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A Novel Technique on Simulation of A Space Vector PWM Controller for a Three Level Inverter FED Induction Motor

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Abstract **- Multilevel inverters are increasingly being used in high-power medium voltage applications due to their superior performance compared to two-level inverters. Among various modulation techniques for a multilevel inverter, the space vector pulse width modulation (SVPWM) is widely used. This paper deals with the three-phase three-level inverter fed induction motor drive. The proposed scheme deals with the development and implementation of three phase three level inverter to improve the efficiency and reliability of the inverter. Simulation tests have been carried out to examine the operating characteristics of the completed three-phase three-level inverter driving induction motor and an RL load with different switching devices and are compared.**

Keywords **– Space Vector, Simulation, PWM, FED, Induction Motor.**

I. INTRODUCTION

Numerous industrial applications have begun to require higher power apparatus in recent years. Some medium voltage motor drives and utility applications require medium voltage and megawatt power level. For a medium voltage grid, it is troublesome to connect only one power semiconductor switch directly. As a result, a multilevel power converter structure has been introduced as an alternative in high power and medium voltage situations.

Three level voltage-fed PWM inverters are recently showing growing popularity for multi-megawatt industrial drive applications. The main reason for this popularity is easy sharing of large voltage between the series devices and the improvement of the harmonic quality at the output as compared to a two level inverter.

To control multilevel converters, the pulse width modulation (PWM) strategies are the most effective, especially the space vector pulse width modulation (SVPWM) one, which has equally divided zero voltage vectors describing a lower total harmonic distortion. This technique results in higher magnitude of fundamental output voltage available as compared to sinusoidal PWM. However, SVPWM used in three-level inverters is more complex because of large number of inverter switching states.

In this paper, modelling and Simulation tests have been carried out to examine the operating characteristics of the completed three-phase three-level inverter driving induction motor and an RL load with different switching devices and are compared.

Space Vector PWM for Three Level Inverter:
Introduction:

Implementation of space vector modulation for multilevel inverters is complex computationally and intensive due to difficulty in determining the location of reference vector, calculation of on-times and determination of switching states. This section proposes a simple space vector PWM algorithm for a multilevel inverter based on standard three-level space vector PWM.

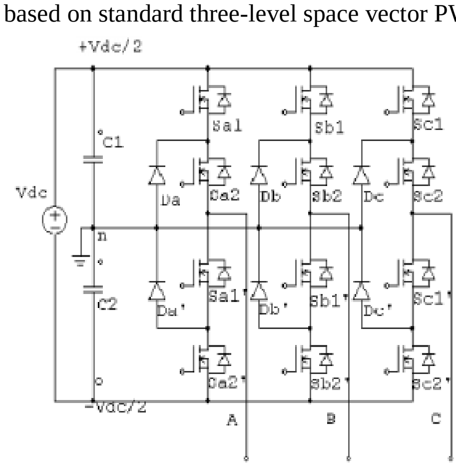

Fig.1. 3-phase, 3-level inverter

S_{a1}	S_{a2}	S'_{a1}	S'_{a2}	Output Pole Voltage (V_{Ao})	Output Phase Voltage (V_{An})
1	1	0	0	$+V_{dc}$	$+V_{dc}/2$
0	1	1	0	$+V_{dc}/2$	0
0	0	1	1	0	$-V_{dc}/2$

Fig.2. Switching States of 3-Level inverter

Ca	Cb	Cc	Sa1	Sa2	Sb1	Sb2	Sc1	Sc2	Vao	Vbo	Vco	Van	Vbn	Vcn	Vα	Vβ	Vinv	N°
0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	V0	1
1	0	0	1	1	0	1	0	1	E/2	0	0	E/3	-E/6	-E/6	E/√6	0	V11	2
0	-1	-1	0	1	0	0	0	0	0	-E/2	-E/2	E/3	-E/6	-E/6	E/√6	0	V12	3
1	1	0	1	1	1	1	0	1	E/2	E/2	0	E/6	E/6	-E/3	E/√24	E/√8	V21	4
0	0	-1	0	1	0	1	0	0	0	0	-E/2	E/6	E/6	-E/3	E/√24	E/√8	V22	5
0	1	0	0	1	1	1	0	1	0	E/2	0	-E/6	E/3	-E/6	-E/√24	E/√8	V31	6
-1	0	-1	0	0	0	1	0	0	-E/2	0	-E/2	-E/6	E/3	-E/6	-E/√24	E/√8	V32	7
0	1	1	0	1	1	1	1	1	0	E/2	E/2	-E/3	E/6	E/6	-E/√6	0	V41	8
-1	0	0	0	0	0	1	0	1	-E/2	0	0	-E/3	E/6	E/6	-E/√6	0	V42	9
0	0	1	0	1	0	1	1	1	0	0	E/2	-E/6	-E/6	E/3	-E/√24	-E/√8	V51	10
-1	-1	0	0	0	0	0	0	1	-E/2	-E/2	0	-E/6	-E/6	E/3	-E/√24	-E/√8	V52	11
1	0	1	1	1	0	1	1	1	E/2	0	E/2	E/6	-E/3	E/6	E/√24	-E/√8	V61	12
0	-1	0	0	1	0	0	0	1	0	-E/2	0	E/6	-E/3	E/6	E/√24	-E/√8	V62	13
1	1	1	1	1	1	1	1	1	E/2	E/2	E/2	0	0	0	0	0	V7	14
1	0	-1	1	1	0	1	0	0	E/2	0	-E/2	E/2	0	-E/2	E.√3/√8	E/√8	V8	15
0	1	-1	0	1	1	1	0	0	0	E/2	-E/2	0	E/2	-E/2	0	E/√2	V9	16
-1	1	0	0	0	1	1	0	1	-E/2	E/2	0	-E/2	E/2	0	-E.√3/√8	E/√8	V10	17
-1	0	1	0	0	0	1	1	1	-E/2	0	E/2	-E/2	0	E/2	-E.√3/√8	-E/√8	V11'	18
0	-1	1	0	1	0	0	1	1	0	-E/2	E/2	0	-E/2	E/2	0	-E/√2	V12'	19
1	-1	0	1	1	0	0	0	1	E/2	-E/2	0	E/2	-E/2	0	E.√3/√8	-E/√8	V13	20
-1	-1	-1	0	0	0	0	0	0	-E/2	-E/2	-E/2	0	0	0	0	0	V14	21
1	-1	-1	1	1	0	0	0	0	E/2	-E/2	-E/2	2. E/3	-E/3	-E/3	E.√2/√3	0	V15	22
1	1	-1	1	1	1	1	0	0	E/2	E/2	-E/2	E/3	E/3	-2.E/3	E/√6	E/√2	V16	23
-1	1	-1	0	0	1	1	0	0	-E/2	E/2	-E/2	-E/3	2. E/3	-E/3	-E/√6	E/√2	V17	24
-1	1	1	0	0	1	1	1	1	-E/2	E/2	E/2	-2.E/3	E/3	E/3	-E.√2/√3	0	V18	25
-1	-1	1	0	0	0	0	1	1	-E/2	-E/2	E/2	-E/3	-E/3	2.E/3	-E/√6	-E/√2	V19	26
1	-1	1	1	1	0	0	1	1	E/2	-E/2	E/2	E/3	-2.E/3	E/3	E/√6	-E/√2	V20	27

Fig.3. Switching states of 3 level inverter

This section proposes a simple space vector PWM for multilevel inverters. This is based on standard two-level SVPWM, and can be implemented for any level using one counter. Since the proposed multilevel space vector modulation method uses the basic two-level modulation to calculate the on-times, computation process for n-level inverter becomes simpler and easier. The main advantage of the proposed methodology is that it uses a simple mapping process to achieve the multilevel space vector modulation.

Proposed system for On-time Calculation:

The basic idea of space vector modulation is to compensate the required volt-seconds using discrete switching states and their on-times. Traditionally, in order to determine the on-times for a triangle of an n-level inverter three simultaneous equations are solved.

However, classical two-level space vector geometry can be used for on-time calculation for a multilevel SVPWM.

The On-time Calculation for two-level SVPWM:

Fig 4: shows the space vector diagram of a two-level inverter. Every sector is an equilateral triangle of unity side and height (h=√3/2), of a sector. On-time calculation for any of the six sectors S_i, where i=1, 2, 6, is same so let us consider the operation in sector-1.

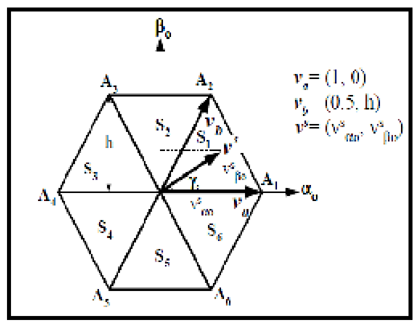

Fig.4. Space-Vector diagram for Two-Level Inverter

On-time calculation is based on the location of the reference vector within a sector. For the sector 1 in Fig- 4, the volt-second balance is given by:

Time balance is given by:

$$\upsilon^s T_s = \upsilon_a t_a + \upsilon_b t_b \quad 1.1$$

$$T_s = t_a + t_b + t_0 \quad 1.2$$

Resolving the above two equations in α_o-β_o, axis we get,

$$\upsilon^s_{\alpha o} T_s = t_a + 0.5 t_b \quad 1.3$$

$$\upsilon^s_{\alpha o} T_s = h t_b \quad 1.4$$

Solving the above three we get the on time equations

$$t_a = T_s \left[\upsilon^s_{\alpha o} - \frac{\upsilon^s_{\beta o}}{2h} \right] \quad 1.5$$

$$t_b = T_s \left[\frac{\upsilon^s_{\beta o}}{h} \right] \quad 1.6$$

$$t_o = T_s - t_a - t_b \quad 1.7$$

The On-time Calculation for 3-level SVPWM:

Fig.5, illustrates the proposed method of on-times calculation for a 3-level inverter. Each sector of a 3-level inverter can be split into 4 triangles Δ_j, where j = 0, 1, 2, 3. To simplify on-time calculation, these triangles can be categorized into two types; type 1 and type 2. The triangle of type 1 has its base side at the bottom, as shown in Fig-5(b). Triangles Δ_0, Δ_1 and Δ_3 are of type 1. The triangle of type 2 has its base side at the top, as shown in Fig-5(d). Triangle Δ_2 is of type 2.

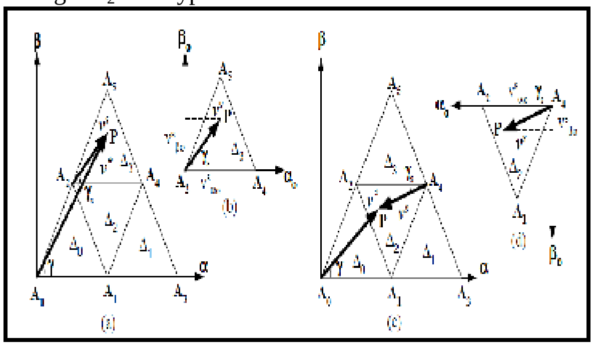

Fig.5. Space Vector Diagram – virtual two level from three level.

Simulation Results from Three-Level inverter:

The below Fig.6. represents the simulation of the Space Vector Pulse Width Modulation Controller for a three level voltage fed inverter motor drive. It consists of a three level bridge Inverter whose gating pulses are controlled by a SVPWM generator and a three phase transformer feeding an Induction Motor.

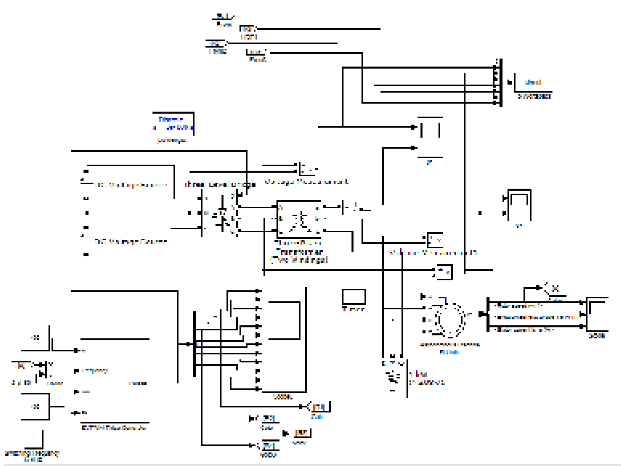

Fig.6. Simulation of the SVPWM fed controller for Three-level Inverter fed Induction Motor Drive

Here are the results of the above simulation at the motor side. They are:

a. Rotor Speed.
b. Electromagnetic Torque.
c. Stator Current.

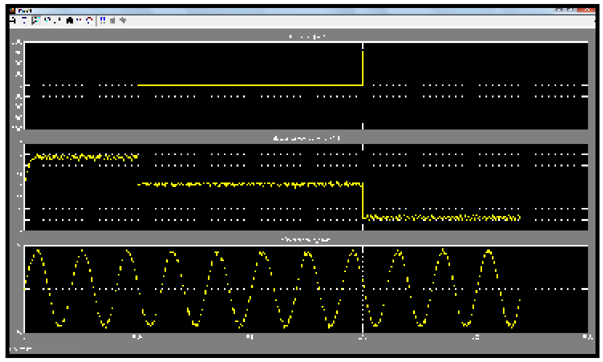

Fig.7. Scope Results for the at the Motor side

Here are the results for Fig 6 of S1, that is across the inverter's phase voltage and the magnitude of current output of the three phase transformer. The upper part shows the Phase voltage and the lower part shows the magnitude of the current from the three phase transformer.

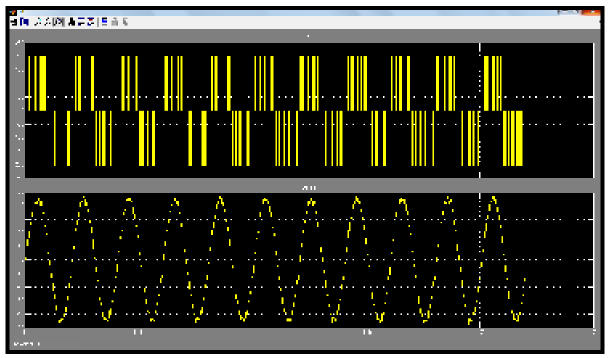

Fig.8. Scope results for motor side

Here are the results for S2 of Fig.6 for the comparison of voltage from the source to the load.

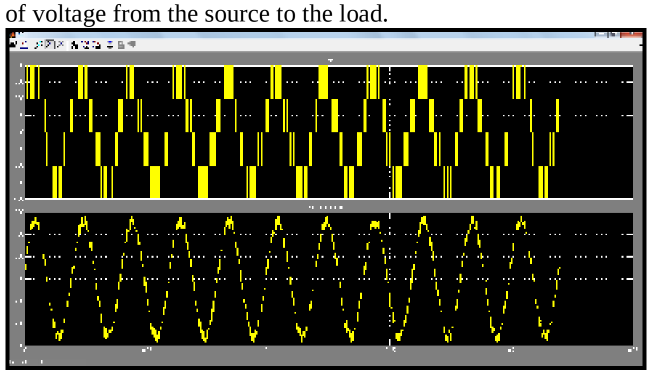

Fig.9. S2 Result for the Fig-6

Simulation of a Space Vector Pulse Width Modulation controller for a three level Voltage fed R-L load.

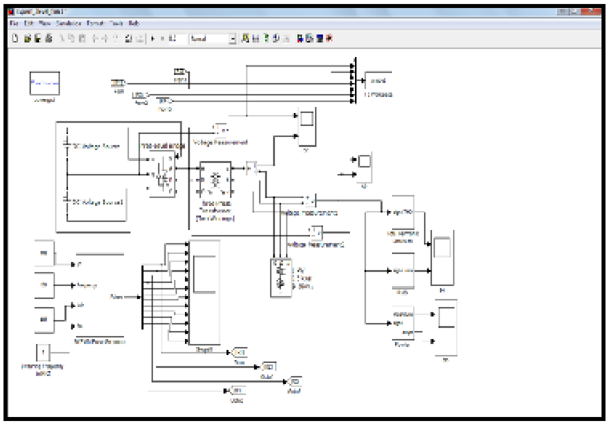

Fig.10. Simulation of three level SVPWM controller fed RL Load

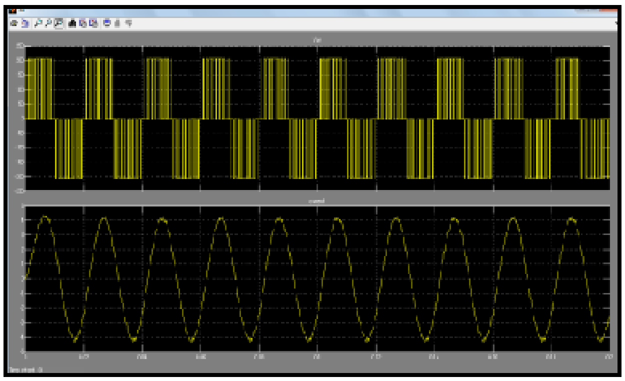

Fig.11. S1 results of the Fig.6

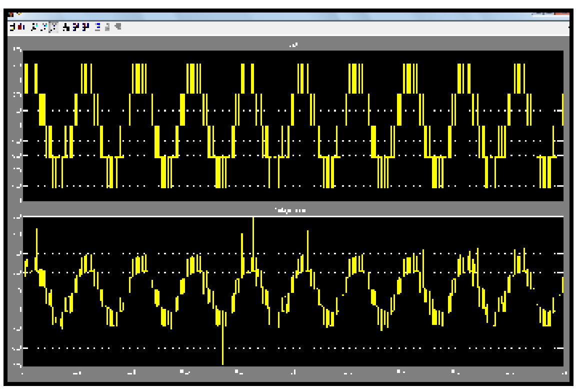

Fig.12. S2 result for Fig-6

Conclusion

The space vector PWM for a three level voltage-fed inverter has been modelled and simulated using Simulink/MATLAB package program. Simulation results have been given for both R-L and induction motor loads. The step by step model gives an insight into the SVPWM. By varying the magnitude of the input reference different modulation index (MI) can be achieved.

1. The Modulation Index is higher for SVPWM as compared to SPWM.
2. The output voltage is about 15% more in case of SVPWM as compared to SPWM.
3. The current and torque harmonics produced are much less in case of SVPWM.

This model can be further extended to higher levels like 4,5,…,n etc.….

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