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Space-Vector-Based Synchronized Three-Level Discontinuous PWM for High-Power VSI TOPOLOGY

M. SRINIVAS KUMAR[1], G.V. RAM MOHAN[2], K. JAYAKARA BABU[3]

[1]*PG STUDENT, EEE DEPT, KAKINADA INSTITUTE OF ENGG & TECH*
[2]*ASSISTANT PROFESSOR, EEE DEPT, KAKINADA INSTITUTE OF ENGG & TECH*

Abstract —*This paper presents the Multi-level pulse width-modulated (PWM) inverters gained increased interest in the recent past years. Three-level inversion is realized with dual two-level inverters in cascade in the proposed configuration. An isolated DC power supply is used to supply each inverter in this power circuit each DC-link voltage is equal to half of the DC-link voltage in a conventional NPC three-level inverter topology. The proposed inverter scheme produces 64 space-vector combinations distributed over 19 space-vector locations as compared to 27 combinations in a conventional three-level topology. A space-vector based discontinuous PWM scheme is used for experimental verification of proposed topology.*

Keywords- *Harmonic analysis, pulse width modulation (PWM), total harmonic distortion (THD), variable speed drives, voltage source inverters (VSIs)*

I. INTRODUCTION

Three-level inverters have been extensively researched ever since they were introduced by Nabae .The advantage of the three-level topology is that multiple level voltage waveforms can be synthesized using devices with lower voltage ratings. The neutral-clamped circuit topology suggested that although simple and elegant, has some disadvantages. The DC-bus capacitors in this circuit configuration carry load currents causing a fluctuating neutral point. The H-bridge topology eliminates this problem, but requires three isolated power supplies and hence is an expensive proposition. **A** modification of the conventional neutral-clamped inverter has been suggested in which a capacitors added across the neutral clamping diodes, to ensure a dynamic balancing of the DC-bus capacitors. However, this method does not eliminate the neutral-point fluctuations completely although it effectively reduces them. Two two-level inverters connected at either end of an open-end winding induction motor drive also achieve three-level inversion. These schemes also require transformer isolation for the elimination of the harmonic currents of the triple n order in the phases. However, to implement these schemes, one needs to open the neutral point of the stator windings.

In this paper, an alternative circuit topology for three level inversions is proposed. In this circuit configuration, three-level inversion is achieved by connecting two two-levelinverters in cascade. A sine-triangle modulation technique for the control of inverters was used for the open-end winding induction motor.

The PWM strategy suggested in this work uses all the space vector locations. The effective time concept proposed in Kim and Suland Chung is extended to a dual-inverter driven open-end winding induction motor drive. In the proposed PWM scheme, the actual gating times for the inverter devices are obtained by a simple relocation of the effective time period in the sampling time interval. The proposed PWM scheme eliminates additional hardware requirements such as auxiliary switches. Specifically, the PWM scheme proposed in this paper significantly induces the zero-sequence current by dynamically balancing the zero-sequence voltages, by the effective time relocation algorithm.

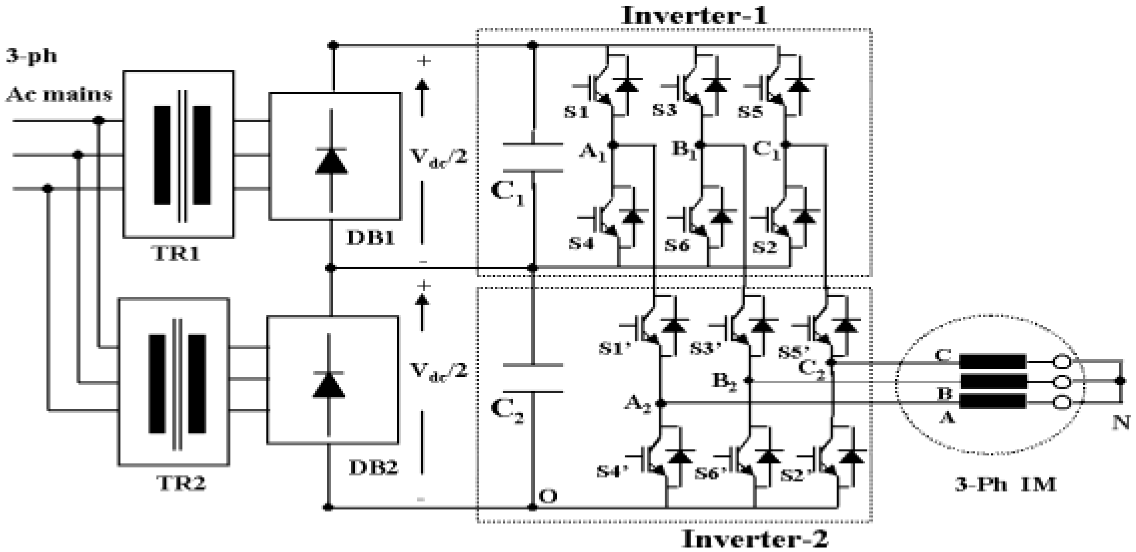


Fig .1. Circuit schematic of three-level cascaded H-bridge inverter.

The pole voltage of any phase for inv-2 attains a voltage of Vdc/2 if the top switch in inv-2 and bottom switch in inv-1 is turned on Vdc if top switch in inv-2 and top switch in inv-1 is turned on Zero if the bottom switch in inv-2 is turned on.

Principle of Space-Vector Modulation

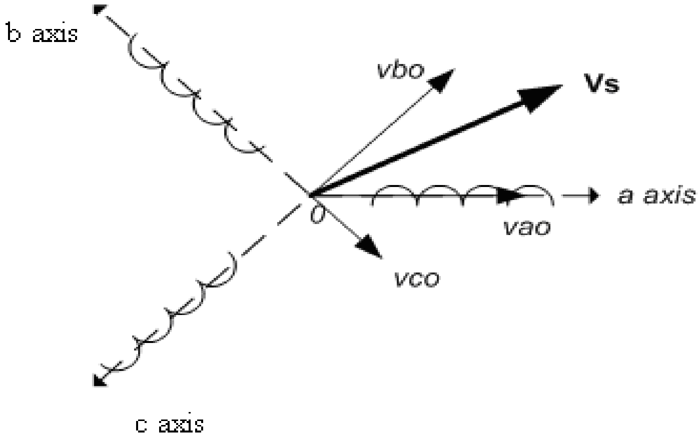


Fig 3.1 Space vector formed by the instantaneous pole voltages

Figure 3.1 shows the three phase windings and the respective axes of an induction motor.

The space vector $\mathbf{V_s}$ as shown in fig.3.1 constituted by the pole voltages v_{AO} , v_{BO} and v_{CO} is defined as:

$$\mathbf{V_s} = v_{AO} + v_{BO}.\exp\,[\,j\;(2\pi/3)] + v_{CO}.\exp\,[\,j\;(4\pi/3)] \qquad (3.5)$$

The relationship between the phase voltages v_{AN} , v_{BN} , v_{CN} and the pole voltages v_{AO} , v_{BO} and v_{CO} is given by:

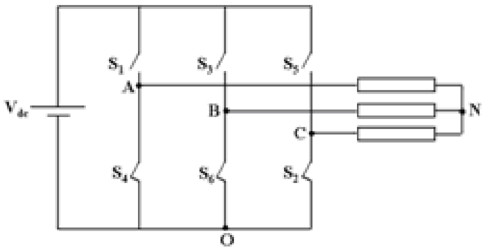


fig 3.2a state 8(---)

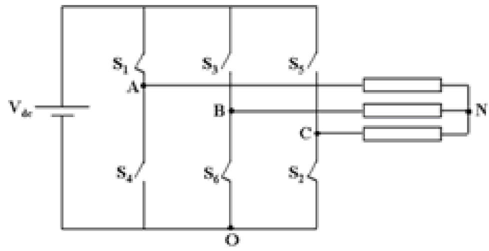


fig 3.2b state1(+--)

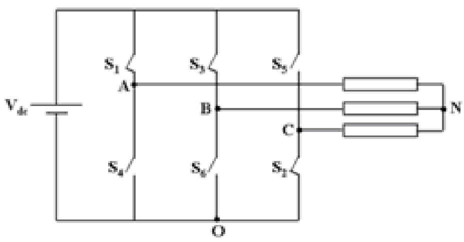


fig 3.2c state 2(++-)

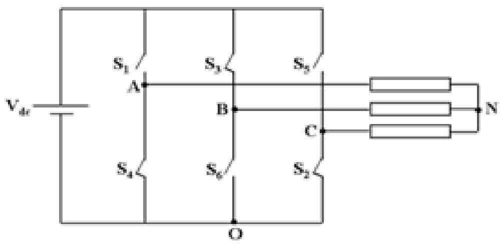


fig 3.2d 3(-+-)

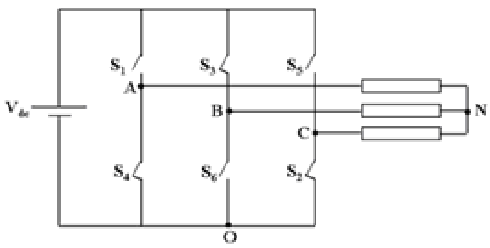


fig 3.2e state 4(-++)

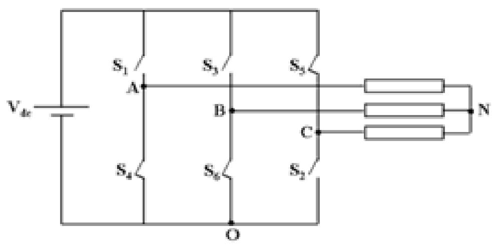


fig 3.2f state 5(--+)

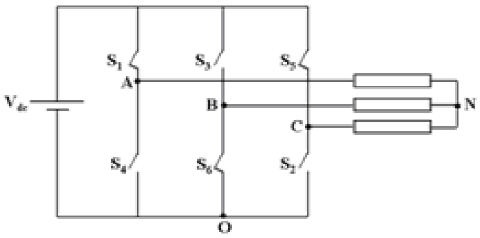


fig 3.2g state 6(+-+)

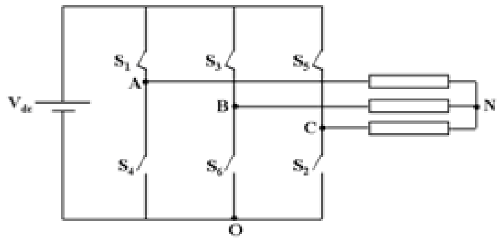


fig 3.2h state7(+++)

Fig. 3.2 Basic possible combinations as per space vector modulation

The following example illustrates the method of determination of the space vector location for a given state. When the inverter assumes a state of

'2' (+ + -) as shown in Fig. 3.2c:

$$v_{AO} = V_{dc} \quad ; \quad v_{BO} = V_{dc} \quad ; \quad v_{CO} = 0 \tag{3.10}$$

Hence the space vector for this state is given by from eqn.5.1,

$$\mathbf{V_s} = (V_{dc}) + (V_{dc}).\exp\,[j\,(2\pi/3)] + (0).\exp\,[j\,(4\pi/3)] = V_{dc}\left(\frac{1}{2} + j\frac{\sqrt{3}}{2}\right) = V_{dc}\ \angle 60^0 \tag{3.11}$$

The space vector locations for the rest of the states may similarly be evaluated. The space vector locations for a two-level inverter form the vertices of a regular hexagon, forming 6 sectors as shown in Fig.3.3. For the states 8 (- - -) and 7(+ + +) the motor phases are short-circuited and therefore are not connected to the source. These states are called the zero states or null states during which there is no power flow from the source to the motor. Hence, by controlling the duration of these zero state intervals, one can control the output voltage magnitude. It is worth noting that in six-state mode of operation, such intervals of zero state switching do not exist. Consequently, the output voltage magnitude in an inverter operating in a square wave mode must be controlled by controlling the input DC link voltage. The rest of the vectors 1 through 6 are called the active vectors.

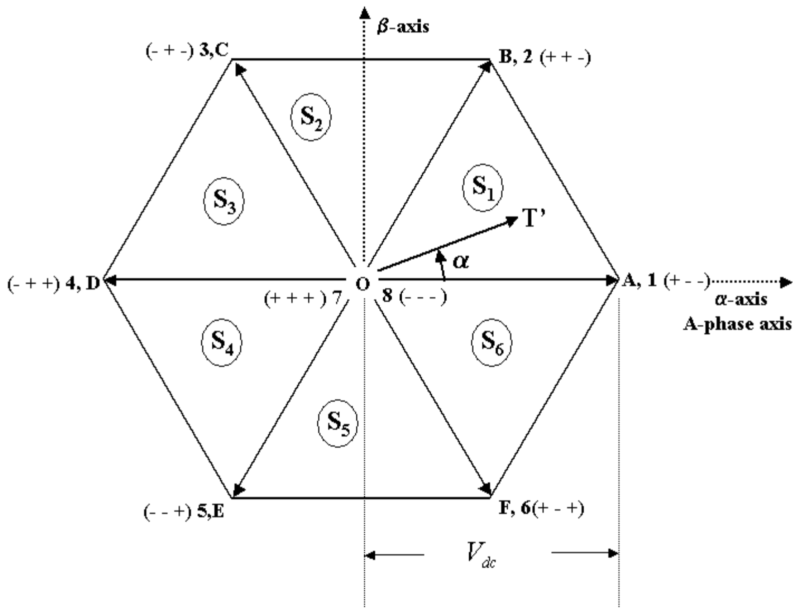
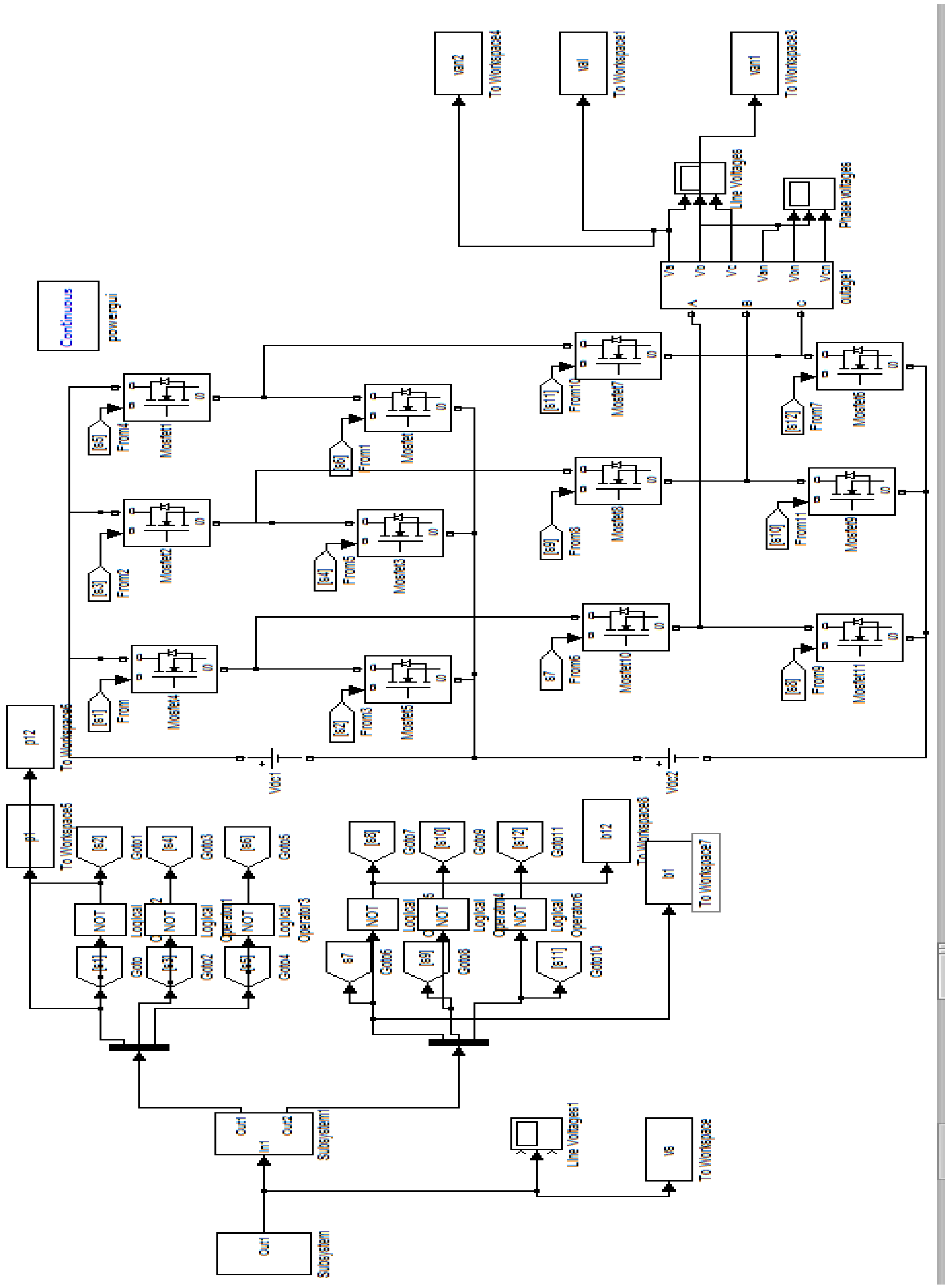


Fig.3.3 Space vector locations for a two-level inverter

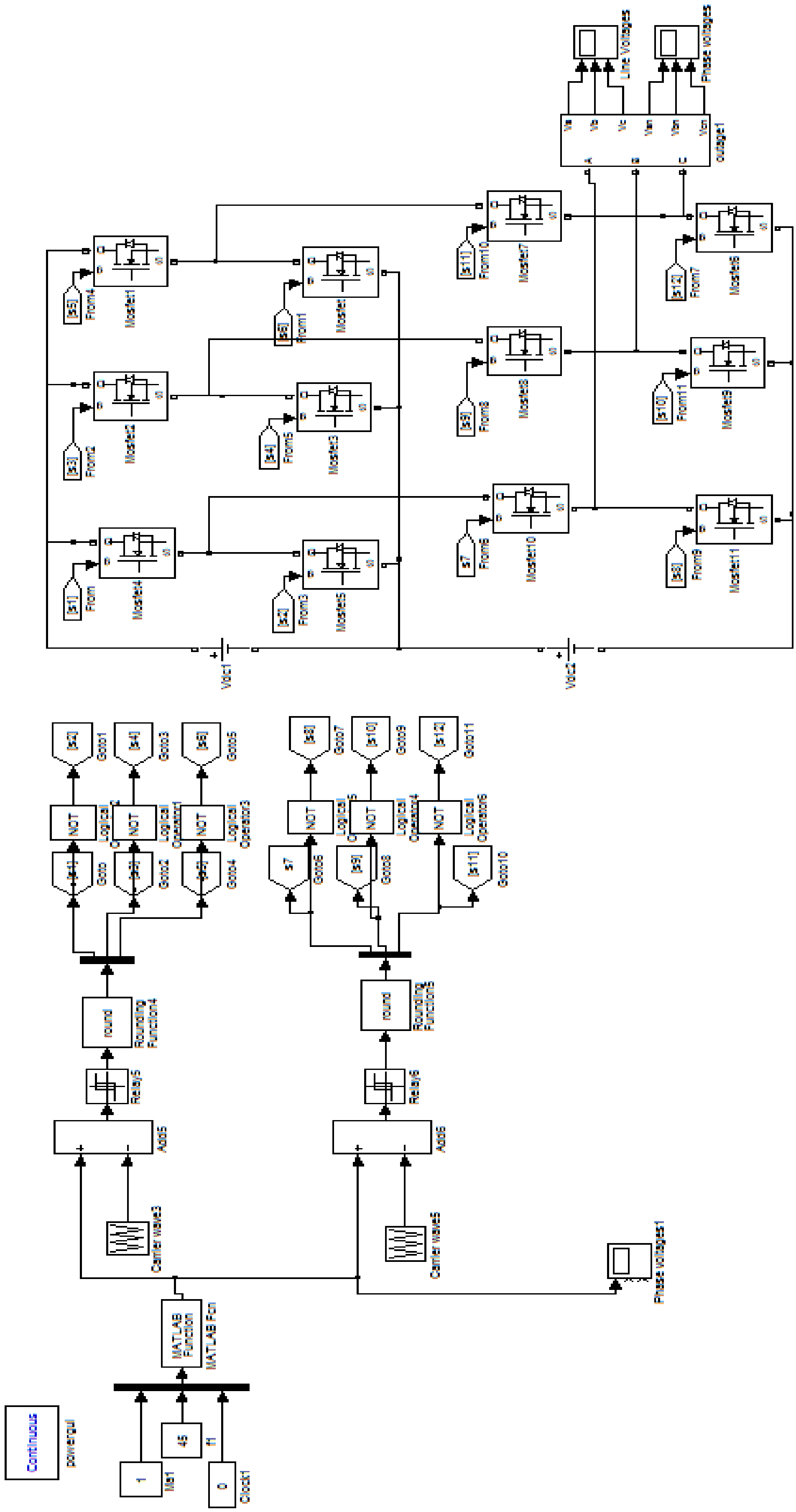
The vector OT' represents the reference voltage space vector (or sample for simplicity), corresponding to the desired value of the fundamental components for the output phase voltages. It is obtained by substituting the instantaneous values of the reference phase voltages, sampled at regular time intervals, in eqn. It may be noted that there is no direct way to generate the sample. It can be reproduced in the average sense by switching amongst the inverter states situated at the vertices, which are in the closest proximity to it. For the situation depicted, the sample can be realized by switching among the inverter states situated at the vertices O, A and B following a certain sequence. The vectors OT', AT' and BT' respectively denote the deviation of the sample when the inverter states situated at O, A, and B are switched to construct the sample in the average sense. Therefore, one may conclude that the realization of the sample in the average sense produces switching ripple corresponding to these vectors (OT', AT'and BT').

SIMULATION RESULTS AND ANALYSIS

SIMULINK MODEL OF 3-LEVEL INVERTER CASCADING TWO 2-LEVEL INVERTER TOPOLOGY USING SINE PWM



SIMULINK MODEL OF 3 LEVEL INVERTER CASCADING TWO 2-LEVEL INVERTER TOPOLOGY USING SPACE VECTOR PWM



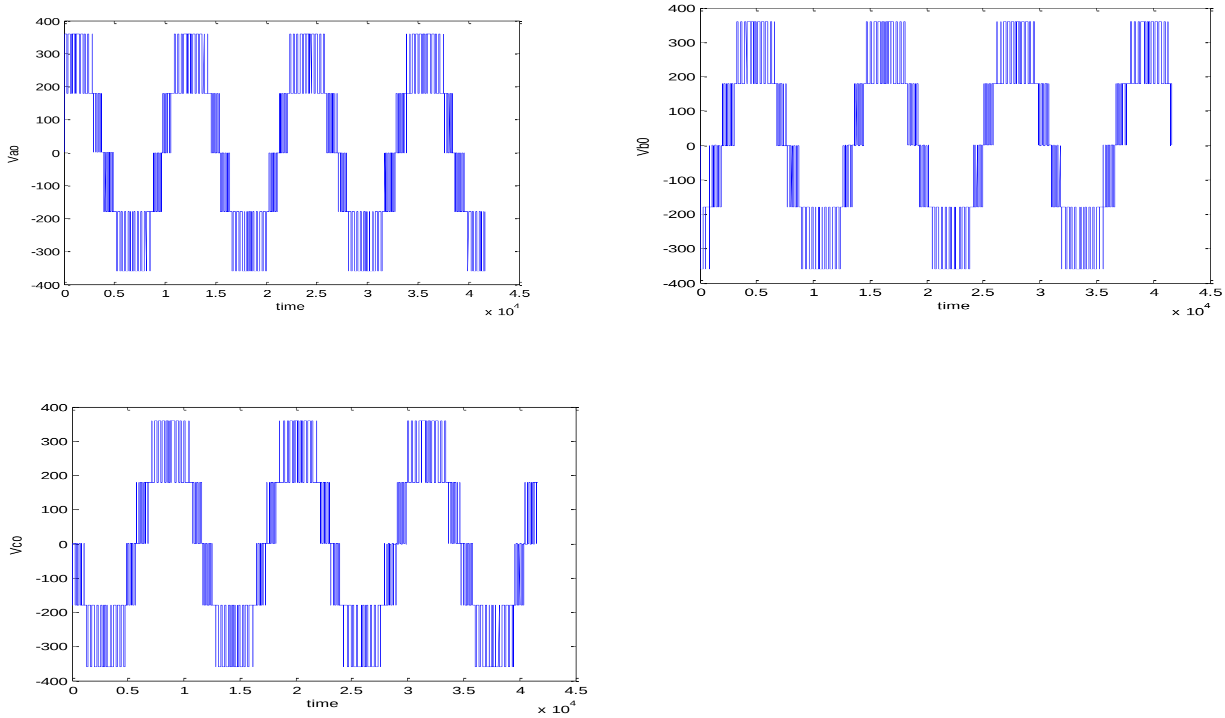


Fig 5.1 Simulated waveform of the SPWM, Pole voltage V_{AO},V_{BO} and V_{CO} in 3-level inversion mode

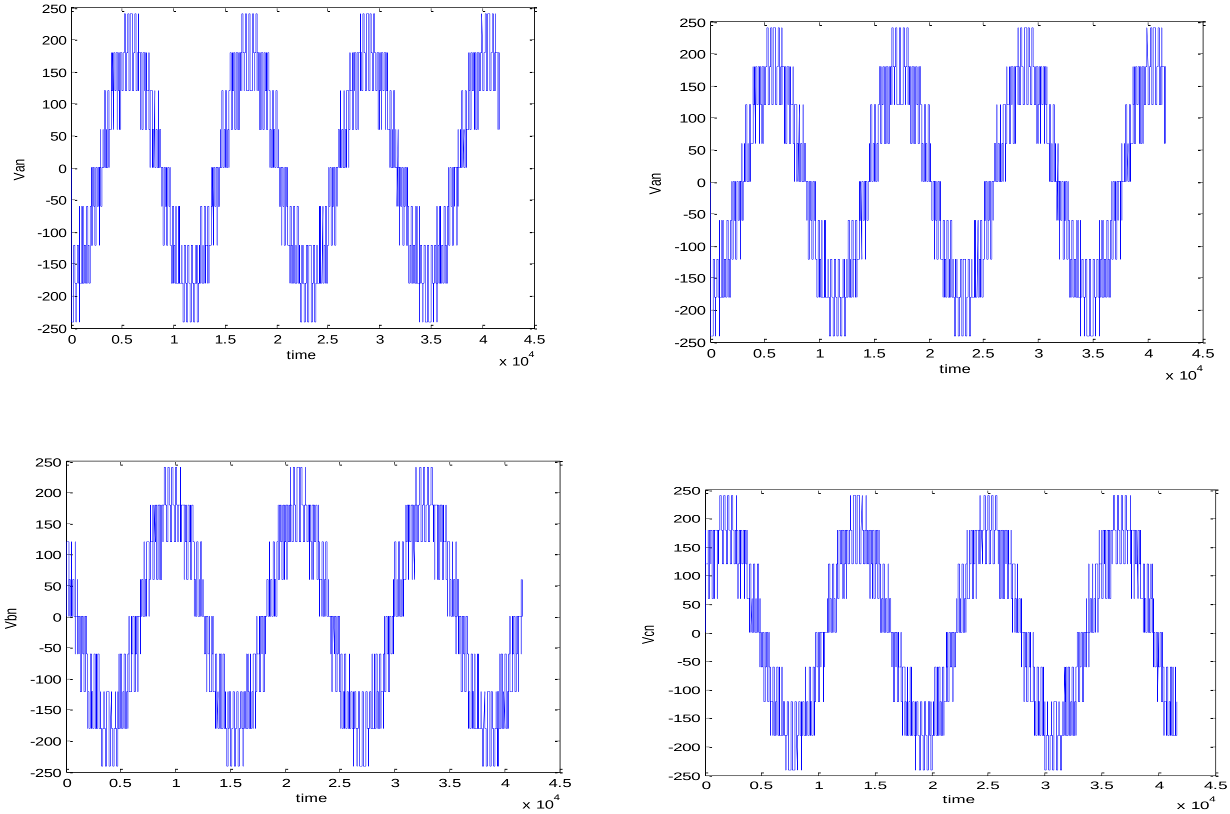


Fig. 5.2 Simulated waveform of the SPWM, effective phase voltages V_{an},V_{bn} and V_{cn} in 3-level inversion mode

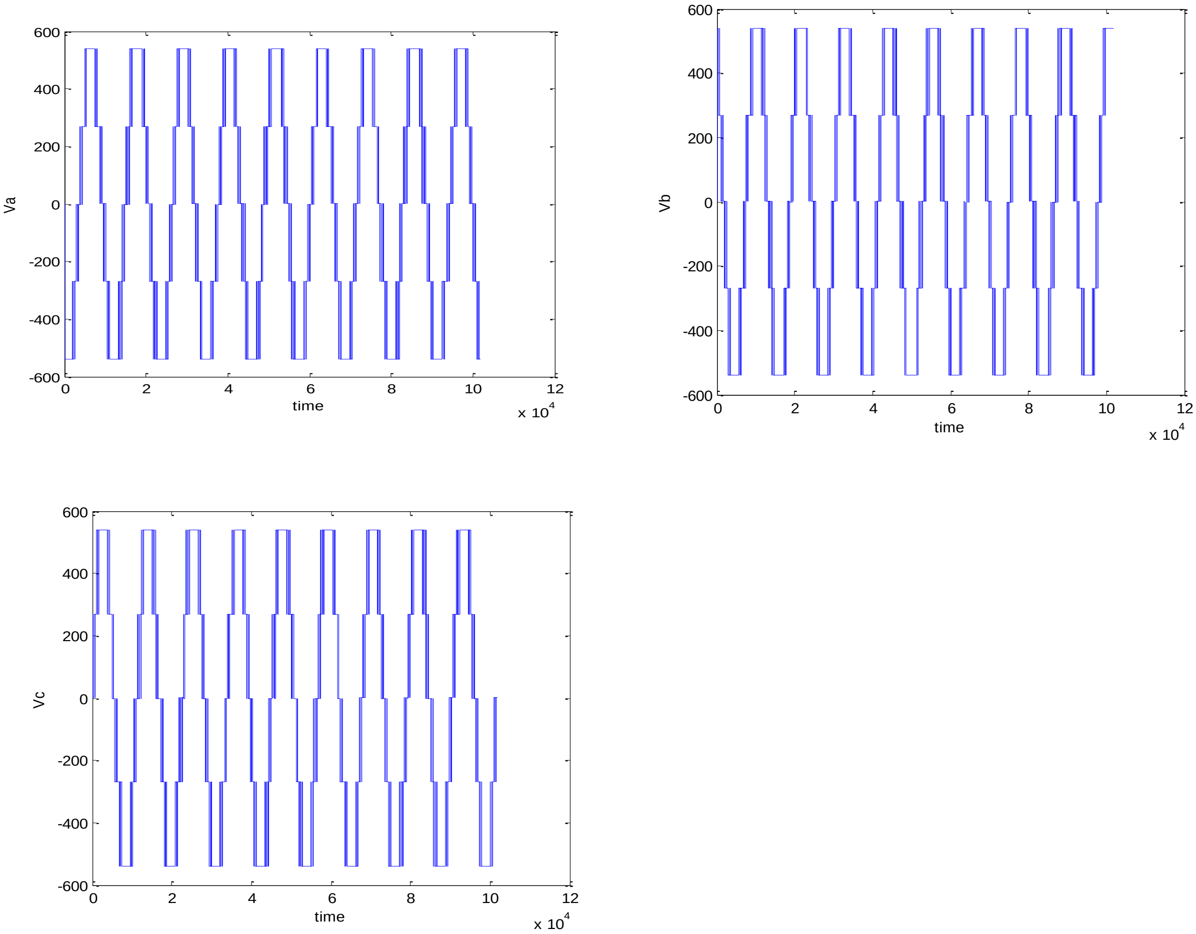


Fig. 5.3 Simulated waveform of the SVPWM, Pole voltages V_{ao},V_{bo} and V_{co} in 3-level inversion mode.

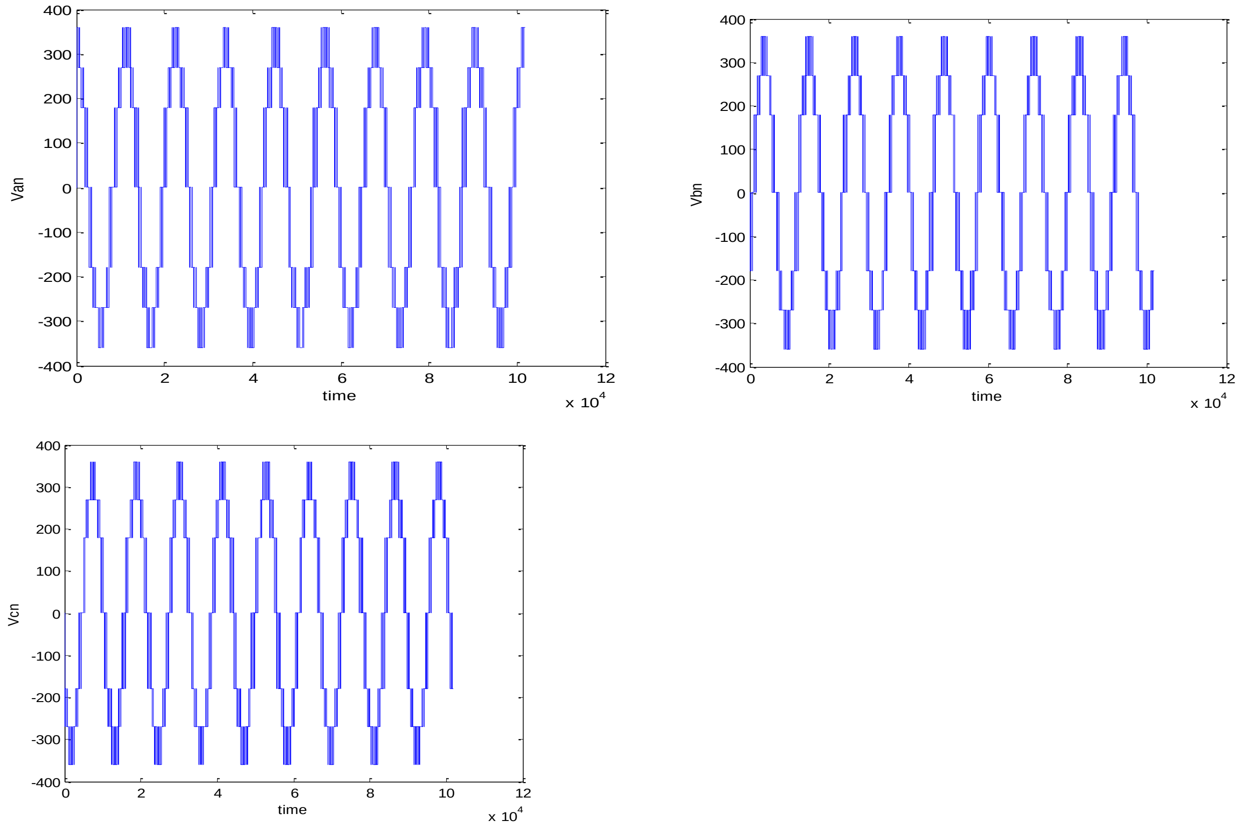
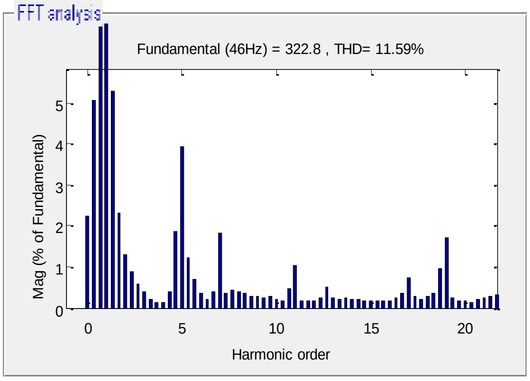
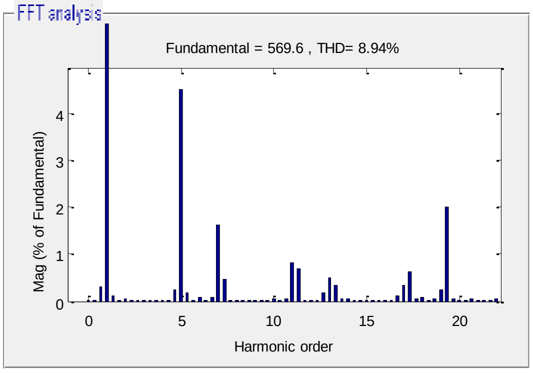


Fig. 5.4 Simulated waveform of the SVPWM, effective phase voltages V_{an}, V_{bn} and V_{cn}

FFT ANALYSIS:





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