Effect of Carrier frequency on THD in -Closed Loop Control of 5-Level Multi-level Inverter fed 3 phase Induction Motor Drive

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ABSTRACT: The main aim of this paper is to analyze the response of five level diode clamped Multilevel Inverter fed three phase Induction Motor drive with closed loop control. The Carrier frequency is varied to analyze its effect on current and voltage in terms of Total Harmonic Distortion. The closed loop control has two loops, inner current loop and outer speed loop .The controller used is PI Controller in both loops .The modulation Technique used is Sinusoidal Pulse Width modulation control (SPWM). The circuit is simulated using MATLAB/SIMULINK

Index Terms: Carrier frequency, Closed loop, Controller, Diodes, Inverter, Multilevel, Sinusoidal Pulse Width Modulation (SPWM), Total Harmonic Distortion (THD).

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1 Introduction

Multilevel Inverters have many advantages compared with and well known two level converters [1]. These advantages are fundamentally focused on improvements on the output quality and a nominal power increase in the inverter. These properties make multilevel inverters very attractive to the industry and nowadays researchers all over the world spending great efforts to improve the performance of multilevel inverters by control simplification and optimized algorithms in order to decrease Total Harmonic Distortion (THD) and torque ripple of the motor.

Multilevel inverters include an array of power semiconductor and capacitor voltage sources, the output of which generates voltages with stepped waveforms, the commutation of switches permit the addition of capacitor voltages, which results as high voltage at output, while the power semiconductors must withstand only reduced voltage [2]. However higher number of levels increase the control complexity. The fundamental multilevel inverter topologies are diode clamped, flying capacitor, and multilevel H-bridge. Diode clamped Multilevel Inverter is a very general and widely used topology for real power flow control and is considered for investigation [3]-[5]. Normally n-level diode clamped Multilevel Inverter has 2(n-1) main switches and 2(n-1) main diodes. In addition, this topology needs 2(n-2) clamping diodes [6]. So in the five level diode clamped inverter 8 main switches, ($SW1$ to $SW4$ and $\overline{SW1}$ to $\overline{SW4}$) 8 main diodes (D1 to D8) and 6 clamped diodes (DB1 to DB6) are used. Fig.1 illustrates five level diode clamped multilevel inverter. Several Modulation and control Strategies have been developed for multilevel inverters including the following i) Sinusoidal Pulse Width modulation (SPWM) ii) Selective Harmonic Elimination (SHE) and iii) Space Vector modulation (SVM) [7].

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Closed loop consists of inner current control loop and an outer speed control loop. In speed control loop speed controller and current limiter are used. In current control loop current controller is used. Tuning a control loop is the adjustment of its control parameters (gain/proportional band, integral gain/reset, derivative gain/reset) to the optimum value for the desired control response [8]

2. SINUSOIDAL PULSE WIDTH MODULATION

The main principle of Sinusoidal Pulse Width Modulation is to compare many triangular carrier signals with one modulating Sinusoidal signal. For five level inverter, four triangular carriers are needed, which is shown in Fig.2. In General if m-level inverter is used (m-1) carrier signals are needed. The carrier signals will have same frequency f_c and same peak to peak amplitude A_c At every instant sinusoidal signal is compared with each carrier signal. In this comparison if modulating signal is greater than triangular carrier signal, then signal is given to appropriate semiconductor switch in respective legs. The appropriate driving signal is obtained by using required logic. The main aspects of modulating process are frequency ratio and modulating index. The frequency ratio is defined as ratio of frequency of carrier signal to frequency of modulating signal (f_c / f_m). The modulating index M is defined as A_m / (m′ * A_c) where A_m is amplitude of modulating signal, A_c is peak to peak amplitude of carrier wave and m′ = (m – 1)/2, where m is number of levels.

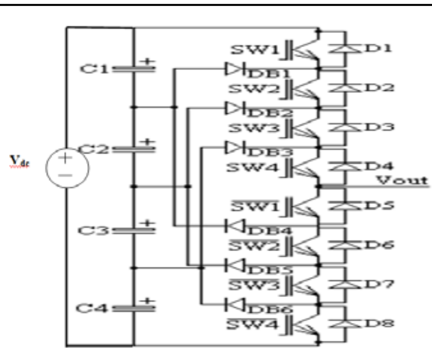

Fig. 1Five Level Diode clamped Multilevel Inverter

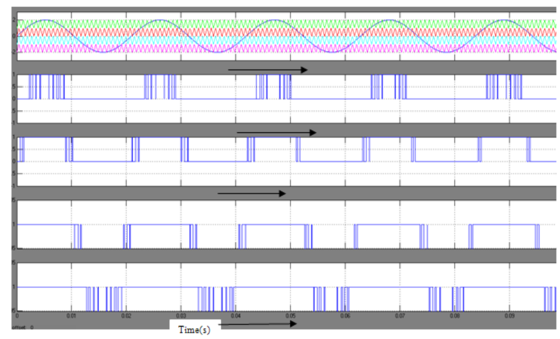

Fig. 2 a) SPWM Technique –Carrier signals b) pulses to SW1 c)pulses to SW2 d)pulses to SW3d)pulses to SW4

3. PI CONTROLLER AND LOOP TUNING

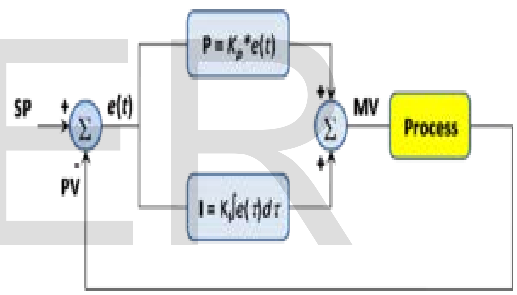

Fig. 3 Basic Block of a PI controller

A PI Controller (proportional-integral controller) is a special case of the PID controller in which the derivative (D) of the error is not used. PI Controller is shown in Fig. 3
The controller output is given by

$$K_P\Delta + K_I \int \Delta\, dt \qquad (1)$$

Where Δ is the error or deviation of actual measured value (***PV***) from the set-point (***SP***). $\Delta = SP - PV$.

A PI controller can be modeled easily in software such as simulink using a "flow chart" box involving Laplace operators:

$$C = \frac{G(1+\tau s)}{\tau s} \quad (2)$$

Where $G = K_P$ = proportional gain $G / \tau = K_I$ = integral gain

Setting a value for *G* is often a tradeoff between decreasing overshoot and increasing settling time. The lack of derivative action may make the system steadier in the steady state in the case of noisy data. This is because derivative action is more sensitive to higher-frequency terms in the inputs. Without derivative action, a PI-controlled system is less responsive to real (non-noise) and relatively fast alterations in state and so the system will be slower to reach set point and slower to respond to perturbations than a well-tuned PID system may be .

Tuning a control loop is the adjustment of its control parameters (gain/proportional band, integral gain/reset, derivative gain/reset) to the optimum value for the desired control response. Stability(bounded oscillation) is a basic requirement , but beyond that, different systems have different behavior, different applications have different requirements, and requirements may conflict with PID tuning is a difficult problem, even though are only three parameters and in principle is simple to describe ,because it must satisfy complex criteria within the limitations of PID control. There are accordingly various methods for loop tuning, and more sophisticated techniques are subject of patents

4. CLOSED LOOP CONTROL

The Simulink diagram of closed Loop control is shown in Fig.4. It consists of inner current control loop and an outer speed control loop. In speed control loop speed controller and current limiter are used. In current control loop current controller is used. The output from controller is given to gate signal generator. From gate signal generator signals are given to five level inverter. The required gate signals are generated using sinusoidal pulse width modulation (SPWM) technique. In this technique triangular wave is compared with sine wave. The carrier signal frequency is varied from 980 Hz. To 8080 Hz. while modulating signal frequency is 50 Hz.

The induction motor ratings are 3Φ 50 Hz, 4500 W, 415 V, star connected

5. RESULTS

In this analysis, the carrier signal frequency is varied from 980 Hz. To 9080 Hz. and its effect on output voltage and current waveforms Total Harmonic Distortion's (THD's) are observed. The variation is THD with carrier frequency is shown in Table 1. The variation of Current THD and voltage THD with reference to carrier frequency in form of plot are shown in fig.4 and fig. 5 respectively..It is observed that as the carrier frequency is varied Current THD is increasing oscillating around 2% , Voltage THD is oscillating around 2.6%.But both current and voltage THD's are as per IEEE standard which are below 5%.

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Minimum Current and voltage THD,s are 1.62% and 2.52% respectively are obtained at carrier frequencies of 5080 Hz. and 2080 Hz. It is analyzed even though that the Minimum current and voltage THDs are more at 5080 Hz. and 2080 Hz. , it is advisable to consider 5080 Hz. as carrier frequency for this circuit as current THD is minimum.

Initially motor is started on no load. The variation of speed and torque are shown in fig. 4. Fig. 5 illustrates Phase Voltage, Line voltage and Line current. The load torque is applied as shown in Fig. 6. The Maximum THD's of current and voltage are 2.58 % and 2.80% respectively.

CARRIER FREQUENCY	CURRENT THD IN %	VOLTAGE THD IN %
980	2.58	2.58
1080	1.75	2.75
1180	1.69	2.80
1280	1.68	2.58
2080	1.85	2.52
3080	1.65	2.57
4080	2.49	2.64
5080	1.62	2.64
6080	1.70	2.51
7080	1.98	2.57
8080	2.38	2.59
9080	1.76	2.64

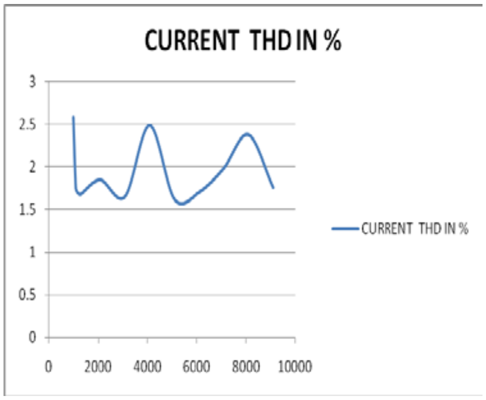

Fig. 4 Variation of Current THD with carrier frequency

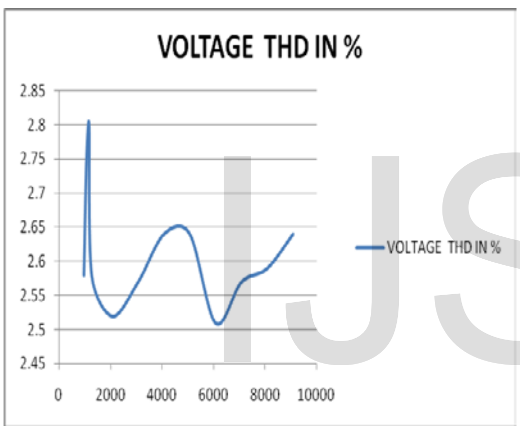

Fig. 5 Variation of Voltage THD with carrier frequency

6. CONCLUSIONS

This paper provides a brief study of Effect of Carrier frequency on THD in Closed Loop Control of 5-Level Multi-level Inverter fed 3 phase Induction Motor Drive. It is clear from analysis that as carrier frequency is varied from 980 Hz. to 9080 Hz., there is no much variation in THDs of both current and voltage .The current THD is fluctuating around 2 percent while minimum being 1.62% at 5080 Hz. and maximum being 2.48% at 980 Hz. Similarly the voltage THD is fluctuating around 2.6 percent while minimum being 2.51% at 6080 Hz. and maximum being 2.8 %. at 1180 Hz. Usually the minimum current THD is considered as the best for selecting the appropriate frequency for given circuit. Here the minimum current THD is 1.62% at 5080 Hz., Which can be considered for the circuit. Although there is variation in current and voltage THD with variation in carrier frequency, it is clear that the THD is well below 5% as specified by IEEE standards.

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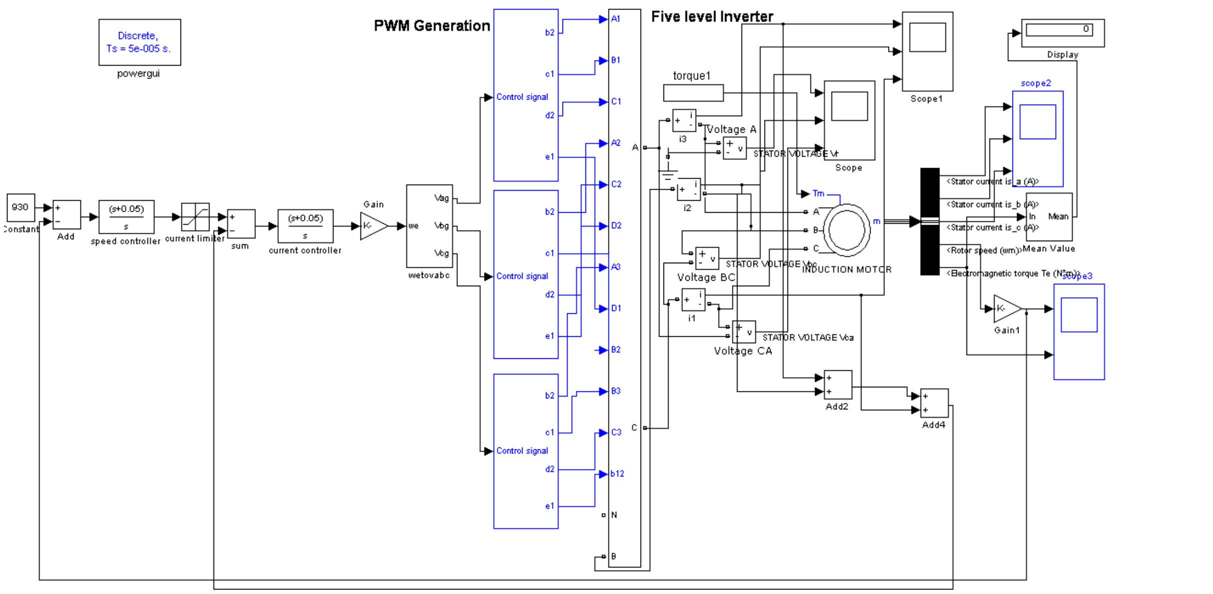

Fig. 4 Simulink Diagram for Closed Loop Control

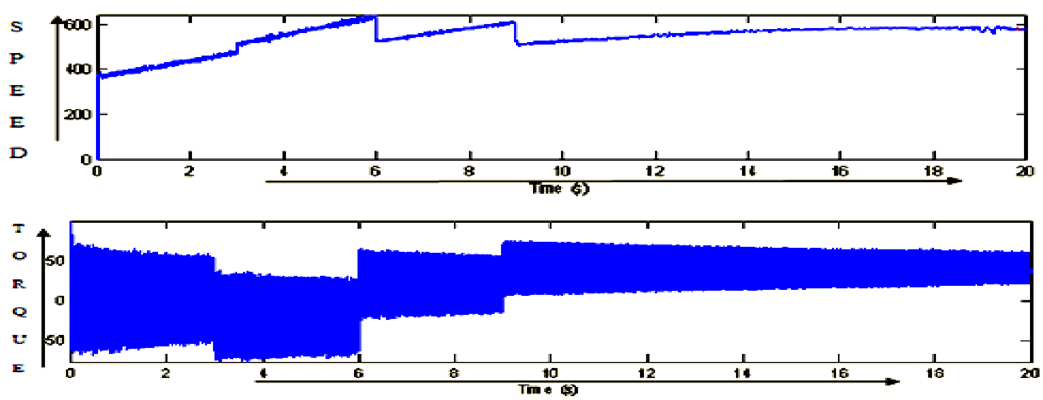

Fig. 4 a) Speed curve and b) Electromagnetic Torque curve

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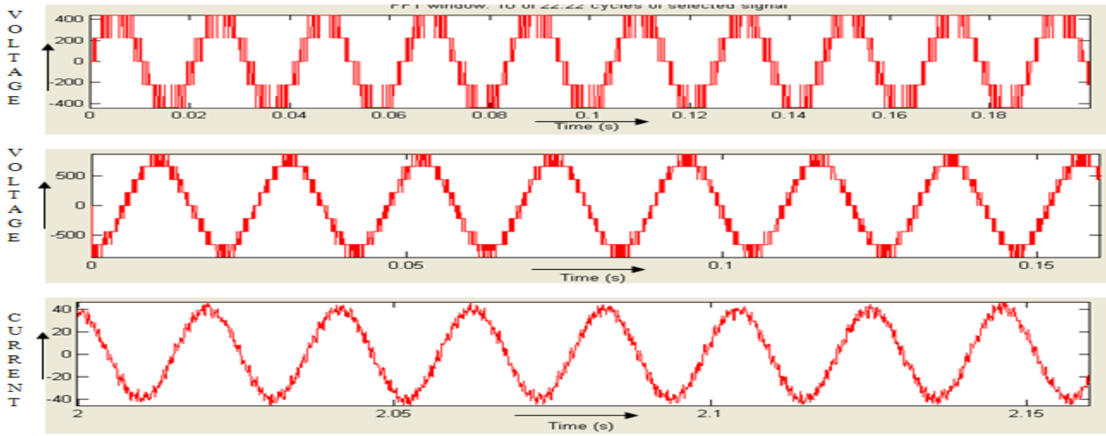

Fig. 5 Line voltage, Phase voltage and Line current

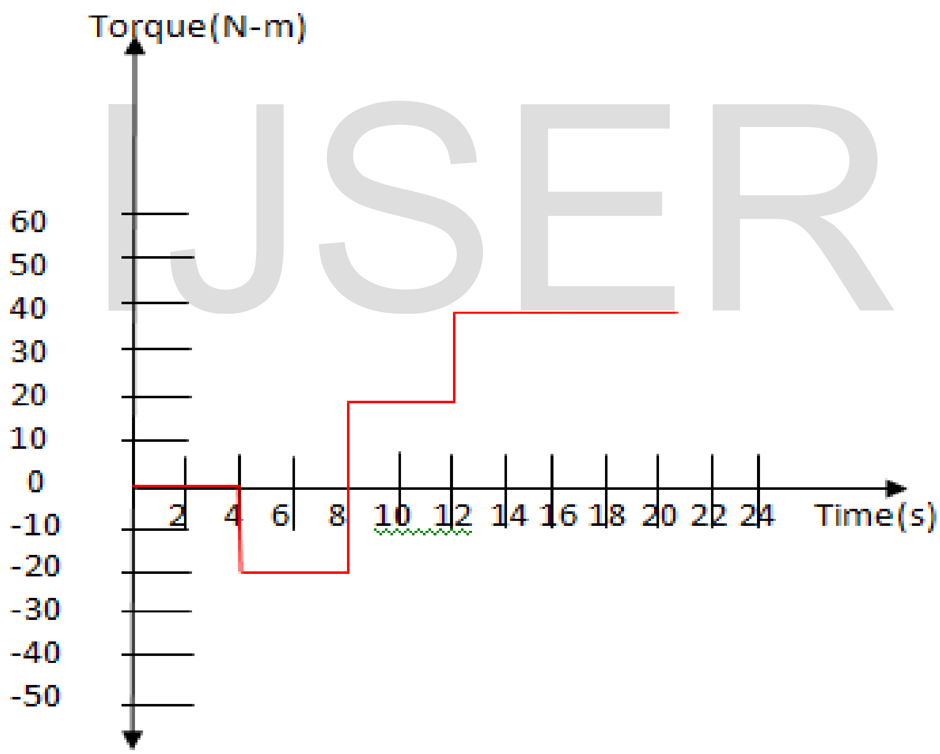

Fig. 6 Load Torque Applied