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Field Oriented Control of Space Vector Modulated Multilevel Inverter fed PMSM Drive

Jose Jacob[a], Chitra A.[b]

[a]*Department of Electrcial and Electronics Engineering,Viwajyothi College of Engineering and Technology, Kerala, India*
[b]*School of Electrical Engineering, VIT University, Vellore, India*

Abstract

In this article, field orient control (FOC) of a space vector modulated asymmetrical Multilevel inverter (MLI) fed Permanent Magnet Synchronous Motor (PMSM) is presented. The MLI considered is a reduced switch inverter which produces seven level output with six power switches and two input sources. A general low computational space vector algorithm is used to modulate the MLI. The PMSM is controlled by Field oriented control with speed regulated PI. The implementation of the FOC applied to a PMSM and validated with simulation results. Simulation of the whole system is carried out in MATLAB/simulink tool.

Keywords: Permanent Magnet Synchronous Motor (PMSM); Field Orient Control (FOC); Space Vector Modulation;Multilevel Inverter (MLI)

1. Introduction

Multilevel inverters are the wise choice for the quality power sources [1-4]. In this study a reduced switch MLI topology is considered which aims to produce seven levels output with two asymmetrical sources and six power switches [5]. The most popular PWM techniques used are Sinusoidal PWM (SPWM) and Space Vector PWM (SVPWM) [6]. The complexity of conventional sinusoidal PWM and Space Vector PWM will increase drastically with increase in number of output levels of MLI [7]. Recently in literature [8-9] a new, general, low computational space vector algorithm is introduced which can be applied to any number of levels of MLI with less computation For the efficient control of PMSM, normally FOC and space vector modulation technique are implemented together for superior performance. Permanent magnet synchronous motor (PMSM) uses permanent magnet to create magnetic

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field instead of rotor field winding in the rotor of a conventional synchronous motor [10]. This improvement lead to number of significant advantages such as high power density, ease of control, high torque to inertia ratio, low noise, reduction in size and weight. Field oriented control is a widely accepted and superior closed loop control of PMSM as it offers quick response and reduced torque ripple [11-12].

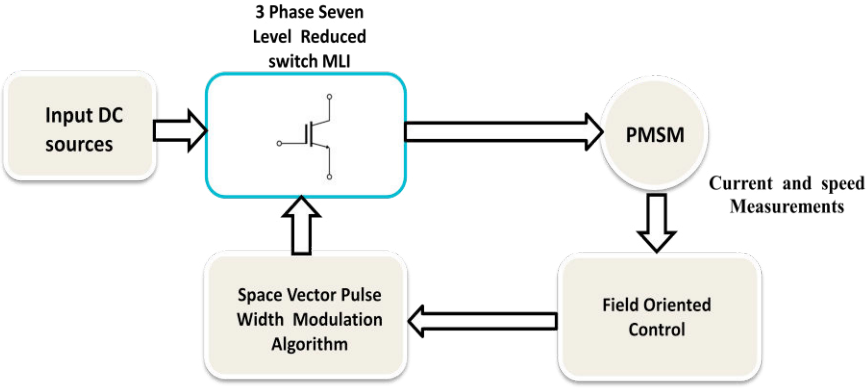

Fig.1. Block Diagram of PMSM control

This paper presents the closed loop vector control of PMSM suing a space vector algorithm with reduced switch seven level MLI. The work aims to regulate the rotor speed in accordance with change in load torque. Block diagram of the proposed system is illustrated in Fig.1.

2. Seven level inverter modeling and control

The Multilevel inverter topology [13] considered for this analysis is shown in fig.2. The single phase structure of the topology has two input dc sources, V_{dc1} and V_{dc2} and six power switches, S_1, S_2, S_3, S_4, S_5 and S_6. The two input dc sources can in either be asymmetrical or symmetrical configurations. The DC sources are connected through power switches in such a way that the higher potential terminal of the second source is connected to the lower potential terminal of the first source and vice versa.

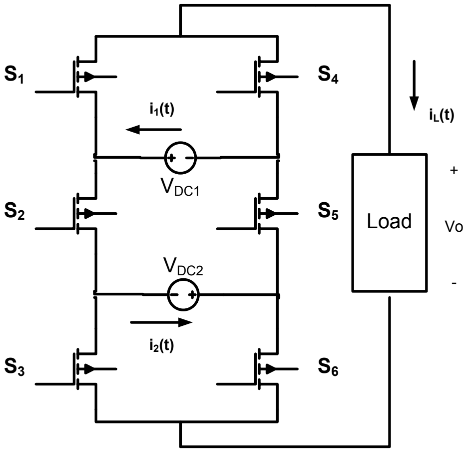

Fig.2.Multlevel Inverter Topology

It single phase structure has three pairs of active power switches. The topology has eight operating modes as the elements of three pairs of power switches are complementary. These modes of operations are summarized in Table 2.1 along with switch states and output voltages, Here load is supplied with seven level output voltage, viz., V_{dc1}, V_{dc2}, $V_{dc1}+V_{dc2}$, $-V_{dc1}$, $-V_{dc2}$, $-(V_{dc1}+V_{dc2})$ and zero for asymmetrical input DC sources V_{DC1} and V_{DC2} as illustrated in table.1

Table.1 Switching States of multilevel inverter

	Switch States (1=ON; 0=OFF)						Output Voltage
Mode	S_1	S_2	S_3	S_4	S_5	S_6	
Mode 1	0	0	0	1	1	1	0
Mode 2	1	1	1	0	0	0	0
Mode 3	1	0	0	0	1	1	V_{dc1}
Mode 4	0	0	1	1	1	0	V_{dc2}
Mode 5	1	0	1	0	1	0	$V_{dc1}+V_{dc2}$
Mode 6	0	1	1	1	0	0	$-V_{dc1}$
Mode 7	1	1	0	0	0	1	$-V_{dc2}$
Mode 8	0	1	0	1	0	1	$-(V_{dc1}+V_{dc2})$

3. Space Vector algorithm

Among Various pulse width modulation strategies presently available, space vector pulse width modulation technique (SVPWM) is prominent because of its superior performance. Compared to conventional sinusoidal PWM modulated inverter, space vector PWM modulated inverter enable to feed AC motor drive with higher voltage at reduced total harmonic contents. This study employs a Space Vector PWM algorithm to control the three phase seven level inverter topology. The implementation of space vector PWM tedious and requires tremendous mathematical calculation as the required number of levels in the inverter output is high. The Space Vector algorithm considered [8-9] here is a non conventional one because it does not need any lookup table or any other complex mathematical functions to modulate the inverter. The Steps of space vector algorithm are summarized [14-17] in the flowchart shown in Fig. 2

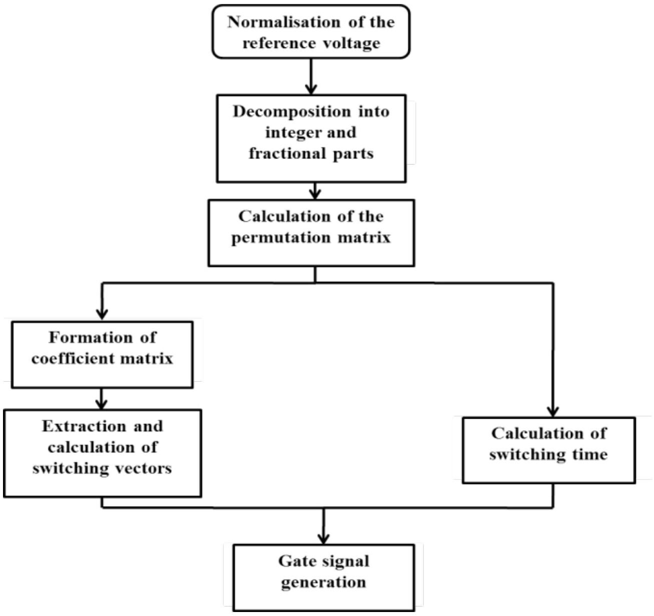

Fig.3. SVPWM algorithm flow chart

- Calculate normalized reference, Vr, from the reference voltage vector using the expression –

$$Vr = \frac{Vr}{Vdc} = \left[vr^1, vr^2, ...vr^p\right]^T \tag{1}$$

- Decompose the normalized reference into the sum of its integer part, V_i, and its fractional part, V_f, by means of the equations

$$Vi = \text{int}(Vr) \in Z^P$$
$$Vf = Vr - Vi \in R^P \tag{2}$$

- Calculate the permutation matrix P that sorts the vector vf in descending order in accordance with

$$P\begin{bmatrix}1\\ Vf\end{bmatrix} = \begin{bmatrix}1\\ \widehat{Vf}\end{bmatrix} \tag{3}$$

Where,

$\widehat{Vf} = [\widehat{Vf}^1, \widehat{Vf}^2, ...\widehat{Vf}^P]^T$ is the sorted vector in which $1 > \widehat{Vf}^1 \geq ..... > \widehat{Vf}^{K-1} \geq \widehat{Vf}^K \geq ....\widehat{Vf}^P \geq 0$

- Rearrange the rows of the triangular matrix D in order to obtain the matrix D by means of

$$D = P^T \hat{D} \tag{4}$$

- From the matrix D extract the displaced switching vectors, V_{dj} by considering the expression-

$$D = \begin{bmatrix} 1 & 1 & ... & ... & 1 \\ vd_1^1 & vd_2^1 & ... & ... & vd_{p+1}^1 \\ vd_1^2 & vd_2^2 & ... & ... & vd_{p+1}^2 \\ ... & ... & ... & ... & ... \\ vd_1^p & vd_2^p & ... & ... & vd_{p+1}^p \end{bmatrix} \tag{5}$$

- By adding the integer part of the reference, V_i, to the displaced switching vectors V_{dj} obtain the final switching vectors, V_{sj} .

$$Vsj = Vi + Vdj \tag{6}$$

- From components of the vector V_f Calculate switching time corresponding to each switching vector by following equations

$$t_j = \begin{Bmatrix} 1 - \widehat{v}_f^{\,1}, & if...j = 1 \\ \widehat{v}_f^{\,j-1} - \widehat{v}_f^{\,i}, & if...2 \leq j \leq p \\ \widehat{v}_f^{\,p}, & if...j = p+1 \end{Bmatrix} \tag{7}$$

4. Principle of Field Oriented Control (FOC) for PMSM

The operating principle of permanent magnet synchronous motor (PMSM) is same as that of synchronous motor except that PMSM has a Permanent Magnet rotor. The constructional features of PMSM offers various advantages like high power density, high efficiency, and low torque to weight ratio and easiness in control as compared to induction motors [18]

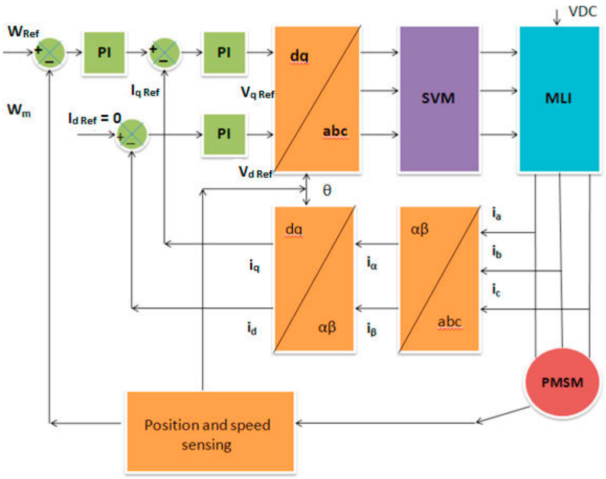

Fig.4. FOC of PMSM

For the smooth and efficient control of PMSM Field Oriented Control (FOC) is widely adopted in practice. In AC Motors the flux and torque producing currents has a coupled effect and cannot be controlled independently. The basic idea of FOC is to decompose the stator current of AC machine into a flux generating part and torque generating part so that it can be controlled as a separately excited DC motor [19-20]**.** Fig.4. Shows the block diagram for Field oriented control permanent magnet synchronous motor.

5. Simulation

Simulation of field oriented control is performed with MATLAB/simulink software. Field oriented control in constant torque region is implemented here. Space vector modulation scheme is used to generate the trigger signals for MLI. Table.2 shows the permanent magnet synchronous motor parameters considered in simulation and Table.3 shows the simulation parameters for the closed loop system.

Table.2. PMSM Motor Parameters

Number of poles	P	4
Permanent Magnet Flux	Y	0.1717 Wb
Stator Resistance	R_s	18.7 Ω
d-axis and q-axis Inductance	L_d , L_q	0.02682 H
Inertia	I	2.26e-5 KgM^2
Rated speed	Ns	3000 Rpm
Rated Torque	T	0.8 Nm
Voltage	V	120 V

Table.3. Simulation Parameters of the system

	Parameter	Value
MLI	V_{dc1}	50 V
	V_{dc2}	100 V
SVPWM	Switching Frequency	2000 Hz
	Modulation Index	0.85
	Reference Frequency	50 Hz
PMSM	Rated Voltage	120 Vph
	Rated Torque	0.8 Nm
	Rated Speed	3000 RPM
Filter Values	L	100 mH
	C	1000 µF

For the analysis of field oriented control two cases are considered while simulation, Dynamic torque change with constant reference speed and dynamic speed chance with constant reference torque. Speed control obtained is below the rated speed since no flux weakening control employed here.

6. Simulation with Reference speed change

Fig.5 to Fig.8 Shows the simulated waveforms of PMSM closed loop control system using field oriented control with dynamic speed change. Fig.7. shows that speed of PMSM is decreased from 3000 rpm (Rated) to 1000 rpm at t=0.2 sec and increased to 2000 rpm at t=0.4 sec. the corresponding torque response of the system is shown in Fig.8 and the load torque follows the electromagnetic torque, which has a constant value of 0.8Nm.

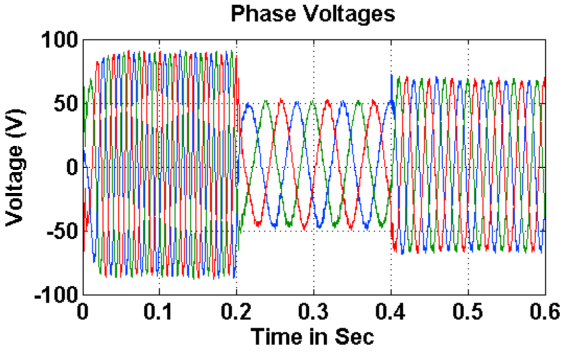

Fig.5. Stator Voltage Waveform.

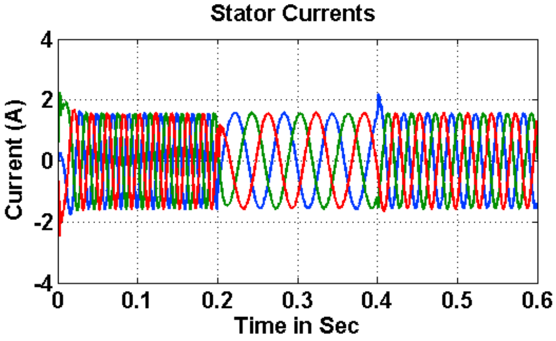

Fig.6.Stator Currents Waveform

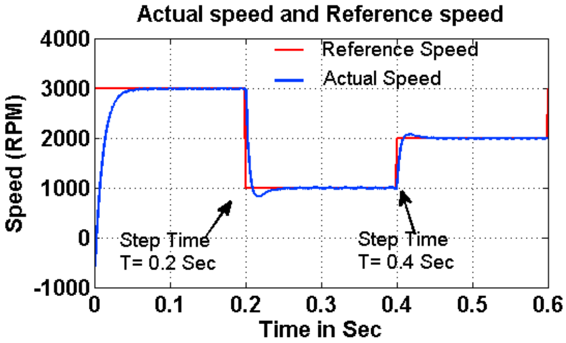

Fig.7. Speed Waveform.

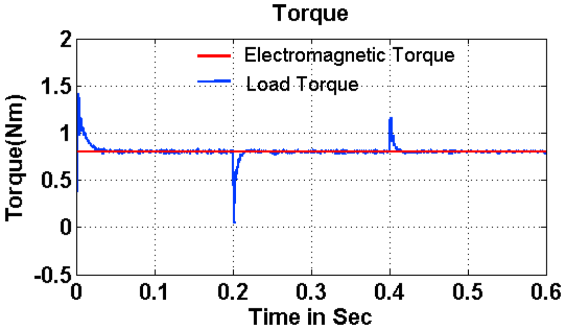

Fig.8.Torque Waveform

It is clear from Fig.6 that stator current is kept constant during sudden reference speed variations also it is evident form Fig.5 that the stator voltage is adjusted in accordance with reference speed change to maintain torque constant.

7. 5.4. Simulation with Dynamic torque change

Fig.9 to Fig.12 Shows the simulated waveforms of PMSM closed loop control system using field oriented control with dynamic torque change. Fig.11. shows that torque of PMSM is decreased from 0.8 Nm (Rated) to 0.5Nm at t=0.2 sec and increased to 1Nm at t=0.4 sec. the corresponding speed response of the system is shown in Fig.12 and the actual speed follows the reference speed, which has a constant value of 3000rpm

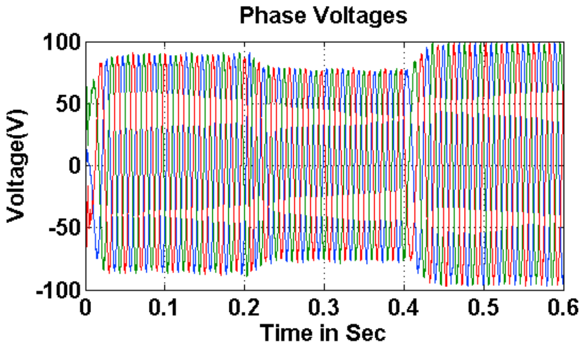

Fig.9 Stator Voltage Waveform.

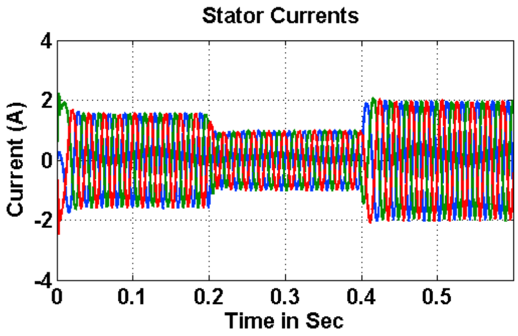

Fig.10.Stator Current Waveform

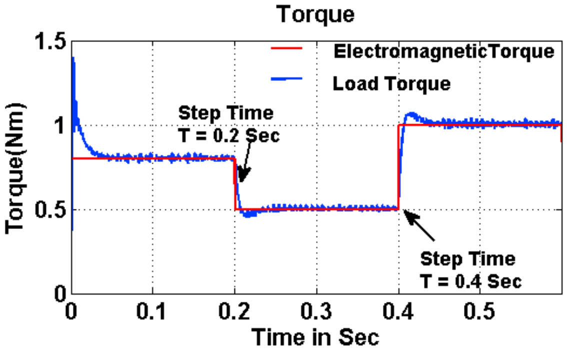

Fig.11 Speed Waveform.

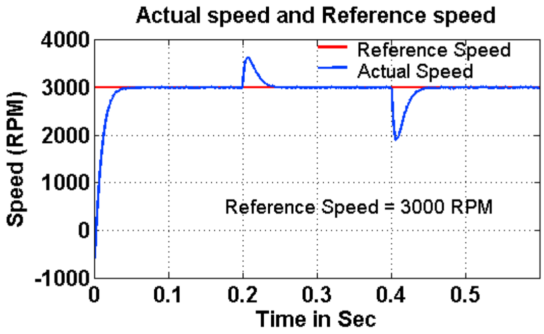

Fig.12.Torque Waveform

It is clear from Fig.10 that stator voltage (flux) is kept constant during sudden torque variations also it is evident form Fig.9 that the stator current is adjusted in accordance with torque change to maintain speed constant.

8. Conclusion

Field oriented control is the one of the efficient way of controlling PMSM drive. Field oriented control in constant torque region is implemented here. The closed loop model simulated using MATLAB/simulink tool. The FOC system performance driving PMSM observed to be quite precise, tracking the reference speed and the load torque and providing smooth transitions over various dynamic load conditions.

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