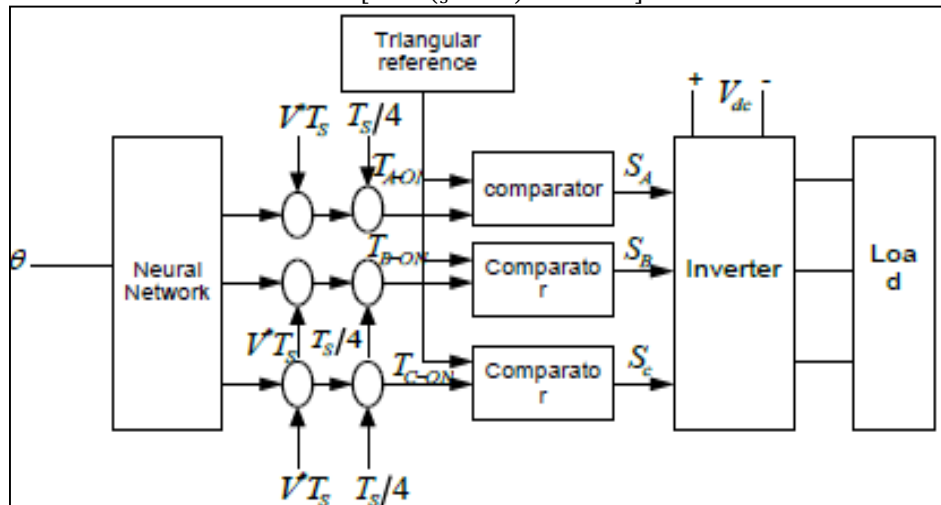


Fig. 8: Schematic of an ANN based SVPWM inverter

The above figure 8 shows the schematic of SVPWM inverter using ANN method. The input signal to the neural network is given at an angle θ . The model uses a multilayer function only in the first and second layer. The neural network uses twenty five neurons in the hidden layer, uses one neuron at the input and three neurons at the output. The digital words to turn on time are generated by multiplying the output of neural networks with V^*T_s and then adding $T_s/4$ as shown in the above figure 8. The comparator compares the PWM signals and the triangular reference having time period T_s and amplitude $T_s/4$. The output of comparator is then given to the inverter which is a PWM signal.

III. RESULTS AND DISCUSSIONS

A. Using DSPTMS320F2812

The generated waveforms of SVPWM are symmetric with respect to each PWM period. This symmetric waveform will eliminate even harmonics and reduces the odd harmonics. The waveform of symmetric SVPWM is shown in figure 9.



Fig. 9: Symmetric waveform of SVPWM

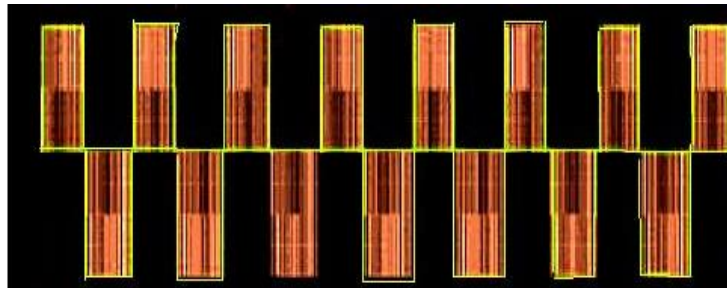


Fig. 10: Output voltage of two level inverter



Fig. 11: Line current waveforms

Figure 10 shows the output voltage waveform of two level inverter. Waveforms generated as shown in figure 11 is obtained by placing different values of three phase voltages with different frequencies. The generated PWM signals are given to an inverter. This inverter will display the output waveforms.

B. Using microcontroller ATmega16

With microcontroller ATmega 16 the signals formed are sinusoidal. PWM signal_AB at different range of increase in frequencies get decrements as shown in figure (12), (13) and (14) at $f_s=25\text{Hz}$, $f_s=50\text{Hz}$, $f_s=100\text{Hz}$ respectively.

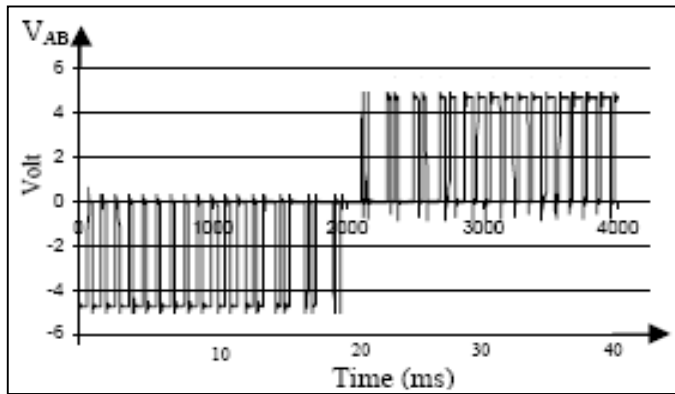


Fig. 12: PWM Signal at $f_s=25$ Hz

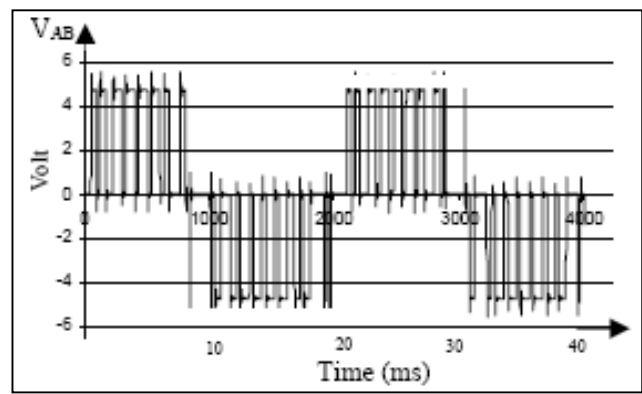


Fig. 13: PWM Signal at $f_s=50$ Hz

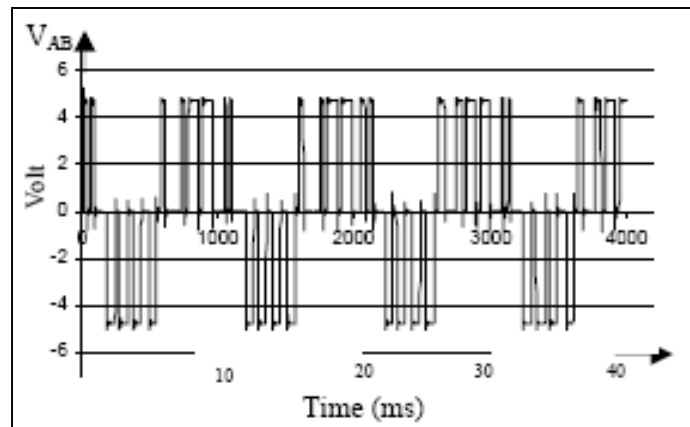


Fig. 14: PWM Signal at $f_s = 100$ Hz

As shown in the above figure (12), (13), and (14) at frequency $f_s = 25$ Hz the time required for one period is $T_s = 40$ ms. At frequency 50Hz, the time period is $T_s = 20$ ms for one period and for the frequency $f_s = 100$ Hz, the time period for one cycle is $T_s = 10$ ms. With this the sinusoidal frequency is boosted and therefore the switching time also increases. The output voltage of the inverter should not contain harmonic because it results in additional heating at the motor, that may damage the motor. Therefore spectrum of FFT should know the THD (Total Harmonic Distortion). THD represents the energy level of the harmonic content in the waveform.

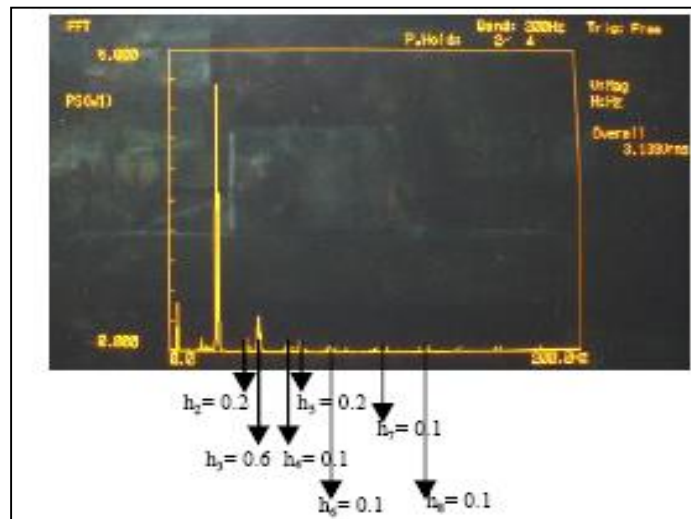


Fig. 15: Spectrum of FFT at $f_s= 25$ Hz

The Total Harmonic Distortion THD, is given by equation (19)

$$\text{THD [\%]} = 100 * \sqrt{\sum_{h=2}^{\infty} 1 * \left[\frac{V_h}{V_1} \right]^2} \% \quad (19)$$

Where, V_h : Amplitude of harmonic voltage

H: order of harmonic

V_1 : Amplitude of fundamental voltage

At fundamental frequency $f_s=25\text{Hz}$, THD is

$$\text{THD [\%]} = 100 * \sqrt{\left[\frac{0.2}{5}\right]^2 + \left[\frac{0.6}{5}\right]^2 + \left[\frac{0.1}{5}\right]^2 + \left[\frac{0.2}{5}\right]^2 + \left[\frac{0.1}{5}\right]^2 + \left[\frac{0.1}{5}\right]^2 + \left[\frac{0.1}{5}\right]^2} \% = 13.85\%$$

At fundamental frequency $f_s=50\text{Hz}$, THD = 24.89%

At fundamental frequency $f_s=100\text{Hz}$, THD = 17.43%

C. Using Artificial Neural Network

Figure (16) and Figure (17) shows the characteristics of the motor. This waveform is generated with the help of simulink model. As it is seen in figure (16) the speed of the motor increases rapidly up to 1700 rpm at 0.1 sec. It reaches till 1500 rpm in 0.3 seconds and it continues. As shown in figure (17) when the torque has changed from 0 N-m to 10 N-m at 0.75 seconds it attains slightly lower speed than compared to the reference speed. This lower value of speed is due to increase in torque and also the system is working in open loop. Figure (17) shows torque characteristics for load T_1 and developed torque T_e . in the initial the applied torque is zero and developed torque is high till 0.125s. After some time it attains a value of zero at 0.25s. At 0.75s when the load torque has flipped from 10 N-m the developed torque also flip to 10 N-m as shown in the figure (17). In figure (18) and (19) it represents the stator and rotor current waveform in dynamic conditions. These are sinusoidal in nature. These currents have high initial values at the starting due to starting transients. The induced emf takes time to develop itself to the given value. When all the transients are over the current settled down as shown in the figure (18) and (19) at 0.2s. Again the stator current and rotor current gets higher value when the load torque changes to 10 N-m at 0.75s.

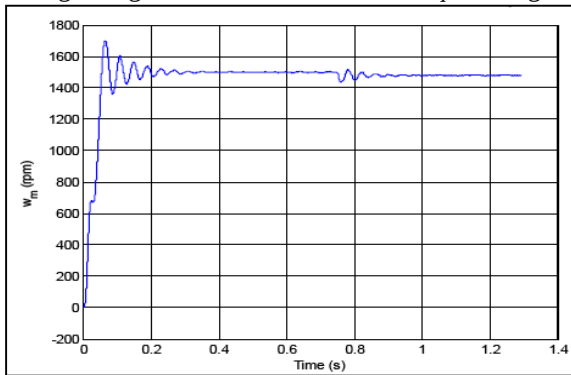


Fig. 16: Speed characteristics

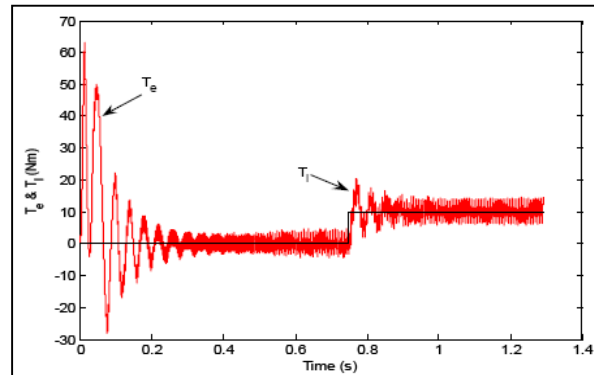


Fig. 17: Torque characteristics

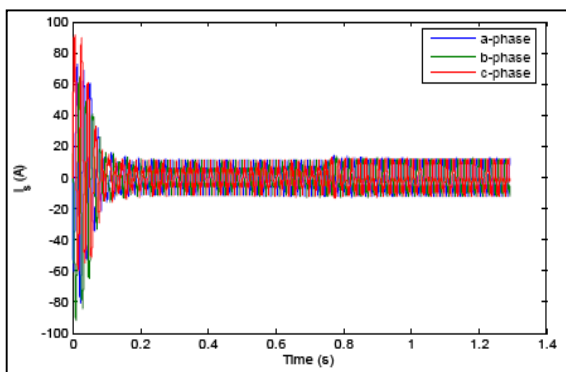


Fig. 18: Stator current waveform

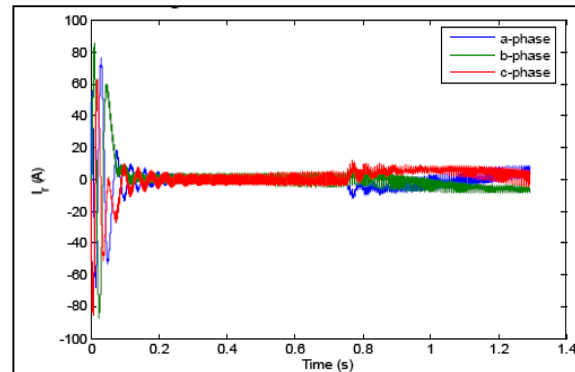


Fig. 19: Rotor current waveform

IV. COMPARISON OF DIFFERENT PROCESSORS OF IMPLEMENTING SVPWM

Table – 2
Comparison of different processors used for SVPWM

Sl. No	Parameters	DSP	μC	ANN
1.	Switching frequency	150MHz	15.625kHz	50kHz
2.	Response time	20 μs	23 μs	
3.	Harmonics	Low	High	Low
4.	Processing	Fast	Moderate	Fast
5.	Signal to Noise ratio	High (62dB)	Moderate	
6.	Noise	Low	High	Low
7.	Fairness	High	Moderate	Low

8.	Number of iterations	Not required	Not required	Required
9.	Implementation	Easy	Complex	Easy
10.	Throughput	150MIPS	16MIPS	
11.	Switching losses	Less	More	
12.	Modulation index	0.3 – 0.9	0 – 0.866	
13.	Cost	Low	Low	More

V. CONCLUSION

This paper presents the survey of three different processors for implementing space vector pulse width modulation technique. The results of DSP, Microcontroller and Artificial Neural Network are analyzed. The comparison of these three processors has been done. Based on this survey it has been concluded that the DSP is an excellent choice for real time applications in the power system. It has wide range of switching frequency, voltage magnitude; modulation index varies from 0.3 to 0.9. The response time of the DSP is very fast which eliminates even harmonics and is economical.

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