FUZZY LOGIC BASED SPACE VECTOR PULSE WIDTH MODULATION FOR TWO LEVEL INVERTER CONTROL

[1]Anugu Saritha, [2]T. Abhiram, [3]Dr. K. Sumanth

[1]PG Scholar, Department of EEE, SNIST, Hyderabad, Telangana, India
[2]Assistant Professor, Department of EEE, SNIST, Hyderabad, Telangana, India
[3]Professor and HOD, Department of EEE, SNIST, Hyderabad, Telangana, India

***Abstract*—AC loads requires variable voltage and variable frequency. These requirements are fulfill by a voltage source inverter. A variable output voltage can be achieved by varying the input dc voltage and keeping the gain of the inverter constant. On the other hand, if the dc input voltage is fixed and it is not controllable, a variable output voltage can be achieved by varying the gain of the inverter, which is normally accomplished by pulse-width-modulation control within the inverter. There are number of pulse width modulation techniques but only Space vector technique is a good choice among all techniques to control voltage source inverter. Space vector pulse width modulation (SVPWM) is an advanced and very popular method with several advantages such as its effective DC bus utilization, less harmonic generation in output voltage, less switching losses, wide linear modulation range etc. Owing to these advantages, it is being mostly used to control an inverter. In this paper, constant dc voltage source inverter has been taken and also SVPWM has been implemented for two-level VSI using MATLAB /SIMULINK.**

***Key words*—Pulse width modulation (PWM), Space vector pulse width modulation (SVPWM), Total harmonic distortion (THD), Voltage source inverter (VSI).**

I. INTRODUCTION

AC drives require high power variable voltage variable frequency supply. Because of lots of advances in solid state power devices, variable speed AC Induction motors powered by switching power converters are becoming more and more popular. To regulate the frequency and voltage of a motor, switching power converters is generally used because it provides higher efficiency and performance with less noise The Pulse width modulation techniques have been developed in last few decades to fulfill the requirements of ac drives.

The main problem for power electronic engineers is to reduce the distortion that will be produced in output voltage of an inverter. It is desired to control frequency and voltage level of an inverter in many power electronic fields. This aim can be achieved by selecting proper switching pattern for an inverter. Inverter may be divided into two categories: CSI (current source inverter) and VSI (voltage source inverter). When impedance of the load is higher than the harmonic current, VSI will be used there while CSI is used when impedance of the load will be less than harmonic current. To fulfill the requirement of an inverter, PWM technique has been developed. For different- different inverter, different-different kind of PWM techniques have been developed that means CSI and VSI have their own PWM technique to control output voltage [1].

In the last few years, Many PWM techniques has been proposed to achieve the following goals; less total harmonic distortion, less switching losses, wide linear modulation range, less computational time, easy to implement and precise control too. Moreover, PWM techniques are used to control the output voltage of an inverter. The main advantage of PWM is that power loss in the switching devices is very low. PWM also works well with digital controls because of its on/off nature and can easily set the needed duty cycle. There are number of modulation techniques such as sinusoidal pulse width modulation (SPWM), Trapezoidal modulation, Staircase modulation, Stepped modulation, Selective harmonic elimination, Space vector control, Third harmonic injected, Space vector pulse width modulation (SVPWM) etc. But the Space vector technique is best among all technique because it has several advantages such as effective dc bus utilization, less harmonic distortion in output voltage/current, simple digital calculation for time. Fuzzy logic rules are framed using input and output Membership Functions(MF) for the three duty ratios d0,d1 and d2 are found in tables 1,2 and 3 respectively. After framing the rules , the SVM is replaced by the Fuzzy Logic Control(FLC) toolbox. Then the fuzzy file will call from the FLC toolbox in place of the svm to run the simulation model file.

II. SPACE VECTOR PULSE WIDTH MODULATION (SVPWM)

The goal of any modulation technique is to provide output voltage / current with less harmonic distortion. Space vector pulse width modulation technique will help to attain this desirable goal. In Space vector PWM, magnitude and frequency of reference voltage vector are used to control the magnitude and frequency of fundamental voltage. Owing to lots of advantages, Space vector pulse width modulation technique has become most popular choice to control the output voltage of three phase voltage source inverter. The SVPWM technique can be implemented in following way-

- Space vector modulation based on sector selection
- Space vector modulation based on reduced switching
- Carrier based space vector modulation
- Reduced switching carrier based space vector modulation

III. SVPWM FOR TWO LEVEL VSI

Fig. 1 demonstrates the three phase three legs two-level voltage source inverter. It has six power switches (S1 to S6) that are used to shape the output voltage. Switches S1, S3, S5 are upper switches and switches S2, S4, S6 are lower switches. In each leg, there must be two switches and these two switches are compliment to each other. If S1 and S4 are the switches in first leg of three phase VSI and when S1 is ON i.e. S1=1, S4 should be OFF i.e. S4=0 and vice versa. Therefore, Controlling of switches are in a way so that two switches should not be turned ON at a same time in a same leg otherwise leg may be short circuited and hence there will be zero output voltage at load side.

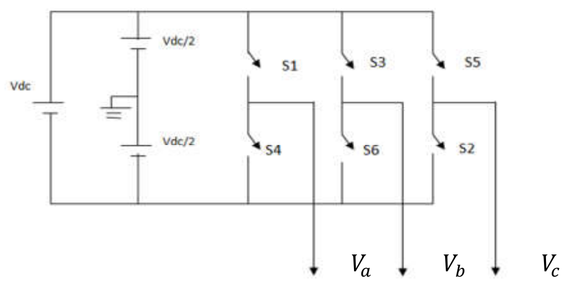

Fig.1. Two-level VSI

The space vector concept is being derived from the rotating field of induction motor and it is used to modulate the inverter output voltage. In this modulation the three phase quantities can be transformed into their equivalent two phase quantity either in synchronously rotating frame or stationary frame. While considering the stationary reference frame let the three phase sinusoidal voltage component be [3, 4],

$$V_a = V_m\, sinwt \tag{1}$$

$$V_b = V_m \sin(\mathrm{wt} - 2\pi/3) \tag{2}$$

$$V_c = V_m \sin(\mathrm{wt} - 4\pi/3) \tag{3}$$

Fig.2 shows the graphical representation of basic switching vectors and sectors. There are eight vectors V0 to V7 in which two vectors are called zero vectors and six are called active vectors. Zero vectors are 000, represented by V0, and 111, represented by V7. Six vectors are 100, 110, 010, 011, 001 and 101, represented by V1, V2, V3, V4, V5 and V6 respectively.

In Fig.2, Vr is the reference voltage vector and here its magnitude and frequency is used to control the magnitude and frequency of fundamental voltage. The reference space vector is synthesized by switching two active vector and one or two zero vectors. The determination of switching pattern may be achieved by space vector modulation based on the representation of switching vector in α-β plane.

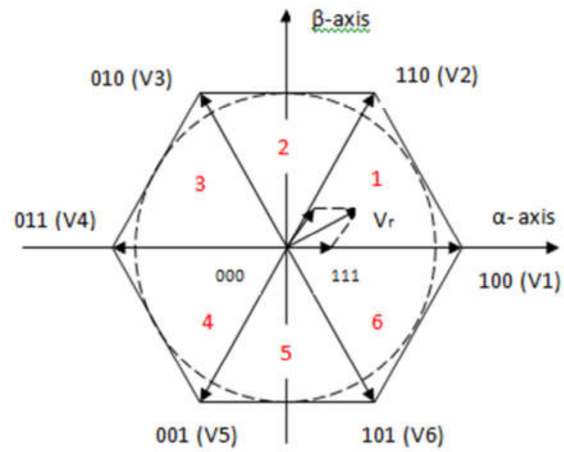

Fig.2. Basic switching vectors and sectors

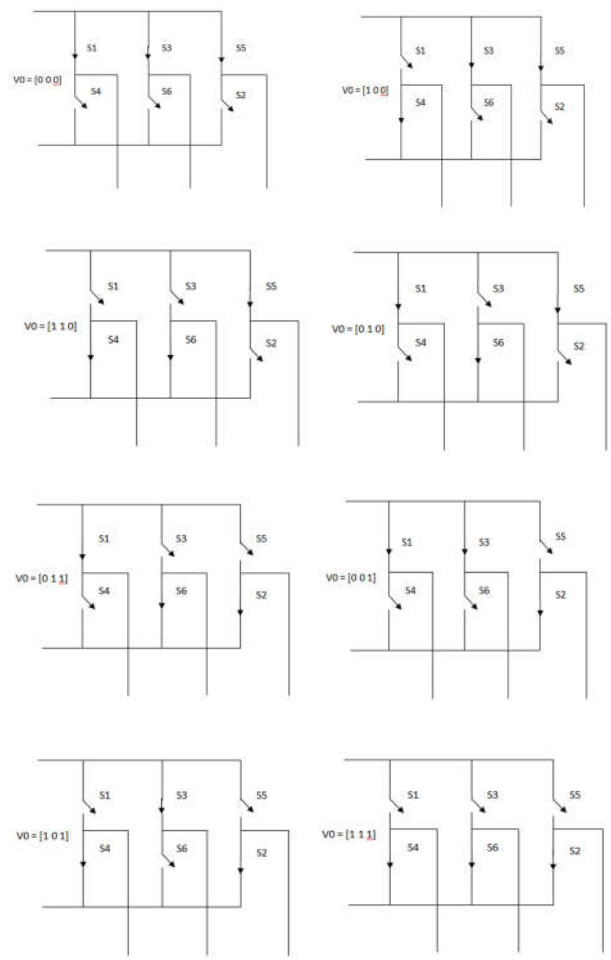

Fig.3. Eight various topologies for two-level VSI

Fig.3 shows the eight switching topologies according to various eight vectors for two-level VSI. Also there are six sectors 1 to 6. Each sector is separated by 60 degree to each other.

TABLE I. Sectors and their respective angle

Sectors	Vr position
1	0<wt<60
2	60<wt<120
3	120<wt<180
4	180<wt<240
5	240<wt<300
6	300<wt<360

Step 1*-Transformation of three phase to two phase quantity*

Firstly, three phase quantity has to be transformed into two phase quantity and after that determine the value of Vα, Vβ, Vr and angle α.

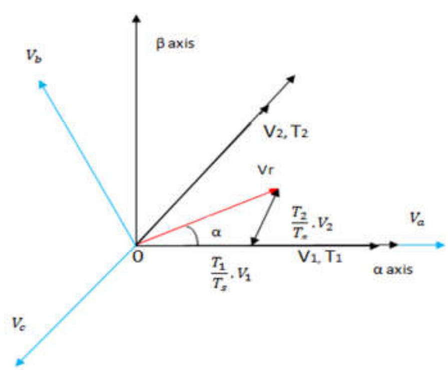

Fig.5. Reference vector as a combination of adjacent vectors

According to the Clarke transformation

$$V_\alpha = \frac{2}{3}(V_a + V_b.cos120^0 + V_c.cos240^0) \quad (4)$$

$$V_\beta = \frac{2}{3}(V_a.0 + V_b.sin120^0 + V_c.sin240^0) \quad (5)$$

By the eq. (4) and eq. (5), a matrix can be formed and is given by

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (6)$$

Now, the Space vector representation of three phase quantity is given by the following equation

$$V_r^* = V_\alpha + jV_\beta \quad (7)$$

The magnitude of reference vector (Vr) is

$$|V_r| = \sqrt{V_\alpha^2 + V_\beta^2} \quad (8)$$

And Angle $\alpha = \tan^{-1}(V_\beta/V_\alpha)$ (9)

Step 2*- Determining the switching time duration for sector 1*

After calculating the value of Vr, switching time duration To, T1 and T2 has to be calculated for sector 1. Let, Ts is the switching period and V1 is applied for T1 and v2 is applied for T2 To determine these times, only four vectors, 000 111 100 110, will participate. By the Volt – Sec method

$$\int_0^{T_s} V_r = \int_0^{T_1} V_1 dt + \int_{T_1}^{T_2} V_2 dt + \int_{T_1+T_2}^{T_s} V_0 \quad (10)$$

$$\therefore T_s.|V_r| = (T_1.V_1 + T_2.V_2) \quad (11)$$

But $V_r^* = V_r e^{j\theta},\ V_0 = 0,\ V_1 = \frac{2}{3}V_{dc}$

and $V_2 = \frac{2}{3}V_{dc}e^{j\pi/3}$

$$\therefore T_s.|V_r|.\begin{bmatrix} \cos(\alpha) \\ \sin(\alpha) \end{bmatrix} = T_1.\frac{2}{3}.V_{dc}.\begin{bmatrix} 1 \\ 0 \end{bmatrix} + T_2.\frac{2}{3}.V_{dc}.\begin{bmatrix} \cos(\frac{\pi}{3}) \\ \sin(\frac{\pi}{3}) \end{bmatrix} \quad (12)$$

Therefore, switching time duration for sector 1 are given as

$$T_1 = T_s.a.\frac{\sin\left(\frac{\pi}{3} - \alpha\right)}{\sin\left(\frac{\pi}{3}\right)} \quad (13)$$

$$T_2 = T_s.a.\frac{\sin(\alpha)}{\sin(\frac{\pi}{3})} \quad (14)$$

$$\therefore T_0 = T_s - T_1 - T_2 \quad (15)$$

Here $a\ (modulation\ index) = \frac{V_r}{\frac{2}{3}V_{dc}}$

***Step 3**- Determine the switching time duration for all sectors*

Switching time durations for all sectors can be determined by the following equation 16, 17. TABLE II shows the switching time duration for all sectors (i.e. 1 to 6) [4].

$$T_1 = \frac{\sqrt{3}}{V_{dc}}.|V_r|.T_s.sin\left(\frac{n}{3}.\pi - \alpha\right) \quad (16)$$

and

$$T_2 = \frac{\sqrt{3}}{V_{dc}}.|V_r|.T_s.sin\left(\alpha - \frac{n-1}{3}.\pi\right) \quad (17)$$

Where n= 1 to 6

TABLE II. Switching time duration for all sectors

Sectors	T_1	T_2	T_0
1	$T_s\text{asin}(\frac{\pi}{3}-\alpha)$	$T_s\text{asin}(\alpha)$	$T_s - T_1 - T_2$
2	$T_s\text{asin}(\frac{2\pi}{3}-\alpha)$	$T_s\text{asin}(\alpha-\frac{\pi}{3})$	$T_s - T_1 - T_2$
3	$T_s\text{asin}(\pi-\alpha)$	$T_s\text{asin}(\alpha-\frac{2\pi}{3})$	$T_s - T_1 - T_2$
4	$T_s\text{asin}(\frac{4\pi}{3}-\alpha)$	$T_s\text{asin}(\alpha-\frac{3\pi}{3})$	$T_s - T_1 - T_2$
5	$T_s\text{asin}(\frac{5\pi}{3}-\alpha)$	$T_s\text{asin}(\alpha-\frac{4\pi}{3})$	$T_s - T_1 - T_2$
6	$T_s\text{asin}(2\pi-\alpha)$	$T_s\text{asin}(\alpha-\frac{5\pi}{3})$	$T_s - T_1 - T_2$

***Step 4**- Determine the switching sequence at each switch in each sector*

Switching sequence for each switch can be determined with the help of Fig.6, Fig.7, Fig8, Fig.9, Fig.10 and Fig.11. In TABLE III, all switching sequences have been given for all sectors.

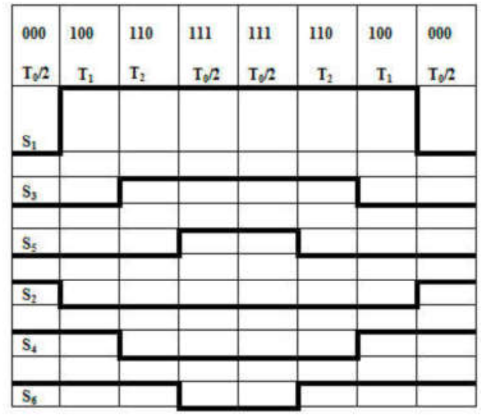

Fig.6. Switching sequence in sector 1

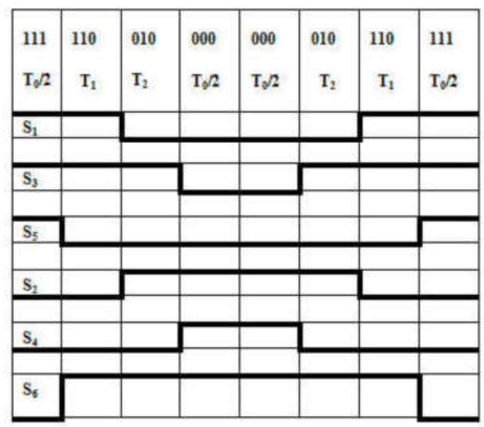

Fig.7. Switching sequence in sector 2

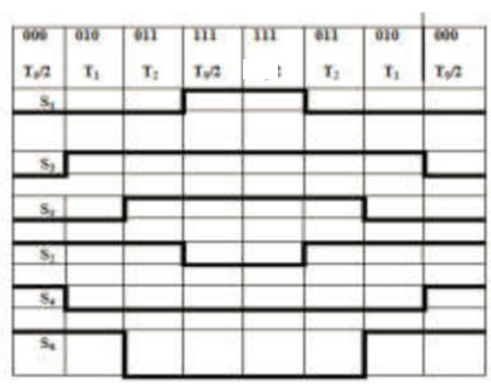

Fig.8. Switching sequence in sector 3

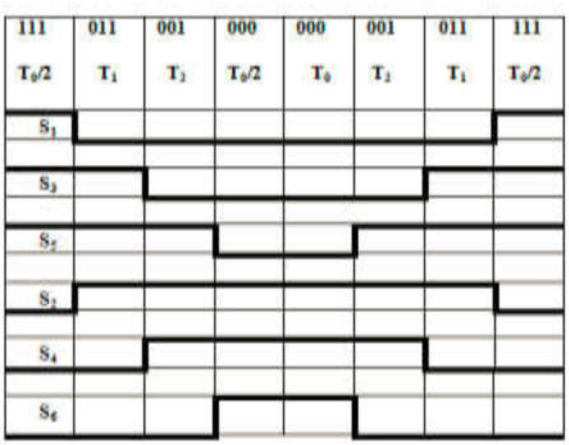

Fig.9. Switching sequence in sector 4

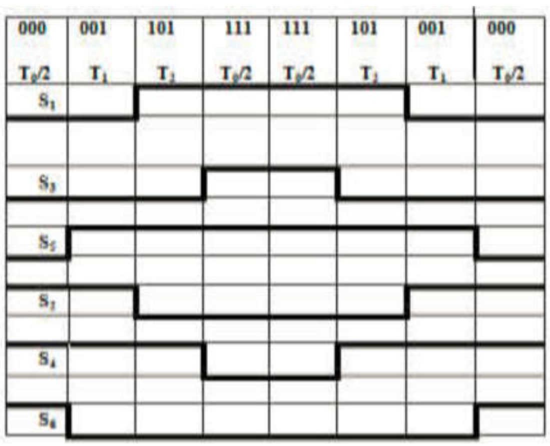

Fig.10. Switching sequence in sector 5

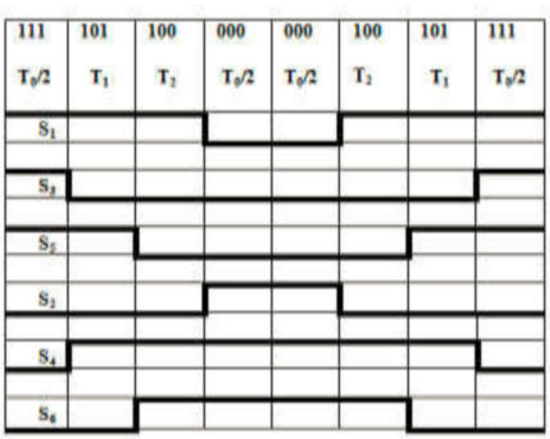

Fig.11. Switching sequence in sector 6

TABLE III. Switching sequence for all sectors and vectors

SECTORS	VECTORS	UPPER SWITCHING (S1, S3, S5)	LOWER SWITCHING (S4, S6, S2)
1	V0, V1, V2, V7	S1=T1+T2+T02 S3=T2+T0/2 S5=T0/2	S4=T0/2 S6=T1+T0/2 S2=T1+T2+T0/2
2	V0, V3, V2, V7	S1=T1+T0/2 S3=T1+T2+T0/2 S5=T0/2	S4=T2+T0/2 S6=T1+T2+T0/2 S2=T0/2
3	V0, V3, V4, V7	S1=T0/2 S3=T1+T2+T0/2 S5=T2+T0/2	S4=T1+T2+T0/2 S6=T0/2 S2=T1+T0/2
4	V0, V5, V4, V7	S1=T0/2 S3=T1+T0/2 S5=T1+T2+T0/2	S4=T1+T2+T0/2 S6=T2+T0/2 S2=T0/2
5	V0, V5, V6, V7	S1=T2+T0/2 S3=T0/2 S5=T1+T2+T0/2	S4=T1+T0/2 S6=T1+T2+T0/2 S2=T0/2
6	V0, V1, V6, V7	S1=T1+T2+T0/2 S3=T0/2 S5=T1+T0/2	S4=T0/2 S6=T1+T2+T0/2 S2=T2+T0/2

IV. IMPLEMENTATION IN MATLAB /SIMULINK

The SIMULINK representation of a space vector modulated inverter is shown in figure12 below.

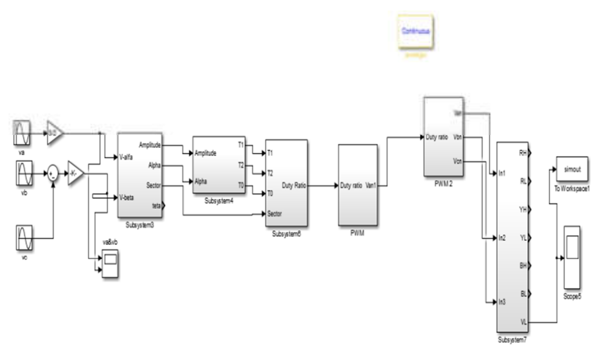

Fig12 .Matlab/simulink model of Space Vector PWM for two level inverter control

The simulink model for Space Vector Pulse Width Modulation is shown in the above figure 6. The three phase sinusoidal voltage is converted into two-phase equivalent using clark's transformation equations. Further the two-phase equivalent is transformed into polar form using "Cartesian to polar" block. The output of this block is the magnitude of the reference as the first output and the corresponding angle of the reference as the second output.

For a given magnitude and position V_{ref} can be synthesized by using three nearest stationary vectors, based on this switching states the gate signals for the active switches can be generated. When V_{ref} passes through the sectors, various sets of switches will be turned on or off. As a result, when V_{ref} rotates one revolution, the inverter output voltage completes one cycle. Thus the output of the inverter block is the phase voltages. The Total Harmonic Distortion of the simulated is shown in below figure.

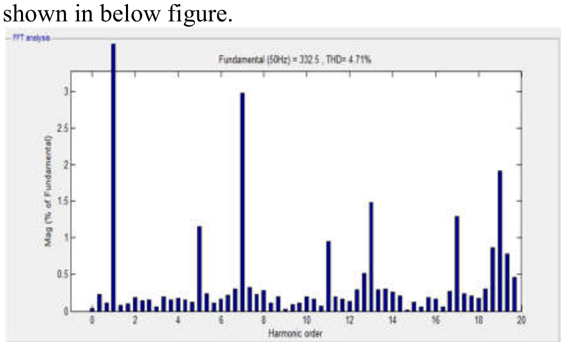

Fig13 : THD analysis of two level inverter using svpwm technique

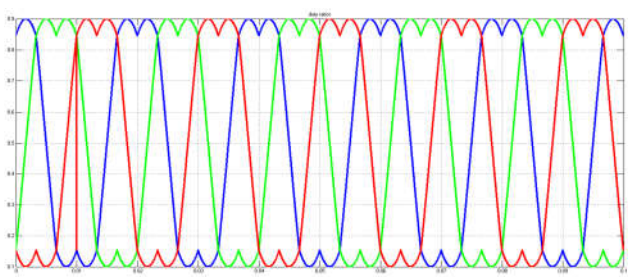

Fig14 . Duty ratios for space vector PWM

3 SIMULINK MODEL OF TWO LEVEL INVERTER CONTROL USING FUZZY LOGIC TECHNIQUE:

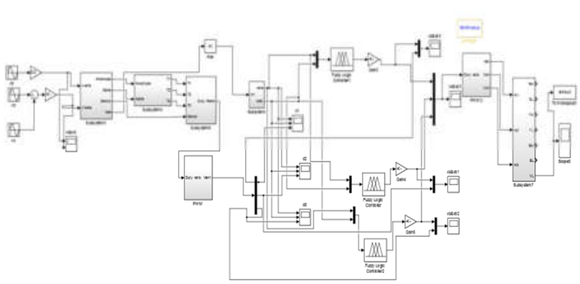

fig15: Matlab model of two level inverter control using fuzzy logic technique

Fuzzy logic rules are framed using input and output Membership Functions(MF) for the three duty ratios d0,d1 and d2 are found in tables 1,2 and 3 respectively. After framing the rules , the SVM is replaced by the Fuzzy Logic Control(FLC) toolbox. Then the fuzzy file will call from the FLC toolbox in place of the svm to run the simulation model file.

Figure16 represents the general fuzzy inference system editor window where the controller is trained based on input and output data, type of membership functions and fuzzy rules. Figure6.5 represents the input and output membership functions of duty ratio'd0' , figure 6.2 shows the rules for duty ratio which are framed by if and then rules.

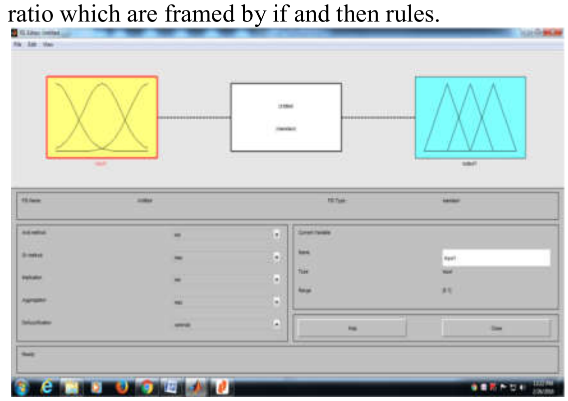

Fig16: general FIS editor window

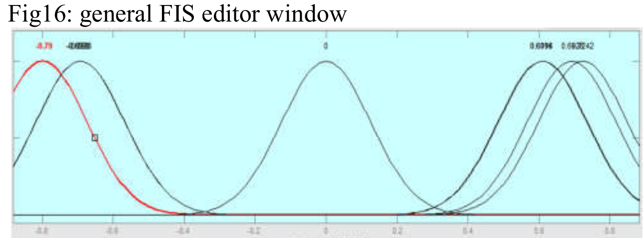

Fig 17: output membership functions for dutyratio'd0'

$\Delta\theta_R$ θ_R	NH -3.14	NM -2.076	NS -1.047	Z 0.00	PS 1.047	PM 2.093	PH 3.14
Z 0	TA 0.8462	TB 0.8467	TC 0.8465	TD 0.8465	TE 0.8464	TF 0.8463	TA 0.8462
PS 0.5	TG 0.9	TG 0.9	TG 0.9	TG 0.9	TG 0.9	TG 0.9	TG 0.9
PM 1	TH 0.854	TH 0.854	TH 0.854	TH 0.854	TH 0.854	TH 0.854	TH 0.854
PH 1.5	TI 0.55	TI 0.55	TI 0.55	TI 0.55	TI 0.55	TI 0.55	TI 0.55
PL 2	TJ 0.22	TJ 0.22	TJ 0.22	TJ 0.22	TJ 0.22	TJ 0.22	TJ 0.22
PL1 2.5	TL 0.1	TL 0.1	TL 0.1	TL 0.1	TL 0.1	TL 0.1	TL 0.1
PL2 3.14	TM 0.1538	TN 0.1537	TO 0.1535	TO 0.1535	TP 0.1534	TQ 0.1533	TR 0.1532

Table 4 : rule base to generate dutyratio'd0'

$\Delta\theta_R$ / θ_R	NL -3.14	NM -2.6	NS -0.52	Z 0	PS 0.52	PM 2.6	PL 3.14
NL -3.14	TA -0.608	TB -0.5674	TC -0.6106	TD -0.6114	TD -0.692	TD -0.692	TD -0.692
NM -2.6	TF -0.7217	TF -0.7217	TF -0.7217	TF -0.7217	TF -0.7217	TF -0.7217	TF -0.7217
NS -0.52	TG 0.6928	TH -0.692	TH -0.692	TH -0.692	TH -0.692	TH -0.692	TH -0.692
Z 0	TI 0.8	TI 0.8	TI 0.8	TI 0.8	TJ -0.7217	TJ -0.7217	TJ -0.7217
PS 0.52	TK 0.6386	TK 0.6386	TK 0.6386	TK 0.6386	TL -0.692	TL -0.692	TL -0.692
PM 2.6	TI 0.782	TI 0.782	TI 0.782	TI 0.782	TI 0.782	TI 0.782	TI 0.782
PL 3.14	TL 0.6094	TL 0.6094	TL 0.6094	TG 0.61	TG 0.8455	TM 0.6129	TN 0.6928

Table 5 : rule base to generate dutyratio'd1'

$\Delta\theta_R$ / θ_R	NL -3.14	NM -2.6	NS -0.52	Z 0	PS 0.52	PM 2.6	PL 3.14
NL -3.14	TO -0.6936	TO -0.6936	TD -0.693	TD -0.693	TA -0.6928	TA -0.6928	TA -0.6928
NM -2.6	TA -0.6928	TA -0.6928	TA -0.6928	TA -0.6928	TA -0.6928	TA -0.6928	TA -0.6928
NS -0.52	TH 0.6928	TH 0.6928	TH 0.6928	TH 0.6928	TH 0.6928	TH 0.6928	TH 0.6928
Z 0	TA -0.6928	TI 0.7242	TI 0.7242	TI 0.7242	TI 0.7242	TI 0.7242	TI 0.7242
PS 0.52	TO -0.693	TJ 0.6116	TJ 0.6116	TJ 0.6116	TJ 0.6116	TJ 0.6116	TJ 0.6116
PM 2.6	TI 0.7242	TI 0.7242	TI 0.7242	TI 0.7242	TI 0.7242	TI 0.7242	TI 0.7242
PL 3.14	TN 0.6094	TN 0.6094	TN 0.6094	TN 0.6094	TN 0.6094	TN 0.6094	TN 0.6094

Table 6: Rule base to generate dutyratio 'd2'

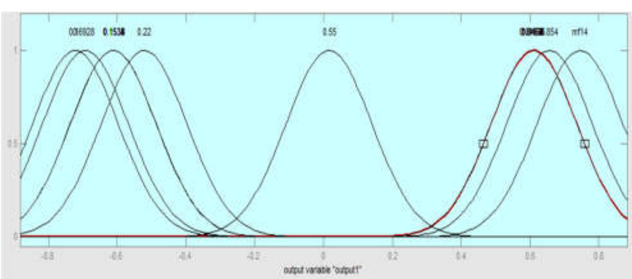

Fig 18: output memebership functions for 'd2'

The figures below represents the surface view of the three duty ratiosd0,d1 and d2.

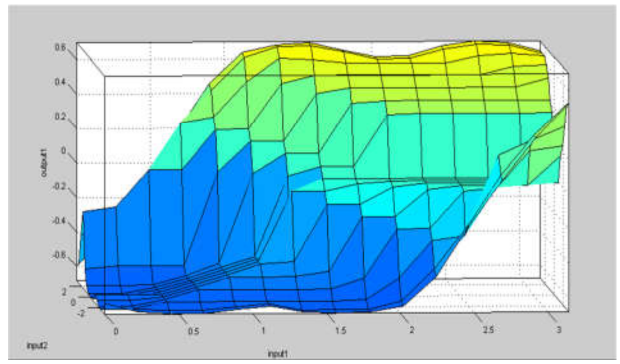

Fig 19 : Surface view of duty ratio 'd0'

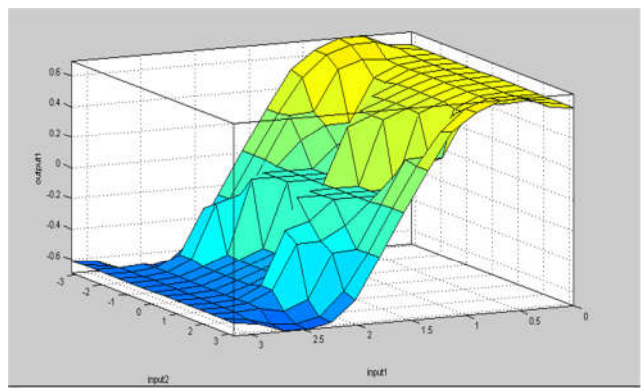

Fig 20 : Surface view of duty ratio 'd1'

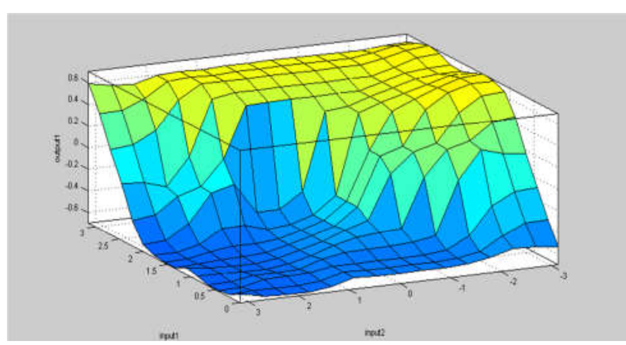

Fig 21 : surface viewer of dutyratio "d2".

The simulation results of the two level inverter using fuzzy logic controller are shown in table7

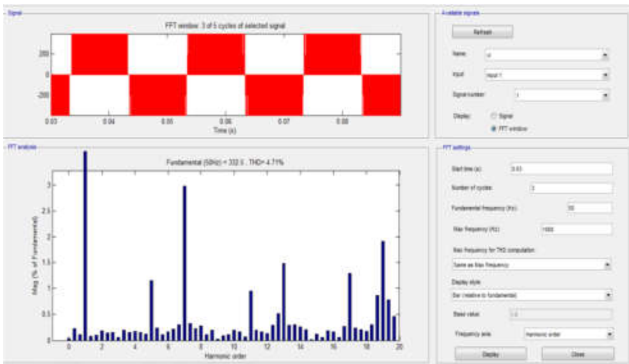

Fig 22 : THD of the output voltage of inverter using fuzzy controller.

V. RESULTS

Space vector PWM technique has been implemented for two-level VSI using MATLAB. All values of voltages have been obtained at modulation index 0.8. As observed from the simulation results, i.e., Figures 15 to 22. Fuzzy controllers provide superior control when compared to Space vector pulse width modulation and also neural network technique. It overcomes the disadvantage of SVPWM technique . that is it requires complex online computation which limits the inverter switching frequency .

It can also be obtained at 0.1 to 0.9 modulation index. By varying the value of modulation index total harmonic distortion is decreased.

A comparison of Total Harmonic Distortion obtained using the SVPWM technique and Fuzzy logic based svpwm technique at different modulation index is shown in the below table.

	Conventional SVPWM	Fuzzy logic controller
MI=0.8	4.71	4.38
MI=0.866	4.62	4.31

TABLE 7 : variation in %THD of three phase voltages for different Modulation Index(MI)

VI. CONCLUSION

A systematic approach of achieving lower Total Harmonic Distortion(THD) of output voltage of two level inverter using Fuzzy logic based space vector pulse width modulation has been investigated in this project work. SIMULINK representation of Fuzzy logic based SVPWM scheme is shown. The Total Harmonic Distortion of three phase voltages is determined. Due to so many advantages of Fuzzy controller, it becomes a good choice to use over the rest of the techniques.

REFERENCES

[1]. JBV Subrahmanyam, Sankar, "Application of Svpwm Technique to Three Level Voltage Source Inverter," *International Journal of Engineering and Technology,* Volume 1 No. 1, pp.15-22October, 2011.

[2]. K. Vinod Kumar, Prawin Angel Michael, Joseph P. John, Dr. Suresh Kumar, "Simulation and comparison of SPWM and SVPWM control for three phase inverter," *ARPN Journal of Engineering and Applied Sciences,* vol. 5, No. 7, pp.61-74, July 2010.

[3]. H.W.v.d.Brocker, H.C.Skudenly, G.St nke, "Analysis and realization of a pulse width modulator based on the voltage space vector," *Conf. Rec. IEEE-IAS Annu. Meeting, Denver*, CO, pp. 244-251, 1986.

[4]. Chandan Kumar, Sushma Kamlu & Sudhansu kumar Mishra, "d-space based space vector PWM for a two-level VSI," *ITSI Transactions on Electrical and Electronics Engineering (ITSI-TEEE)*,Vol. 1, No. 6, pp.15-18, 2013.

[5]. B.N.Kartheek, P.S.D.M.Chandana, S.Niveditha, "An optimized code for space vector PWM for a two –level voltage source inverter," *International Journal of Science and Modern Engineering (IJISME),* Vol. 1, No. 5, pp.50-52, July 2013.

[6]. P.Tripura, Y.S.Kishore Babu, Y.R.Tagore, "Space Vector pulse width modulation schemes for two-level voltage source inverter," *ACEEE Int. J. on Control System and Instrumentation,* Vol. 2, No. 3, pp.34-38, October 2011.

[7]. Ayse Kocalmis Bilhan, Erhan Akbal, "Modelling and simulation of two-level space vector PWM inverter using Photovoltaic cells as dc source," *International Journal of Electronics; Mechanical And Mechatronics Engineering,* Vol.2,No.4, pp.311-317.

[8]. Ashish Gupta, Sanjiv Kumar, " Analysis of Three Phase Space Vector PWM Voltage Source Inverter for ASD's," *International Journal of Emerging Technology and Advanced Engineering ,* Vol.2, pp.164-168, October 2012.

[9]. P.Tripura, Y.S.Kishore Babu, Y.R.Tagore, "Space Vector Pulse Width Modulation Schemes For Two-Level Voltage Source Inverter," *ACEEE Int. J. on Control System and Instrumentation,* Vol. 02, No. 03, pp.34-38, October 2011.

[10].Keliang Zhou and Danwei Wang, "Relationship Between Space-Vector Modulation and Three-Phase Carrier-Based PWM:A Comprehensive Analysis," *IEEE Transactions On Industrial Electronics,* Vol. 49, No. 1, pp.186-196, February 2002.

[11].I. Çolak, E. Kabalcı, R. Bayındır, S., Sağıroglu, "The Design and Analysis of a 5-Level Cascaded Voltage Source Inverter with Low THD,"*9nd Power Engineering Energy and Electrical Drives Conference*, Ankara, pp. 575-580, 18-20 March.