Analysis of 3 Level SVPWM based Open Loop and Closed Loop V/F Control of Induction Motor

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***Abstract*— This paper aims on space vector modulation (SVM) for controlling of induction motor. It is not easy to control an induction motor (IM) in light of its poor dynamic response in correlation to the DC motor. Space vector PWM (SVPWM) is widely used because of their better dc bus utilization and easier digital realization. It is achievable to control the electromagnetic torque and stator flux linkage using optimized selection of inverter switching vectors using VSI. In this paper V-F control used because of its simplicity and good response here simulation of open loop and closed loop control of induction motor using V-F principle by space vector modulation is done using MATLAB/Simulink.**

***Keywords*— Three-level inverter; Space vector pulse width modulation (SVPWM); V-F control;**

I. INTRODUCTION

Pulse-width modulation (PWM) inverters reduce harmonics in the output current and/or voltage by increasing the switching frequency and control the inverter output voltage as well as frequency by changing modulating wave. PWM inverters are more appropriate for speed control of induction motor (IM) instead of other techniques. The most popular technique is Sinusoidal PWM (SPWM), which is appropriate for, linear modulation index up to 0.7855 only. Above this modulation index, SPWM produce more harmonics in output voltage and current of the inverter. For enhancing the linear modulation range up to 0.907, third harmonic injected PWM (THIPWM) and space vector PWM (SVPWM) techniques are used to improve the total harmonic distortion (THD) as well as increase the basic value of inverter output voltage. [1-4]

The control techniques for induction motor are of three types: scalar control, vector control and Direct Torque Control (DTC). In this paper V/f scalar control is used is the simplest controller, it is the largely used in industrial applications [5]. It works by imposing a constant relation between voltage and frequency, to give constant flux for the wide range of speed variation [6]. Constant voltage/hertz control keeps the stator flux linkage fixed in steady state without decoupling between the flux and torque. In this paper we have implemented closed loop as well as open loop V/f control of Induction motor using SVPWM based 3 level inverter.

The paper is organised as follows. In section II, principal of V/f control is elaborated. Section III describes 3 level inverter design using SVPWM technique. Section IV deals with Simulink modeling analyzing the results. Section V concludes the contribution of this paper.

II. V/F CONTROL

In motors relationship between rotor speed, synchronous speed, and slip is as follows,

$$S = \frac{N_s - N_r}{N_s} \tag{1}$$

$$N_r = N_s(1-S) \tag{2}$$

$$\text{Rotor speed } N_r = \frac{120 f}{P}(1-S) \tag{3}$$

Hence, changing frequency (f), number of poles (P) or slip (S) can change the speed of an induction motor. In scalar control speed is controlled by increasing or decreasing in frequency Units. But change in frequency results change in impedance. This thusly is the explanation behind change in current drawn by the motor. Lessening in supply current expand the air gap flux which bring about saturation at the core. To keep away from these issues, it is important to vary the frequency and the voltage simultaneously. From equation (4) of induced voltage it can be concluded that constant V/f control provide constant flux in the stator.

$$\frac{V_{rms}}{f} = 4.44 N \varphi \zeta \tag{4}$$

Where V_{rms} induced voltage in stator, f is frequency of voltage supplied, N is number of turns, φ flux linkage in stator and ζ is coil constant.

$$T_{air-gap} = \frac{3R_r}{2\omega_m S} I_r^2 \tag{5}$$

$$T \approx \frac{V^2}{2\pi f} \approx \frac{V}{f} \tag{6}$$

From equation (5) and (6) it reveals that torque generated by induction motor remains fixed if V/f ratio is constant up to the base speed. Above base speed torque is decrease in inverse proportion to increase in frequency.

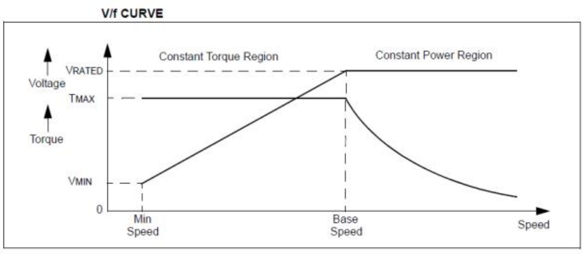

Fig. 1 V/f Curve

A. Open loop speed control

In this strategy, the stator voltage was varied, and the supply frequency was at the same time differed such that the V/f ratio stayed steady. This kept the flux consistent and thus the maximum torque at the time of varying speed.

B. Close loop speed control

In this speed of the rotor is measured and compared with reference speed. The difference is given to a PI controller which tries to minimize error to zero and according to PI output frequency and voltage is define for SVPWM based inverter

III. 3 LEVEL INVERTER DESIGN USING SVPWM

The main circuit NPC Three-level inverter circuit is as shown in Fig.2 theoretically proposed by Holtz, then being developed by A. Nabae. In three-phase three-level inverter for each phase there are three output levels (1, 0, and -1) having three values, they are terminal voltage(+$E_d/2$), negative voltage(-$E_d/2$), and the zero-voltage(0).

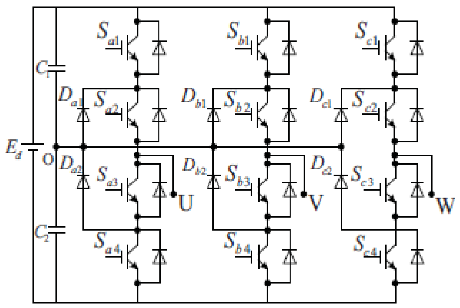

Fig. 2 Three level inverter

Three-level topology has advantages over two-level topology, which are

1. Every switching device's carrying voltage is half of the DC voltage, Quality of waveform has improved and switching frequency is reduced
2. Voltage rate is half as compared to the two-level inverter
3. Due to increase in the number of output levels, three level inverters have smaller output voltage steps that diminish motor issues.

SVPWM of 3- level is different from 2 level. In SVM strategy for two level inverter 6 pulses are generated for 6 switches. In three level every arm of the bridge has three different types of on-off combination which gives three different potential output (+ $E_d/2$,0,-$E_d/2$), P, O and N represents each output. Each phases switch states can be defined as:

$$S_i = \begin{cases} 1 & U = \frac{E_d}{2} \\ 0 & U = 0 \\ -1 & U = -\frac{E_d}{2} \end{cases} \quad i = (a,b,c) \tag{7}$$

So there are 27 possible states which produce voltage vectors. Inverter's switching states and space vector graph can be drawn, according to their phase and amplitude as shown in Fig. 3.

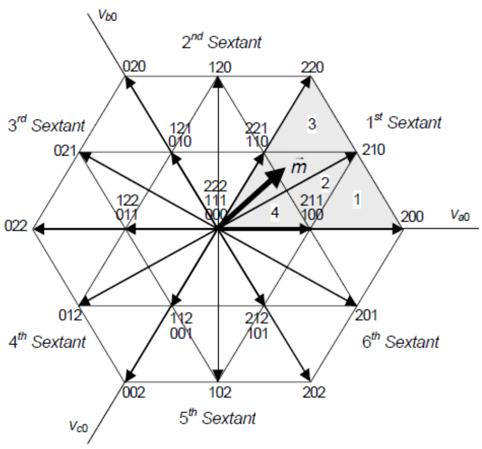

Fig. 3 Three level vector diagram

As shown in figure three there are 24 non-zero vectors and 3 null length vectors. These space vectors can be divided in to 4 groups according to the size of vectors, large vector, medium vector, short vectors and zero vectors. Suitable vectors from the (state vector) SV diagram should be chosen for every modulation cycle to generate the reference vector (m_r). The vectors nearest to m_r are appropriate selections to minimize the switching frequencies of the power devices, improve the electromagnetic interference (EMI), and quality of the output voltage. Each short-vector represents to two switching states; Switching states which contain 0 and 1 as positive short-vector, which only contain 0 and -1 as negative, this pair of short-vectors has the same function for the output voltage, but has the opposite function for the mid-point current. Detailed classification of state vectors is given in table.

Table I

Classification of Space Voltage vectors	
Group	***State vectors***
Large Vector	200, 220, 020, 022, 002, 202
Mediam Vector	210, 120, 021, 012, 102 ,201
Short Vector	100-211, 110-221, 010-121, 011-122, 001-112,101-212
Zero Vector	000, 111, 222

The traditional SVPWM algorithm is based on the sector and triangular regions (sextant) of the reference vector, the basic vectors are selected by the principle of the recent three vectors, which are used to produce the reference voltage vector, and Volt-second balance method is used to calculate the effective time of the basic vector. Seven or five stage modulation method generates the required PWM waveform [5]

1. Sector is judged by the angle of reference voltage.

Three variables are respectively:

$$\begin{aligned} V_{ref1} &= V_\beta > 0 \\ V_{ref2} &= V_\alpha - (1/\sqrt{3})V_\beta \\ V_{ref3} &= -V_\alpha - (1/\sqrt{3})V_\beta \end{aligned} \qquad (8)$$

Here

V_{ref}	**More then 0**	**Less than 0**
V_{ref1}	A=1	A=0
V_{ref2}	B=1	B=0
V_{ref3}	C=1	C=0

From the Sector judgement formula S'= A+2B+4C six different sector can be identified

Table II. Reference voltage vector sector judgment table

S	I	II	III	IV	V	VI
S'	3	1	5	4	6	2

2. Reference voltage vector is located in which small triangle is judged by its amplitude
3. Then the basic vectors are selected by the last three vector principle, and then its function time is calculated through the volt-second principal.

Finally, the switch states related to three basic vectors are determined (only one switch action in any one bridge arm every time). Seven or five stage modulation method used to generates the required space vector sequence.

IV. SIMULATION RESULTS ANALYSIS

The V/f control of induction motor using above algorithm has been successfully simulated using MatLab/ Simulink Software. Fig 5 shows the open loop V/f Control of induction motor using 3 level SVPWM based inverter and Simulink model of close loop V/f Control is shown in Fig 6

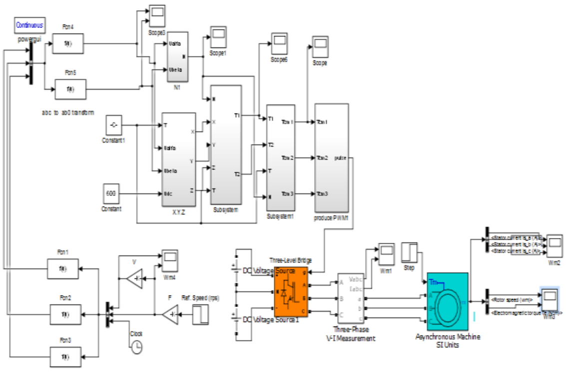

Fig 5. Open loop V/f Control of Induction Motor using 3 level SVPWM based inverter

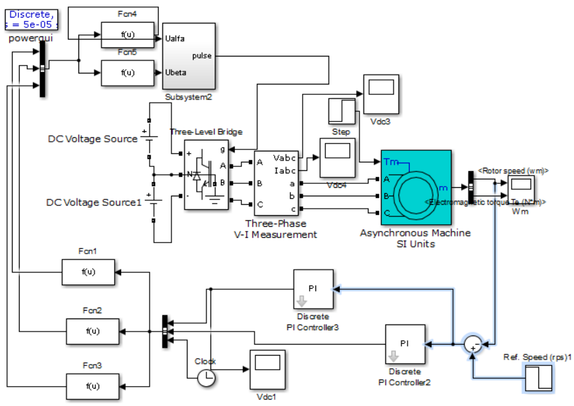

Fig 5. Close loop V/f Control of Induction Motor using 3 level

In this paper open loop control and close loop control analyzed by varying load torque and reference speed .It can be analyzed from Fig 6 and 7 when Reference speed is changing from 157 to 130 rps at t= 1 Sec torque is varying to gain that speed and with V/f control it is achieved within 0.1 Sec. In Fig 8 output of inverter is shown as it can be seen from the figure that inverter will not give pure sinusoidal voltage.

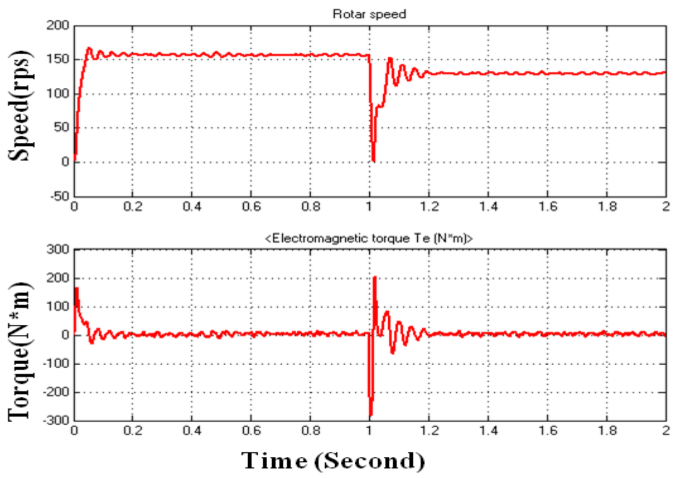

Fig 6. Rotor Speed and Torque of Induction motor in Open loop V/f Control

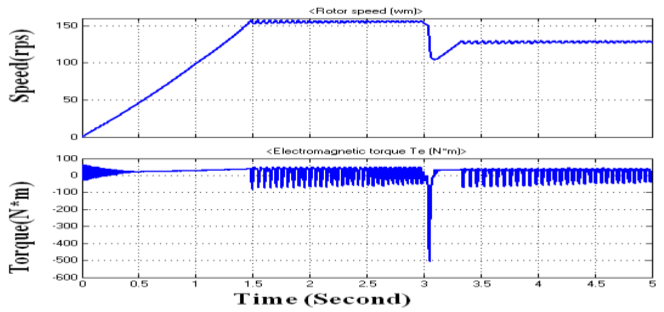

Fig 7. Rotor Speed and Torque of Induction motor in Close loop V/f Control

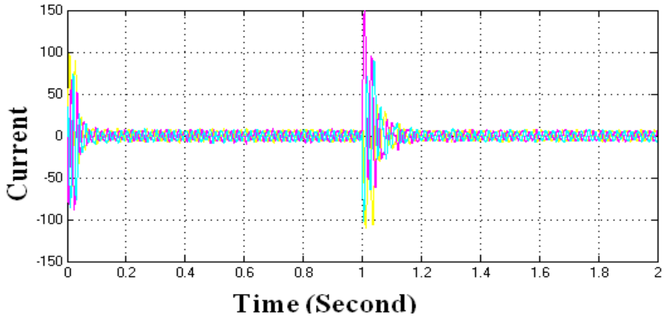

Fig 8. Variation in current at the time of change in speed

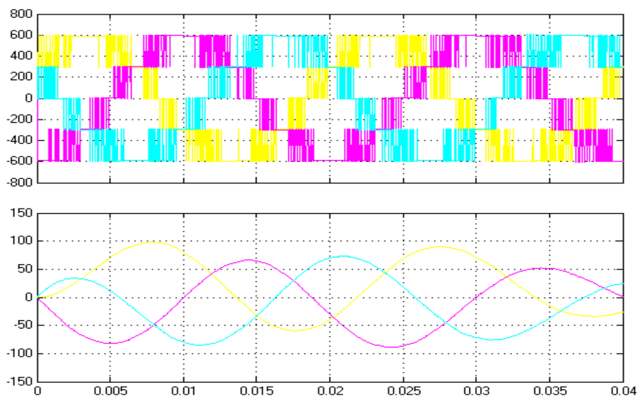

Fig 8. AC Voltage and Current from Inverter

V. CONCLUSION

SVPWM gives linear control of output voltage up to MI=0.906 for sinusoidal input without having loss of reference voltage. When MI is more then 0.906, it enters in over modulation region, in this region some part of basic voltage is lost.. SVPWM provide efficient control of induction motor in linear as well as over modulation region. V/f control open loop and close loop control gives good control of induction motor for higher speed. Motor is controlled effectively using 3 level space vector PWM(SVPWM) in both mode without crossing current and torque limit.3 level SVPWM increases performances as well as drives life time when compared to 2 level.

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