Comparative Analysis of Conduction Modes for Three Phase Six Switches Voltage Source Inverter

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***Abstract*— This paper presents a comparative analysis of 180^0, 120^0 and 150^0 conduction mode for the most-common and well-known three-phase voltage source inverter (VSI). Each one of the six switches conducts for 150^0. For a wye-connected load, the phase-voltage waveforms consist seven-level and 12 Steps. So, it is closer to the sinusoidal waveform. This result in a 50% reduction of the total harmonic distortion (THD) and the lowest order harmonic (LOH) becomes 11 rather than 5. The simulation is performed using two different software tools PSIM 6.0 and MATLAB-SIMULINK.**

***Index Terms*—Voltage source inverter(VSI), THD, LOH.**

I. Introduction

THREE phase six-switch voltage source inverters (VSI) are more common in industrial applications. In inverter, a step is defined as a change in the firing from one switch to next switch in proper sequence. For one cycle of 360º, each step would be of 60º interval for a six step inverter.

The main objective is to reducing the harmonic contents of generated output waveforms for VSI system [1]. Various theories have been innovated to achieve these goals [2]. These converters have many disadvantages like higher cost compared to the classical three-phase VSI, higher size and weight, complicated power and control circuits. So, the huge numbers of power electronic components are required.

This paper presents comparative study of different conduction modes for three-phase voltage source inverter. Traditionally, three phase voltage source inverter uses 120º or 180º conduction period for its switching operation. The third one is 150º conduction modes. This strategy combines the commonly used 180º conduction and 120º conduction modes to generate a new operating mode. This mode produces seven levels of voltage instead of the only five levels for wye connected load. It is generated by the simple structure, simple control circuit. In 150º conduction mode, phase output voltage wave shape consist 12 steps. So, it is closer to the sinusoidal waveform [3]. It should be noticed that, without any additional cost or structural changes or complexity, the THD of the output waves has been reduced about 50% in 150^0 conduction mode.

Pattern of gate pulses, phase voltage and common mode voltage (CMV) waveforms, line voltage waveforms and FFT for line voltages are the comparative points discussed in this paper. They are explained in the next section. TABLE II gives the comparative analysis of all the three conduction methods.

II. Comparison of Conduction Modes

Block diagram of three phase VSI system is shown in Fig. 1. DC supply used as an input of three phase inverter. The ac output of inverter is given to the load. In control circuit; 180^0, 120^0 and 150^0 conduction mode is implemented.

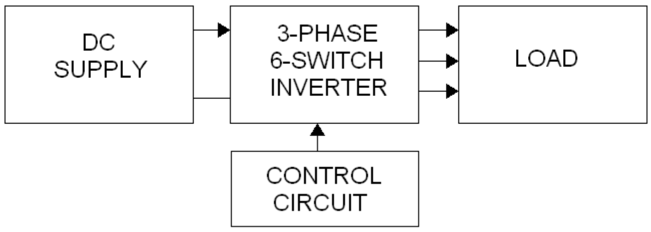


Fig.1 Block diagram of three phase classical VSI

For better comparisons of three different conduction modes, the results are achieved from software packages PSIM 6.0 and MATLAB-SIMULINK. Fig.2 shows the simulated model in PSIM 6.0.

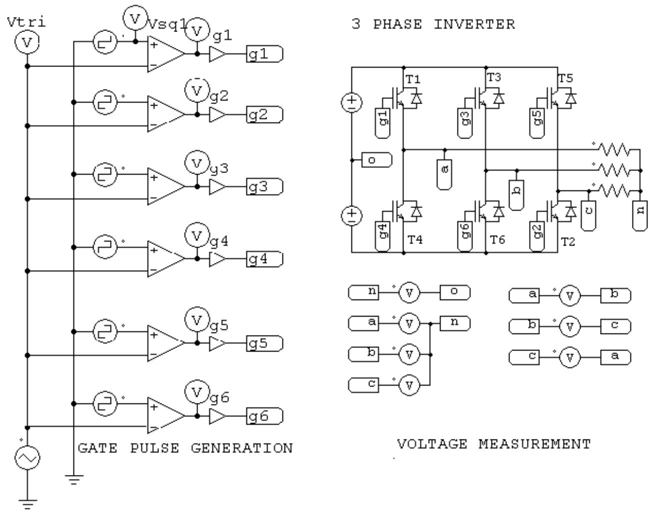
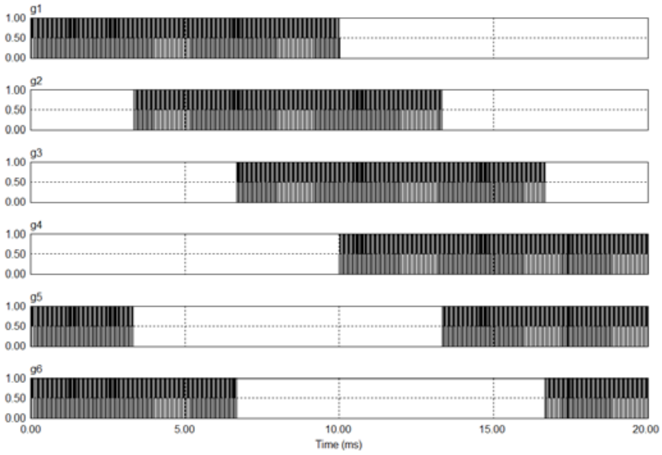


Fig.2 Simulated model of three phase classical VSI

The topics of comparisons are: gate pulses, phase voltage, common mode voltage (CMV), line voltage, FFT for line voltages and V_l/V_d voltage ratio.

A. Gate pulses

Gate pulses of three conduction modes are first topic in comparative analysis. Gate pulses of each switches for three different conduction mode is shown in Fig. 3.



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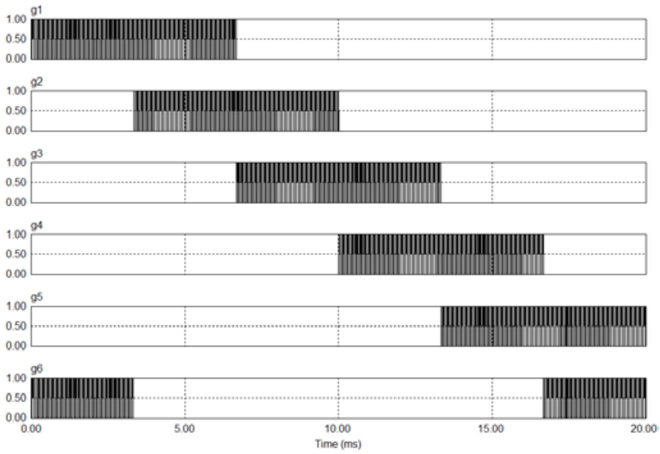

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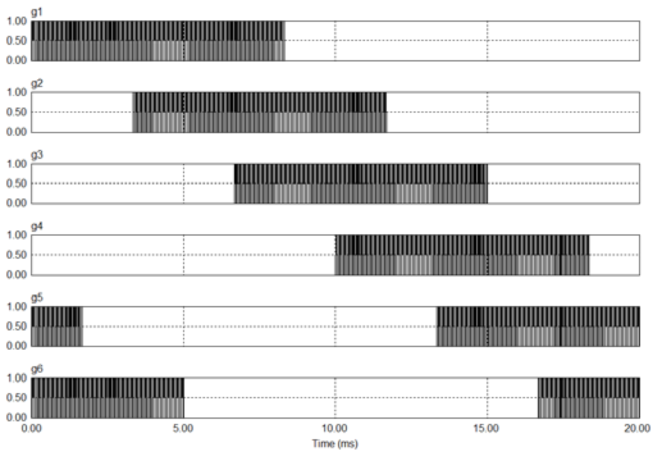

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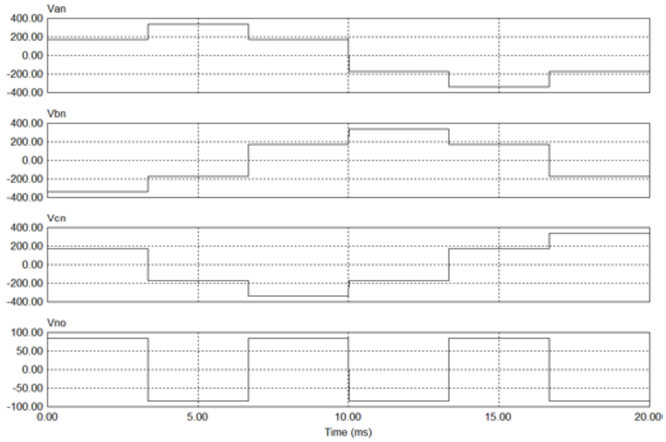
Fig. 3 Gate pulses (g1, g2, g3, g4, g5, g6) of six switches for (a) 180^0, (b) 120^0, (c) 150^0 mode conduction

One switch per inverter leg conducts for 180^0, so three switches remain on at any instant of time in 180^0 mode conduction. For phase "a", when switch T1 is switched on, phase "a" is connected to the positive terminal of the dc input voltage, + $V_d/2$. When switch T4 is switched on, phase "a" is connected to the negative terminal of the dc source,-$V_d/2$. The same sequence is occurred in other two phases "b", and "c". The absence of any time delay between two complimentary switches causing short circuit on the dc bus. In 120^0 conduction mode, the same inverter bridge can be controlled with each switch conducting for 120^0. As a result, at any instant, only two switches conduct. So, 60^0 dead time between two series switches. Therefore a safety margin against simultaneous conduction of the two series device across the dc supply is provided. It means that no short circuit could happen on the dc bus. Here switching device utilization is poor. Now see the gate pulses for 150^0 mode, three switches are conducting in one interval as in 180^0 mode, while only two switches conduct in the next one as in 120^0 mode. In 150^0 mode a 30^0 dead-time is available as a safety margin, which is large enough to avoid short circuit on dc supply. Also utilization of switching device is better.

B. Phase Voltages & Common mode voltage



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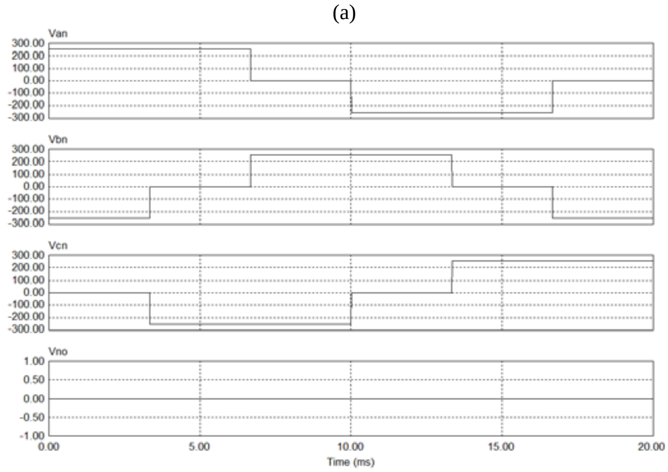

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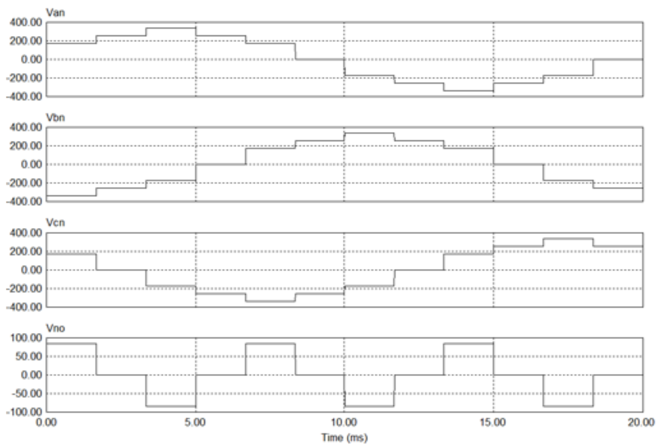

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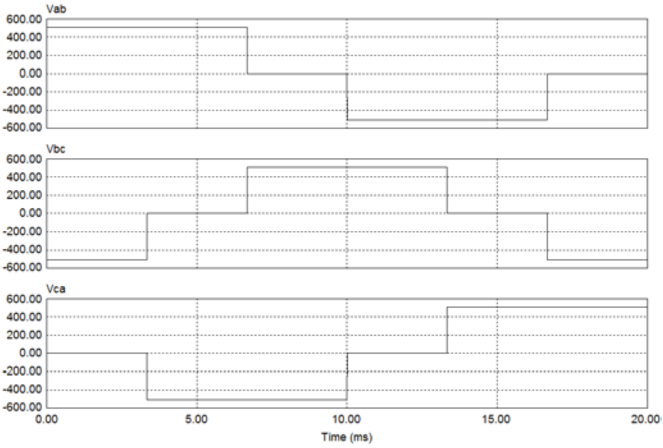
Fig. 4 phase voltages (V_{an}, V_{bn}, V_{cn}) & CMV (V_{no}) waveform: (a) 180^0, (b) 120^0, (c) 150^0 mode conduction

Phase voltage and common mode voltage waveforms for three different conduction modes are as shown in Fig. 4. In 180^0 mode four different voltage levels are obtained $\pm V_d/3$,

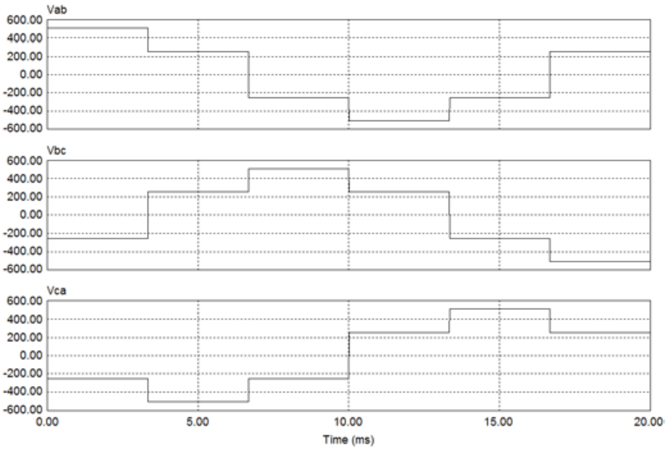
$\pm 2V_d/3$. Each step size is $\pi/3$. CMV is $\pm V_d/6$. While, in 120^0 mode only three levels 0, $\pm V_d/2$ is obtained. CMV is zero in this mode. Comparatively in 150^0 mode the step size is $\pi/3$ with seven voltage levels 0, $\pm V_d/3$, $\pm V_d/2$ and $\pm 2V_d/3$. It is closer to the sinusoidal waveform. Also, in CMV three levels which are; 0 and $\pm V_d/6$.

C. Line Voltage

The waveforms of line voltages for different conduction modes are shown in Fig. 5. 180^0 mode consists three levels 0, $\pm V_d$. On the other side four levels $\pm V_d$, $\pm V_d/2$ is present in 120^0 mode conduction. The 150^0 mode consists five levels 0, $\pm V_d$, $\pm V_d/2$.



(a)



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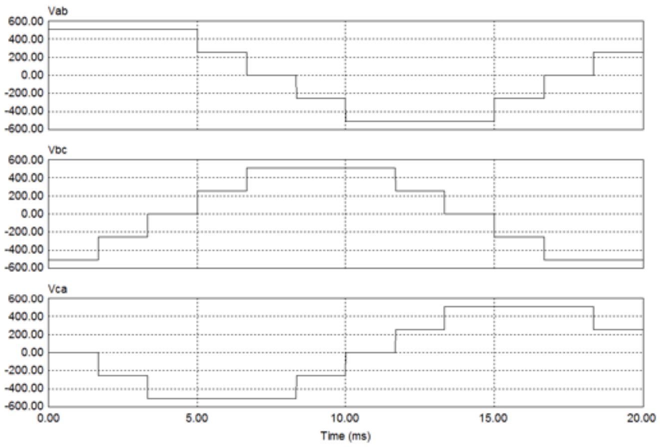

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Fig. 5 line voltage waveforms (V_{ab}, V_{bc}, V_{ca}) :(a) 180^0, (b) 120^0, (c) 150^0 mode conduction

D. FFT analysis of line voltages

For 180^0 conduction mode, the line-to-line voltage, V_{ab} is expressed in Fourier series, as [4]

$$V_{ab\_180^0} = \sum_{n=1,3,5,..}^{\infty} \frac{4V_d}{n\pi}\cos\frac{n\pi}{6} \qquad (1)$$

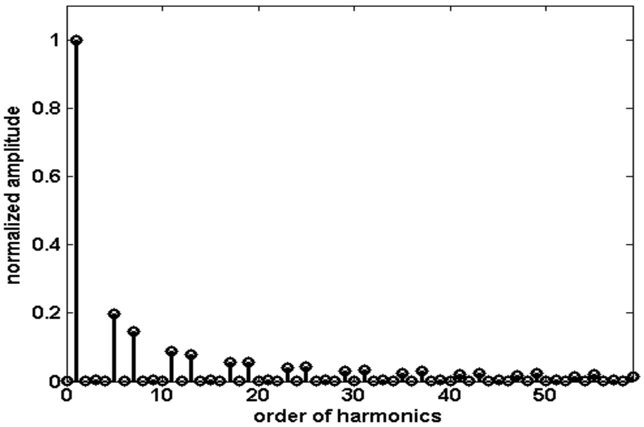
The line-to-line voltage, V_{ab} is expressed in Fourier series for 120^0, as [4]

$$V_{ab\_120^0} = \sum_{n=1,3,5,..}^{\infty} \frac{2\sqrt{3}V_d}{n\pi}\cos\frac{n\pi}{6}\sin n\left(\omega t+\frac{\pi}{3}\right) \qquad (2)$$

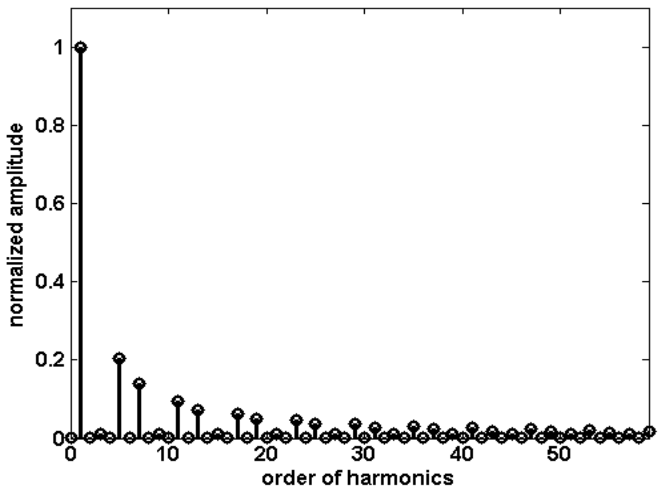
The line-to-neutral voltage, V_{an} is expressed in Fourier series for 150^0, as [3]

$$V_{an\_150^0} = \sum_{n=1,3,5,..}^{\infty} \frac{V_d}{6n\pi}\begin{bmatrix} 4+\cos\frac{n\pi}{6}+\cos\frac{n\pi}{3}-\cos\frac{2n\pi}{3} \\ -2\cos\frac{5n\pi}{6}-\cos\frac{7n\pi}{6}-\cos\frac{4n\pi}{3} \\ +\cos\frac{5n\pi}{3}+2\cos\frac{11n\pi}{6} \end{bmatrix}\sin n\left(\omega t+\frac{\pi}{6}\right) \qquad (3)$$

Fig. 6 shows the FFT results for three different conduction modes. From it, percentage voltage harmonic factor are found and tabulated in table I. The percentage voltage harmonic factor, HF_n, for the n^{th} harmonic is defined as the ratio of RMS of n^{th} harmonic component, V_n, to fundamental component, V_1, involved in output voltage. To find out this harmonic factor for three conduction modes FFT analysis is done from simulated results of MATLAB-SIMULINK.



(a)



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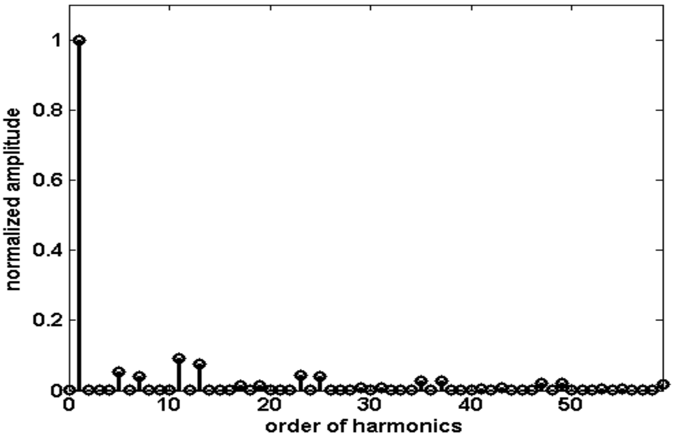

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Fig. 6 FFT for line voltage: (a) 180^0, (b) 120^0, (c) 150^0 mode conduction

TABLE I

HARMONIC FACTOR FOR DIFFERENT MODES

H.Order	180°	120°	150°
5	20	20	1.43
7	14.28	14.28	1.02
11	9.09	9.09	9.09
13	7.69	7.69	7.69
17	5.88	5.88	0.42
19	5.26	5.26	0.37
23	4.34	4.34	4.34
25	4.00	4.00	4.00
29	3.44	3.44	0.24
31	3.22	3.22	0.23
35	2.85	2.85	2.85
37	2.70	2.70	2.70
41	2.43	2.43	0.17
43	2.32	2.32	0.16
47	2.12	2.12	2.12
49	2.04	2.04	2.04

From Table I, it is recognized that: harmonics of order n=12m±1 (m=1, 2, 3, etc.), such as 11, 13, 23, 25, etc. remain unchanged in 180^0, 120^0, 150^0 modes. Other harmonics of order n=6m±1 (m =1, 3, 5, etc.), such as 5, 7, 17, 19, etc. are extremely reduced in the 150^0 conduction mode. The Lowest order harmonic has been moved from the 5^{th} component in 180^0 and 120^0 to the 11^{th} one in 150^0 conduction mode.

E. V_l/V_d voltage ratio

For 180^0 conduction mode, the V_l/V_d ratio is 0.846 and for 120^0 conduction mode, it is 0.707[4]. Now V_l/V_d ratio for 150^0 is as,

$$V_{l\_150^0} = \sqrt{\frac{7}{12}} V_{dc} \tag{4}$$

$$V_{l\_150^0} = 0.746 V_{dc} \tag{5}$$

$$\frac{V_{l\_150^0}}{V_{dc}} = 0.746 \tag{6}$$

From this analysis Table II is formulated with comparison points like type of dc source, no. of step per cycle, voltage ratio, levels in phase voltage, LOH, %THD (LL) etc. All and average the 150^0 conduction mode is much better than both of the other.

TABLE II

COMPARATIVE TABLE FOR 180^0, 120^0 AND 150^0 MODES

Topic	180^0	120^0	150^0
dc source	dc with Np	dc with Np	dc with Np
no of switches	6	6	6
V_l/V_d	0.816	0.707	0.746
no. of step per cycle	6	6	12
step size	60^0	60^0	30^0
levels in phase voltage	4	3	7
LOH	5	5	11
V_{ph}/V_d	0.471	0.408	0.441
THD(LL)%	31.17	31.04	16.88

III. CONCLUSION

In 150° conduction mode, better performance can be achieved without any additional components in the circuit. Proper delay, better utilization of switches, more numbers of steps in output voltage waveform, %THD is half with respect to others, LOH is 11^{th} one are the topics which supports to put this mode of conduction in the first priority level.

IV. REFERENCES

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