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Implementation of Three Phase 12-Step VSI with Harmonics Reduction

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Abstract- **In this paper a novel circuit topology for reducing the harmonics in the output voltage of a three-phase voltage-source inverter is proposed. It is found that in comparison with conventional conduction modes like 120° and 180°, there are introduced less harmonics with 150° conduction mode. The quality of output voltage can be improved by only changing the conduction mode which is very simple to implement. In this paper, the scheme is implemented and tested for 1.5kW, 50 Hz VSI. The control signals are generated using AT89C51 microcontroller. The output waveforms under various load conditions were examined, analyzed and verified.**

Keywords- **Voltage Source Inverter; AT89C51; 150° Conduction mode; Harmonic analysis;**

I. Introduction

The three phase six-step voltage source inverter is universally used as D.C. to A.C. converter. In industrial applications like A.C. drives, VFD controllers, hybrid electrical vehicle 3-phase VSI is used to operate and control the motor. Nowadays renewable energy like solar system and wind energy systems also use VSI. The common modes of conduction of inverter employing almost all applications are mainly 180° and 120°. Conduction mode decides the output voltage and harmonics of the system.

It is known that the usage of inverter lead to harmonics added in the system. Instead of higher order, lower order harmonics are more harmful to the system. To take full advantage of three phase VSI, improved control techniques and modulation techniques are used to control and eliminate the harmonics of inverter, but still lower order harmonics are present in the system.

To eliminate lower order harmonics, filters are designed. Also some advance control techniques as harmonics injection method and vector control techniques can be used. Passive filter are massive, expensive and short subsist and not suitable for all applications. Advance control techniques required skill and advance controllers which are also costly and hardly used for general applications.

A simplified technique to reduce the effect of lower order harmonics from the output of three phase VSI is 150° conduction angle. Instead of using conventional 180° and 120° conduction mode, we can cut down the harmonics up to 50% using this nonconventional conduction mode.

II. 150° Conduction Mode VSI

The power circuit for 150° conduction mode inverter is same as conventional conduction mode inverter, but conduction modes are different. By adjusting the utility factor of switches the THD can be minimized. It is simple to achieve, implement and does not require any advance controllers. Circuit diagram for three phase VSI is shown in figure 1:

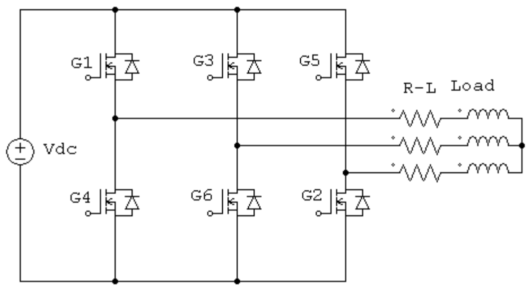


Figure 1 Three-Phase VSI circuit

In 180° conduction mode each switch conducts for 180°, means its duty cycle is 50%. While in 120° conduction mode each switch conducts for 120°, i.e. the duty cycle is 33.33%. But in 150° conduction mode each switch is conduct for 150°, means its duty cycle is 41.67%. The switching pattern is specified in the Table I.

A. *Switching Sequence*

In Table I switching pattern for half cycle is provided and voltage level with respect to time. Figure 2 shows the gating signals for all six switches for 150° mode of conduction.

Sr. No.	Angle Of Conduction	Conducting Switches	Output Voltage Level
1	0° to 30°	S1, S5, S6	Vdc/3

2	30° to 60°	S1, S6	Vdc/2
3	60° to 90°	S1, S2, S6	2Vdc/3
4	90° to 120°	S1, S2	Vdc/2
5	120° to 150°	S1, S2, S3	Vdc/3
6	150° to 180°	S2, S3	0

Table I Switching pattern for half cycle

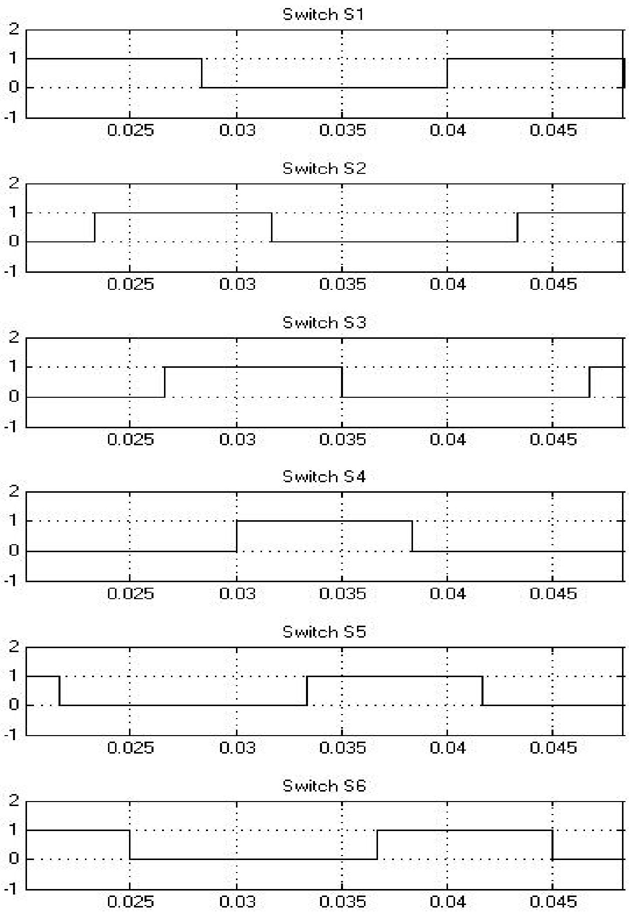


Figure 2 Switching pattern of 150° conduction mode

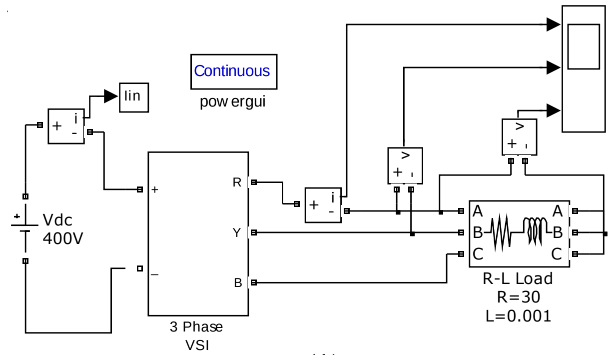
Above VSI can be used in many applications. In the 1st step the output switches S5, S6 and S1 are ON to achieve output of Vdc/3, similarly in the 4th step S1, S2 are conducting and output is Vdc/2, in the last step switches S2, S3 are conducted hence output is zero.

B. Output Analysis of VSI

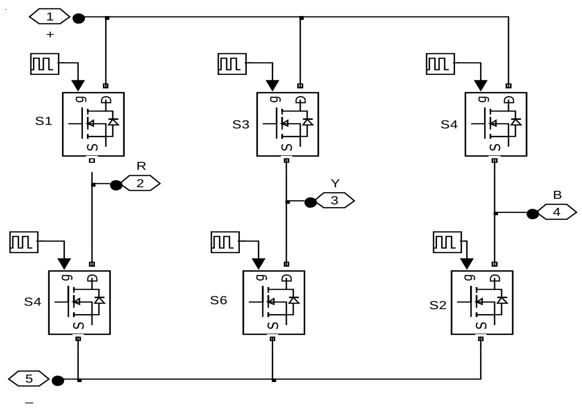
Simulative results of output phase voltages for 180°, 150° and 120° are shown in figure 4. So we can directly compare the levels and steps. The simulation model in MATLAB is represented by Figure 3.

Inverter output change according to its switching pattern. Value of output voltage level also decided by the switches conducted in each interval. Figure 4 shows output voltage for an ohmic load.

The 150° conduction mode has more levels than other conventional conduction angle also the waveforms are symmetrical and contain zero as one level so it will reduce the harmonics. In 180° conduction mode, the phase voltage has only six steps while in 120° conduction mode only four steps. Six step and quasi square wave cannot provide numbers of steps that can be achieved in 150° conduction mode VSI. Higher numbers of level means lesser harmonics. We can prove this practically by FFT analysis shown in Figure 5, 6.



(A)



(B)

Figure 3 (A) Simulation model of MATLAB (B) Subsystem of 3 Phase VSI

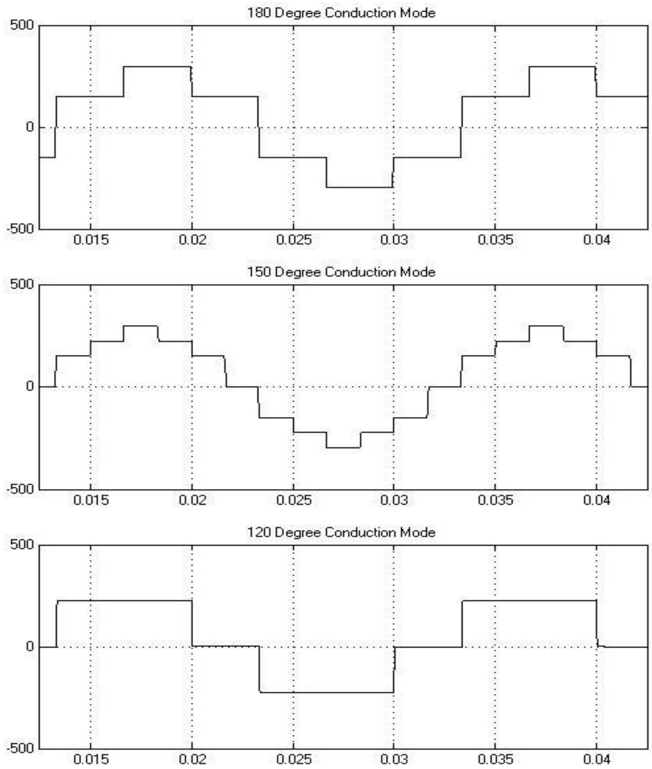


Figure 4 Phase voltages of output voltages VaN for (a) 180°, (b) 120° and (c) 150° conduction modes.

III. Testing And Hardware Implimentation

The overall hardware of the system has following subsystems.

- Power MOSFET bridge
- Gate drive circuit
- Microcontroller
- Rectifier Block

Specifications and ratings of the components are given in Table II.

Sr. No.	Hardware Ratings	Value
1	Output Power	1.5kW
2	Operating Frequency	50Hz
3	Input Voltage	450V
4	Full Load Current	4A

Table II Ratings of the system

A. *Power MOSFET bridge*

A three phase full bridge VSI is developed using six IRF840 n-channel MOSFETs. Rated voltage and current ratings are 500V and 7A respectively. The power rating is 3KW. The advantages of power MOSFET are 1. Safe operating area is much better than that of BJT. 2. It can operate at higher frequencies. 3. No possibility of second breakdown. 4. Peak current capability of MOSFET is higher than that of BJT. 5. Switching losses are less. 6. More energy efficient at high frequency. 7. It is a majority carrier device and 8.It is cheap.

B. *Gate Driver Circuit*

The 4N33 opto-coupler provides the isolation between the MOSFET bridge and the microcontroller. Especially isolates the upper group of MOSFETs. Another function of this opto-coupler is to provide amplified gate control signals to IRF840 MOSFETs. The 4N33 opto-coupler has gallium arsenide infra red LED and silicon NPN phototransistor. The switching speed of this type of opto-coupler is higher compared to the other type of optocouplers. This type of opto-coupler provides high voltage isolation.

C. *Microcontroller*

The gate pulses for six IRF840 MOSFETs are generated with the help of AT89C51 microcontroller. It is an 8 bit microcontroller [13]. The VSI is operated in 150° conduction mode. While writing the program three factors should be considered. Each pulse has 8.33msec ON and 11.77msec OFF period. There should be a time delay of 3.33msec between the firing pulses of adjacent MOSFETS. Dead band is not required in this conduction [12]. The magnitude of firing pulses is 5V. The magnitude of the pulses after opto-coupler is 12V. These pulses are given to the six MOSFETS of the power circuit of VSI.
The AT89C51 microcontroller needs 5V DC as input supply. LM7805 provides the regulated 5V DC supply to the AT89C51 microcontroller.

D. *Rectifier Block*

To provide the DC voltage to three phase VSI rectifier block is used. LM3510 is a diode bridge module with 1000V, 35A voltage and current ratings.

E. *Hardware*

Hardware used in experiment is shown in Figure 5. The fabricated VSI is tested under various load conditions. It consists of 230V A.C. mains supply, 230V to 24V transformer is used to step down the voltage, 1.5KW power circuit, AT89C51 microcontroller, 4N33 opto-couplers and its four isolated power supply for six switches. LM7805 DC voltage regulator, 50Ω, 10W balanced three phase R load.

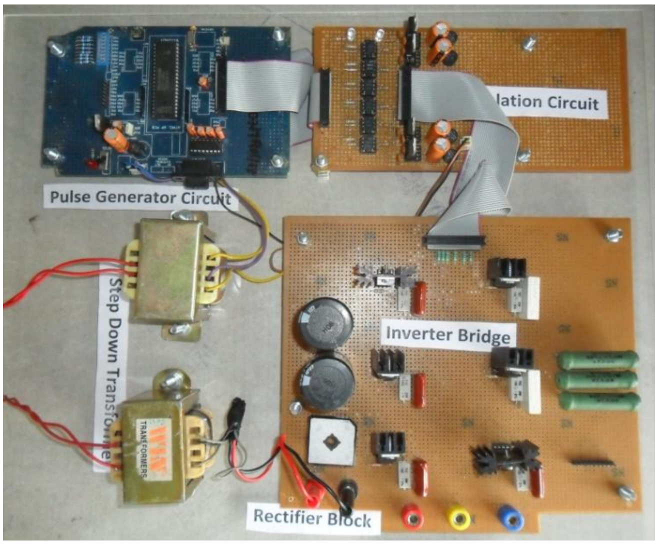


Figure 5 Experimental setup of 3phase VSI

IV. Results Analysis

The increase in steps of output voltage, of inverter, can be made by changing the conduction angle. THD of the output voltage is affected by the power factor and the conductive angle usually. Power factor of load cannot be determined by the designers, and conductive is a facility for designer. So the suitable conductive angle is selected considering high RMS and low THD of the output voltage.

Harmonic analysis and comparison with conventional conduction angle method is derived in point (A) and (B) in this topic.

A. Harmonics Analysis in MATLAB

Harmonic analysis for all the modes of conduction and a comparative study is shown in this paper. Figure 6 shows the harmonic analysis for three phase 180° conduction mode inverter.

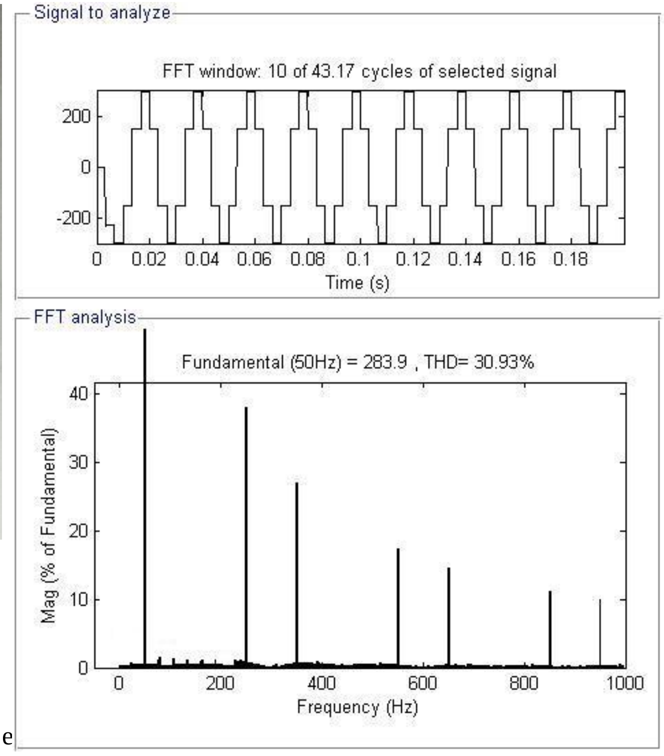


Figure 6 THD spectrum of 180° VSI

Output voltage can be denoted by the equation (1)

$$Vo_{aN,180^\circ} = \sum_{k=1,3,5,\ldots}^{\infty} \frac{4V_d}{\sqrt{3}k\pi} \cos\frac{k\pi}{6} \sin k\omega t \qquad (1)$$

and RMS value of phase voltage in terms of DC link voltage is derived with equation (2) as well as we can find out the THD given in equation(3).

$$Vo_{rms,180^\circ} = 0.48\,Vi \qquad (2)$$

$$THD\ Vo_{180^\circ} = 31\% \qquad (3)$$

For 120° conduction mode inverter the THD remains same but output voltage will be changed. If we change the conduction mode of VSI from 180°-150° or 120° to 150° the THD reduces. Harmonics for 150° conduction mode are less than any other conduction mode without any modulation or control. Comparing 180° and 150° we conclude that THD will be half.

Figure 7 shows the harmonics analysis for 150° conduction mode output phase voltage for R-L load. We can see that the magnitude of lower order harmonics are reduced compare to 180° and 120° conduction mode.

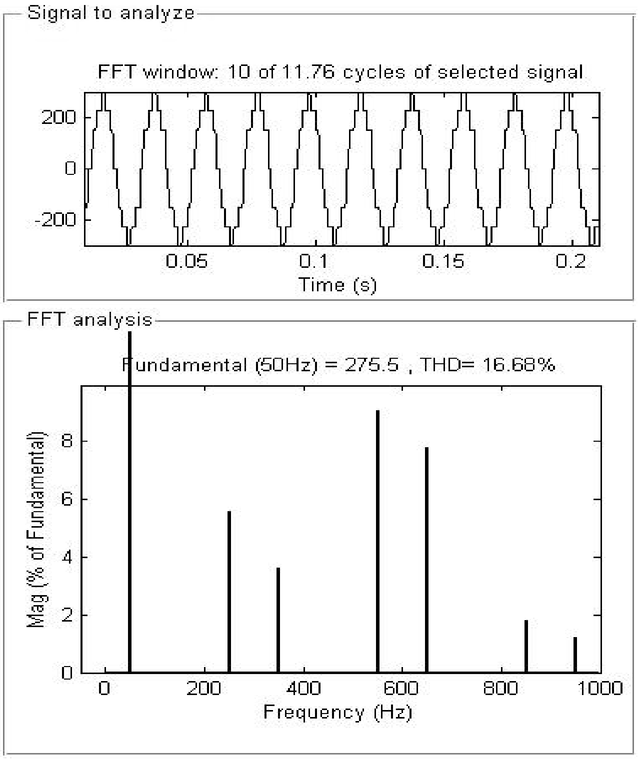


Figure 7 THD spectrum of 150° VSI

RMS value of phase voltage in terms of DC link voltage is derived with equation (2) as well as we can find out the THD which given in equation(3).

$$Vo_{rms,180°} = 0.44\,Vi \qquad (4)$$

$$THD\ Vo_{180°} = 17\% \qquad (5)$$

B. Experimental results

Here in 150° conduction mode we get twelve different voltage steps in phase voltage listed as 1) 0V, 2) -Vdc/3, 3) -Vdc/2, 4) -2Vdc/3, 5)-Vdc/2, 6) -Vdc/3, 7) 0, 8) Vdc/3, 9) Vdc/2, 10) 2Vdc/3, 11) Vdc/2, 12) Vdc/3 and in line voltage five levels can be achieved. Figure 8 shows the phase voltages, achieved by practical implementation. Figure 9 shows line voltages with nine steps.

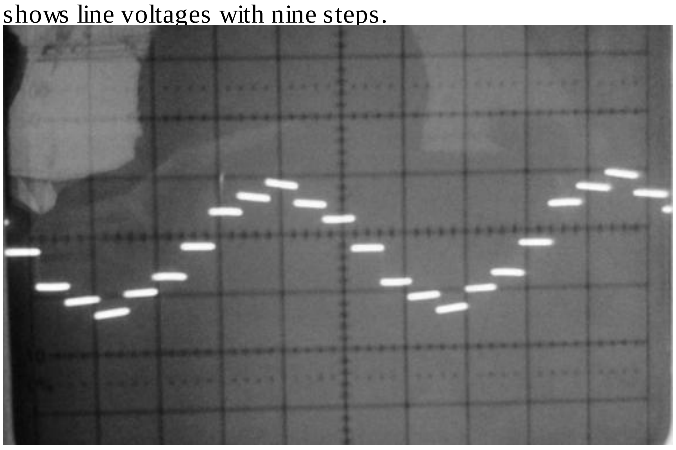


Figure 8 Phase voltage of star connected induction motor for 150° conduction mode

The waveform of line voltage and current for delta connected three phase induction motor are shown in figure 8 and 9. These are the practical results taken in M.S.University's Lab, Vadodara.

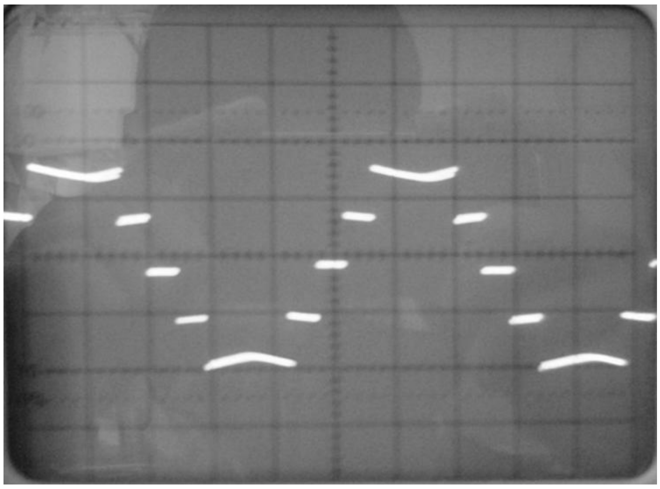


Figure 9 Line voltage of delta connected induction motor for 150° conduction mode

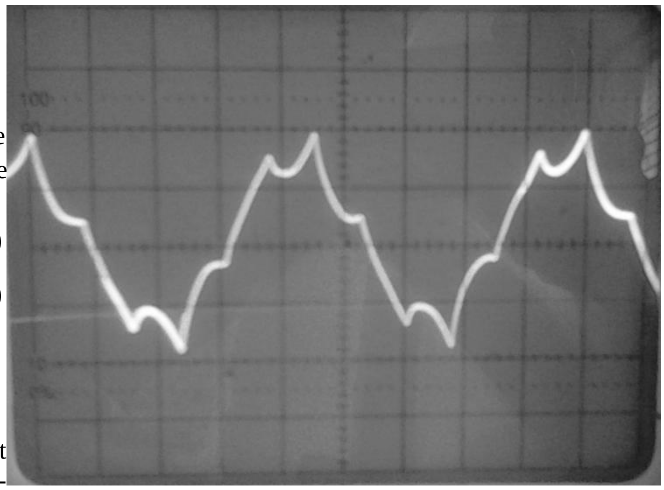


Figure 10 Line current of delta connected induction motor for 150° conduction mode

C. CONCLUSION

In this paper a novel technique for harmonic reduction is proposed. The simulation and hardware analysis give clear idea about 150° degree conduction mode. The main features of this method are,

(i) 12-step output of phase voltage.

(ii) Less significant harmonics at the output side.

(iii) If we change the conduction mode of VSI from 180°-150° or 120° to 150° the THD reduces.

(iv) Without any filter or modulation technique harmonics are eliminated.

In addition, this method can improve the utility factor of switching element and life of the equipment. Requirement of dead band is wiped out so RMS value increases.

Three phase inverter is the highly used power electronic device in industries. This method can be helpful in reducing size of the filter and to avoid the use of highly precise and fast speed costly controllers.

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