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# Speed Control Simulation for Induction Motor by Multi Level VSI-Fed to Analyse Current Harmonics and Selective Harmonics Elimination

Bahram Ramezani
Islamic Azad University Miyaneh Branch, Iran

**Abstract:** This study presented the simulation studies on closed-loop speed control for 3-phase induction motor by applying V/F method. This induction motor is fed by three and five-level diode clamped Voltage Source Inverter (VSI). Sinusoidal pulse with modulation technique is used to control inverter power switches. The harmonics of phase current is analysed. Then selective harmonics is eliminated by comparison of sine wave with modified triangle carrier. In this method, we could eliminate selective harmonics with no need to complex equations solving. In this study, by present the quasi triangle carrier Total Harmonic Distortion (THD) is decreased.

**Key words:** Voltage source inverter, selective harmonic elimination, total harmonic distortion

## INTRODUCTION

Multilevel power conversion was first introduced 26 years ago (Corzine, 2002). The general concept involves utilizing a higher number of active semiconductor switches to perform the power conversion in small voltage steps. There are several advantages to this approach when compared with traditional (two-level) power conversion. The smaller voltage steps lead to the production of higher power quality waveforms and also reduce the dv/dt stresses on the load and reduce the electromagnetic compatibility (EMC) concerns. Another important feature of multilevel converters is that the semiconductors are wired in a series-type connection, which allows operation at higher voltages. However, the series connection is typically made with clamping diodes, which eliminates overvoltage concerns. Furthermore, since the switches are not truly series connected, their switching can be staggered, which reduces the switching frequency and thus the switching losses.

Figure 1 shows the general structure of the multilevel converter system. In this case, a three-phase motor load is shown on the AC side of the converter. Generally, variable-speed induction motor employs the inverter as power-varying component (Tipsuwanporn *et al.*, 2006; Carbone and Scappatura, 2005). However, the converter may interface to an electric utility or drive another type of load. The goal of the multilevel Pulse-Width Modulation (PWM) block is to switch the converter GTOs in such a way that the phase voltages $v_{as}$, $v_{bs}$ and $v_{cs}$ are equal to commanded voltages $v^*_{as}$, $v^*_{bs}$ and $v^*_{cs}$. The commanded voltages are generated from an overall supervisory control and may be expressed in a general form as:

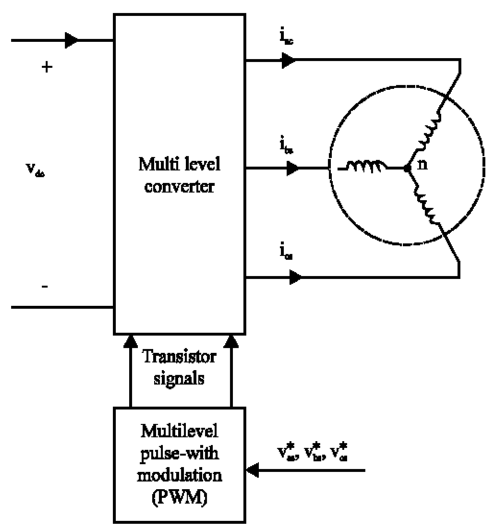


Fig. 1: Multi level inverter structure

$$\begin{aligned} v^*_{as} &= \sqrt{2}v^*_s\cos(\theta_c) \\ v^*_{bs} &= \sqrt{2}v^*_s\cos(\theta_c - \frac{2\pi}{3}) \\ v^*_{cs} &= \sqrt{2}v^*_s\cos(\theta_c + \frac{2\pi}{3}) \end{aligned} \quad (1)$$

where, $v^*_s$ is a voltage amplitude and $\theta_c$ is an electrical angle.

The fundamental multilevel inverter topologies are diode-clamped, flying capacitor, cascaded H-bridge and multilevel H-bridge (Aghdam and Fathi, 2006; Corzine and Baker, 2002). Diode clamped multi-level inverter is a very general and widely used topology for real power flow control and is considered for investigation

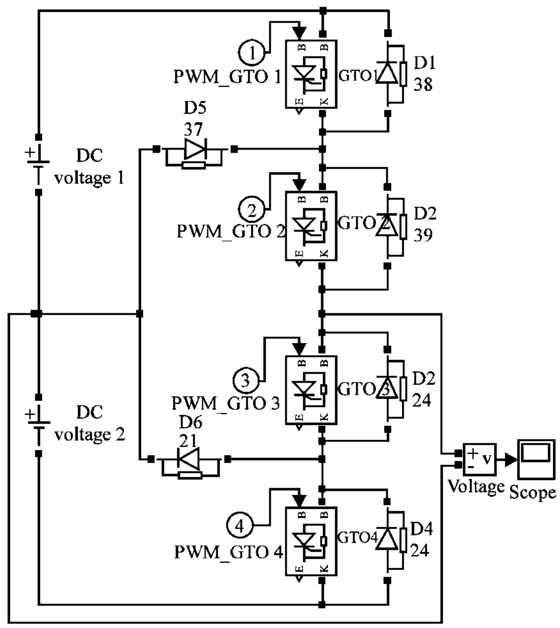


Fig. 2: Three-level diode clamped inverter

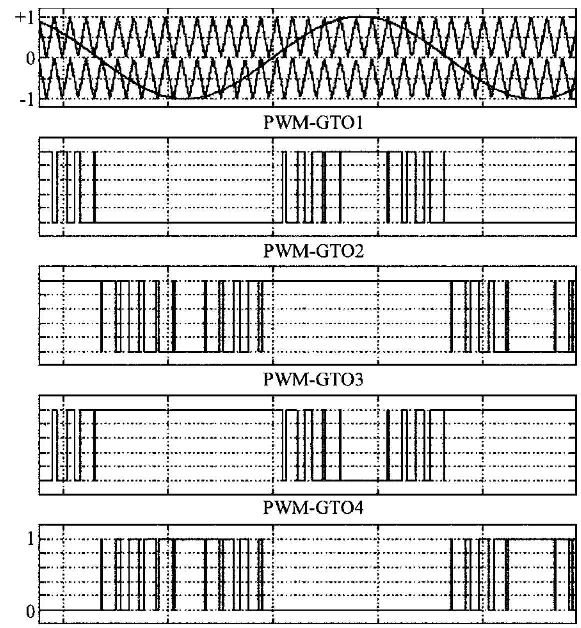


Fig. 3: Three-level sine-triangle modulation technique

purpose in this study. The three-level diode clamped inverter is shown in Fig. 2. Comparing this topology with that of a standard two-level converter, it can be seen that there are twice as many GTOs as well as added diodes (Choi *et al*., 1991; Corzine and Wielebski, 2003). However, it should be pointed out that the voltage rating of the GTOs is half that of the GTOs in a two-level converter. In three-level inverter, the GTO blocking voltage is one half the DC-link voltage. When compared with the two-level converter, the additional voltage level allows the production of line-to-ground voltages with lower harmonic distortion. Selective harmonic elimination pulse-width modulation methods remain of great interest for the control of high-voltage high-power voltage-source converters (Xu and Agelidis, 2007; Dahidah and Agelidis, 2007). The main challenge associated with SHE-PWM techniques is to obtain the analytical solution of the resultant system of the non-linear transcendental equations that contain trigonometric terms, which in turn provide multiple sets of solutions (Sahali and Fellah, 2006; Dahidah and Agelidis, 2006; Agelidis *et al*., 2006). This study is presented a method that by applying it, we could eliminate selective harmonics with no need to complex equations solving.

## SINUSOIDAL PULSE WITH MODULATION

The control principle of the SPWM is to use several triangular carrier signals keeping only one modulating sinusoidal signal. For the three level inverter, two triangular carriers are needed (Fig. 3) (Generally speaking, if a m-level inverter is employed, (m-1) carriers will be needed) (Massoud *et al*., 2004). The carriers have the same frequency $f_c$ and the same peak-to-peak amplitude $A_c$. The zero reference is placed in the middle of the carrier set. The modulating signal is a sinusoid of frequency $f_m$ and amplitude $A_m$. At every instant, each carrier is compared with the modulating signal. Each comparison switches the switch on if the modulating signal is greater than the triangular carrier assigned to that switch. Obviously, the actual driving signals for the power devices can be derived from the results of the modulating-carrier comparison by means of a logic circuit. SPWM technique can be classified according to carrier and modulating signals.

The main parameters of the modulation process are:

- The frequency ratio $k = f_c/f_m$, where $f_c$ is the frequency of the carriers and $f_m$ is the frequency of the modulating signal
- The modulation index $M = A_m/(m' * A_c)$, where $A_m$ is the amplitude of the modulating signal, $A_c$, is the peak-to-peak amplitude of the carriers and $m' = (m-1)/2$, where m is the number of level

## SPEED CONTROL FOR INDUCTION MOTOR

In recent years, application of three, four and five level VSI has become common in speed control for

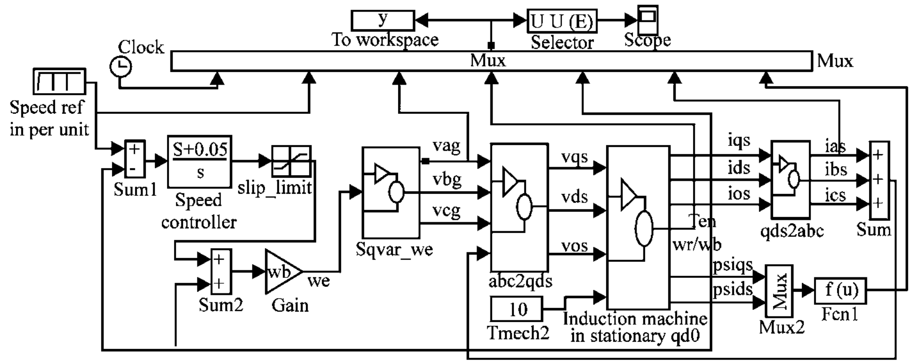


Fig. 4: Schematic of speed control of induction motor

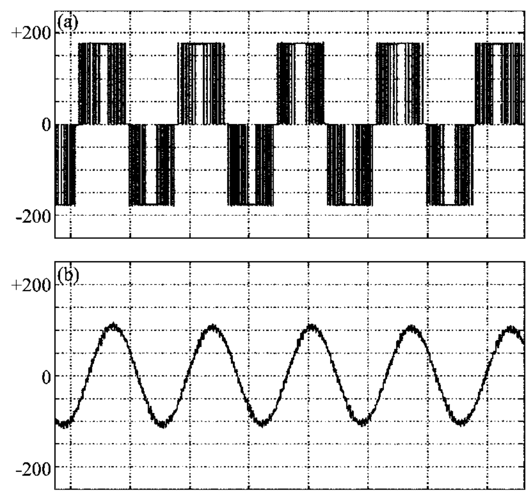


Fig. 5: (a) Phase voltage and (b) phase current of induction motor fed by 3-level diode clamped inverter

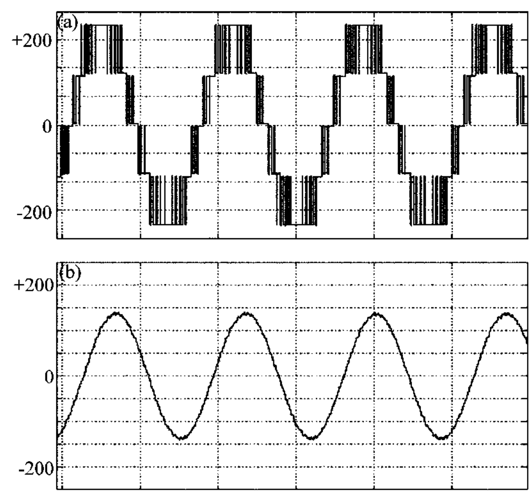


Fig. 6: (a) Phase voltage and (b) phase current of Induction Motor Fed by 5-level Diode Clamped Inverter

Induction Motors in order to reduce torque variation and accelerate dynamic response (Fang *et al*., 1995; Singh *et al*., 1998; Song-Manguelle and Rufer, 2003). An egregious problem of this method is balancing of capacitor voltage so use of the isolated power supply is proposed. The isolated power supply is used here. The induction motor is controlled by V/F method (Dubey, 1989; Ong, 1997). The schematic of speed control of induction motor is shown in Fig. 4. The parameters of the induction motor are given:

$S_b$ = 3*746
$V_{rated}$ = 220
$P_f$ = 0.853
P = 2
$f_{rated}$ = 60
$w_b$ = 2*pi*$f_{rate}$
$s_{rated}$ = $0.0287N_{rated}$ = 1748.3
$w_{mrated}$ = 2*pi*$N_{rated}$/60
$r_s$ = 1.1062
$x_{ls}$ = 1.5079
$x_{plr}$ = 0.7539
$x_m$ = 26.1296
$r_{pr}$ = 0.816
J = 0.08

The phase voltage ($V_{ag}$) and stator phase current ($i_{as}$) wave forms are shown in follow Fig. 5 and 6. In this study, the frequency ratio is 33(K = fc/fm = 33). The three and five level voltage waveforms that feed the induction motor are shown in Fig. 5a and 6a. The current waveform of induction motor is shown in Fig. 5b and 6b.

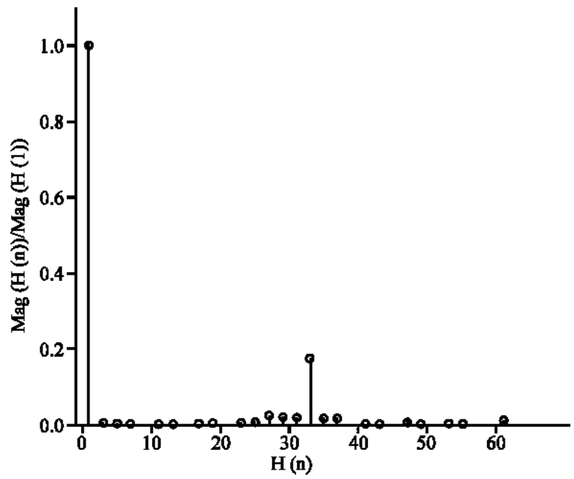


Fig. 7: Phase current harmonic spectrum of induction motor fed by 3-level diode clamped inverter

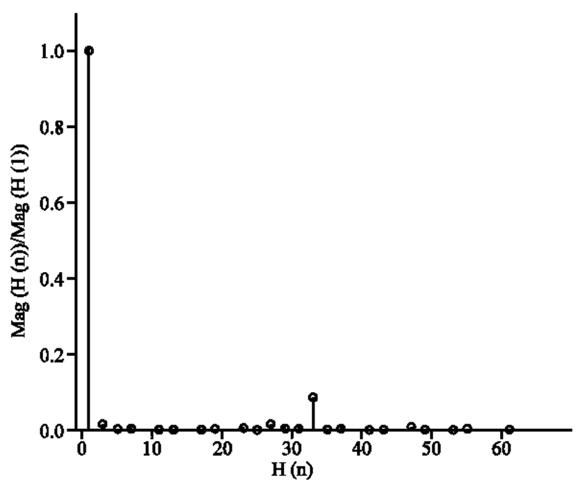


Fig. 8: Phase current harmonic spectrum of induction motor fed by 5-level diode clamped inverter

## SELECTIVE HARMONIC ELIMINATION

Application of multilevel VSI in induction motor drive to cause to generation of current and voltage harmonics (Dubey *et al*., 1986; Corzine *et al*., 1998; Iturriz and Ladoux, 2000; Krein *et al*., 2004). Selective Harmonic Elimination (SHE) is normally a two-step digital process. First, the switching angles are calculated offline, for several depths of modulation, by solving many nonlinear equations simultaneously. Second, these angles are stored in a look- up table to be read in real time. Consider a quasi-triangular waveform to be used as the carrier signal in a PWM implementation. A PWM implementation is a technique to control inverter power switches. By applying this technique, we could generate a quasi Sinusoidal waveform with desired frequency. In principle, the frequency and phase can be modulated. To represent this, consider a triangular carrier function written as:

$$c(t) = 1 - \frac{2}{\pi}\cos^{-1}\left(\cos(\omega_{sw} t + \beta(t) + \phi\right) \quad (2)$$

where, $\omega_{sw}$ is the base switching frequency, $\beta(t)$ is a phase-modulation signal and ö is a static phase shift. The modulating signal will be represented as $m(t) = m_d \times \sin(\omega t)$ where $m_d$ is the depth of modulation and $\omega$ is the desired output fundamental frequency.

$$\beta(t) = \sum G\ (m_d)\frac{J_n(n\sigma(m_d))}{n\sigma(m_d)}\sin(2n(wt + \frac{\pi}{2})) \quad (3)$$

where, $J_n$ is a Bessel function of the first kind. The natural number M is infinity in principle. The functions $\sigma(m_d)$ and $G(m_d)$ have been determined by curve fitting as:

$$\sigma(m_d) = \frac{-0.1384\ m_d^3 + 0.1527\ m_d^2 - 0.01358\ m_d + 0.0003431}{m_d^3 - 1.948\ m_d^2 + 0.7006\ m_d + 0.2491}$$
$$G(m_d) = \frac{0.9992\ m_d^4 - 2.399\ m_d^3 + 1.426\ m_d^2 - 0.02446\ m_d + 0.0018421}{m_d^2 - 2.124\ m_d + 1.125} \quad (4)$$

Figure 7 and 8 show a magnitude spectrum for K = 33($\omega_{sw}$ = 33$\omega$). By applying this switching frequency ratio are eliminated second, 3th, ..., 32th harmonics. By using this method, we could eliminate the selective harmonics(second, 3th, ..., 32th Harmonics). In this method we don't require to solve complex equations.

By using the quasi-triangular waveform (Eq. 2) to be used as the carrier signal in a PWM implementation, the current THD of Induction Motor by 3-level Diode Clamped Inverter- fed is 6% and for Induction Motor by 5-level Inverter fed is 2.7%. If we use a common triangular waveform to be used as the carrier signal, the current THD of Induction Motor by 3-level Diode Clamped Inverter-fed would be 9% and for Induction Motor by 5-level Inverter fed is 5%.

## CONCLUSIONS

In this study, the simulation studies on closed-loop speed control for 3-phase Induction Motor by applying V/F method was presented. This induction motor was fed by Multi-level diode clamped Voltage Source Inverter (VSI). Sinusoidal pulse with modulation technique was used to control inverter power switches. Then the harmonics of the phase current were analysed. The Selective harmonics were eliminated by comparison of sine wave with modified triangle carrier (Eq. 2). In this study, the frequency ratio was 33($\omega_{sw}$ = 33$\omega$). By applying this switching frequency ratio, second, 3th, ..., 32th current harmonics were eliminated. In this method, we don't require to solve complex equations. In this study, by present the Novel triangle carrier Total Harmonic Distortion (THD) was decreased.

Using the quasi-triangular waveform (Eq. 2) as the carrier signal in a PWM implementation, the Phase current THD of Induction Motor fed by 3-level Diode Clamped Inverter is 6% and for Induction Motor by 5-level Diode Clamped Inverter 2.7%.

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